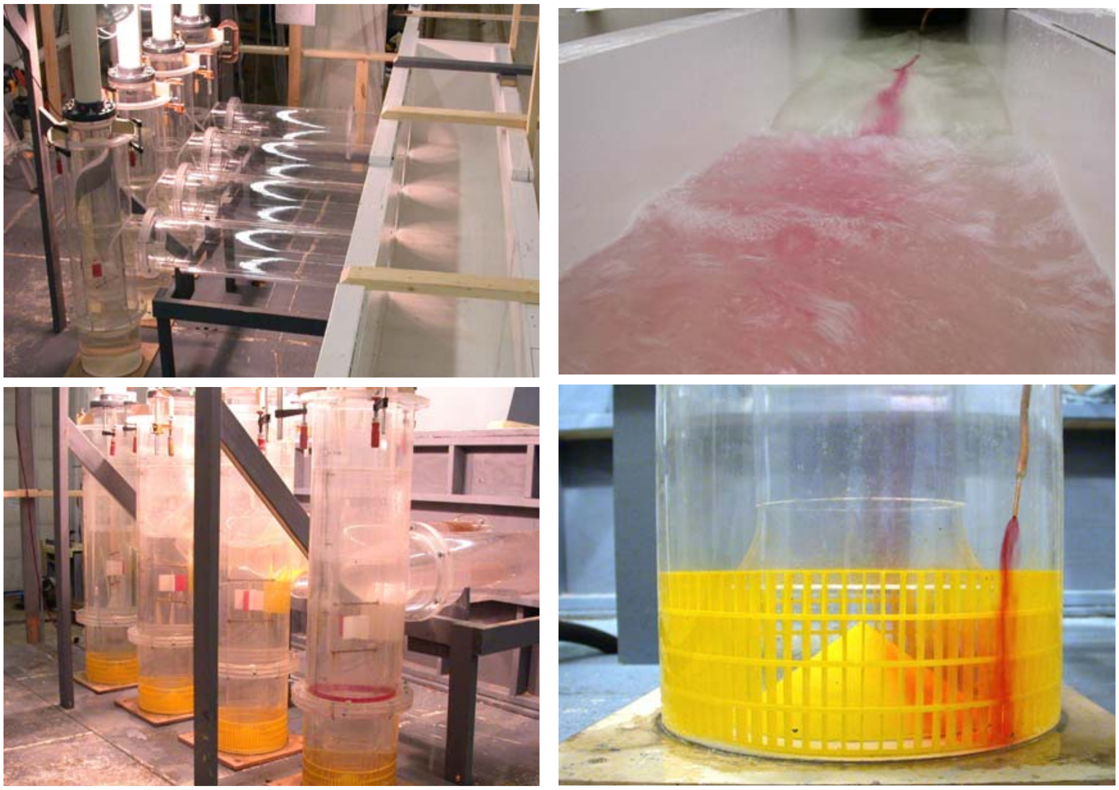
EARTH TECH CANADA INC.



CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

FINAL REPORT

JANUARY 2005

nhc northwest hydraulic consultants

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EXECUTIVE SUMMARY

northwest hydraulic consultants (**nhc**) was retained by Earth Tech Canada Inc (Earth Tech) to construct and test a 1:5 scale physical hydraulic model for the interim pump station for the City of Winnipeg's North End Water Pollution Control Centre (NEWPCC). The station will contain an effluent conduit with four lateral pipes extending from the side of the conduit to four pump cans that will house four vertical propeller pumps. Each pump will be rated at 100 million litres per day (ML/d). The firm capacity of the proposed pumping station will be approximately 400 ML/d, with all four pumps in operation.

The objectives of the hydraulic model study were to determine if the proposed intake structure would provide uniform flow to the pumps and, if necessary, to develop modifications to improve the hydraulics entering the pump suction bell. The findings of the study demonstrated that the initial intake design was susceptible to strong subsurface vortices that originated from the floor beneath the pump bell and on the pump can walls. Although no surface vortices were observed in the pump can, intermittent air entraining surface vortices developed in the conduit near the laterals pulled air into the pumps. At a water level of El. 4.3 m, a hydraulic jump formed on the sloping transition in the conduit during three and four-pump operation. The hydraulic jump created a significant amount of turbulence and entrained air bubbles that entered the pumps. Time-averaged and time-varying velocity fluctuations at the pump impeller location were also well outside the specified criteria.

Modifications were developed in the model to reduce the turbulence and air-core vortices in the conduit, to reduce vortex activity, and to improve spatial and temporal velocity fluctuations entering the pumps. The proposed modifications included relocating the sloping transition on the conduit upstream, installing vortex breaker bars in the conduit near the laterals, installing flow turning vanes at the entrances to the laterals, installing downward turning vanes at the entrances to the pump cans, installing rings of vanes surrounding the pump bells and centering floor cones beneath the pump bells. With these modifications installed in the model, flow pre-swirl, vortex activity, and the velocity distribution entering the pumps were within acceptable limits for the range of operating conditions examined in the model. The maximum fluctuations in the velocities entering the pumps were substantially reduced; however they were 5 percent outside the criterion. Because all the other performance criteria were met, this is not considered to be a significant performance issue.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTO PLATES

APPENDIX A

1.0 INTRODUCTION

1.1 GENERAL

northwest hydraulic consultants (nhc) conducted a physical model study to assist in evaluating the hydraulic design of the City of Winnipeg North End Water Pollution Control Centre (NEWPCC) interim pump station to be constructed in Winnipeg, Manitoba. The study was conducted in accordance with an agreement between Earth Tech Canada Inc. (Earth Tech) and **nhc** dated September 13, 2004 (File No. 66303)

Model design and construction started in late September 2004 and was completed by early November. Model testing commenced immediately following construction and was completed in late November.

Technical liaison for the study was maintained with Mr. Chris Lipscombe of Earth Tech. The study was conducted under the direction of Mr. Tom Demlow of **nhc**, and Ms. Kristin Hagel was **nhc**'s modeling engineer for the study.

1.2 SYSTEM DESCRIPTION

The new station as shown in Figures 1-1 to 1-3, will consist of an effluent conduit with four lateral pipes extending from the side of the conduit to four can pumps, see **nhc** 27 September 2004 conceptual design review report[1] (included in the Appendix) for background information. The discharge from the can pumps will enter the side of a rectangular conduit that will direct flow to a discharge chamber, located directly upstream of three UV channels. The new effluent pumping station will be required only in the short term before a permanent pump station is built further upstream as part of the future secondary process upgrade.

Effluent from the existing secondary effluent/outfall system will flow to the pump station via a 2.3 m wide conduit, which is set at El. 3.658 m (all elevations are given with respect to a plant datum of elevation zero, unless stated otherwise). This conduit will be 33.5 m long by 4.2 m deep. A 12.0-degree sloping transition extending downstream beginning at a position 20.6m downstream from the tie in point at El. 3.658 m will lower the floor to El. 1.9 m over a horizontal distance of 8.3 m.

[1] Northwest Hydraulic Consultants, 2004. "City of Winnipeg, North End Water Pollution Control Centre Pump Station Model Test – Conceptual Design Review, September 27.

Four inlet laterals will connect the effluent conduit with the pump cans. Each lateral will each be 1.2 m in diameter and 6.0 m in length. The invert of each lateral will be set at El. 1.9 m and the centreline spacing of each lateral will be 2.8 m, with the centreline of the most downstream lateral located one pipe diameter (1.2 m) upstream from the bypass gate (the gate will remain closed during the operation of the proposed station). The four pump cans will be each 1.5 m in diameter and set at a floor level of El. –1.0 m.

The four axial flow pumps will each be centred within a can and set 0.5 m above the sump floor at El.-0.5 m. The pumps will have 1.0 m diameter vertical pipe columns that incorporate the pump and pump bell. Each pump will be rated at 100 million litres per day (ML/d). The firm capacity of the proposed pumping station will be approximately 400 ML/d, with all four pumps in operation.

The water level at the downstream end of the effluent conduit system will be approximately El. 4.8 m, however it may vary ±0.5 m, which will give a potential minimum water level of El. 4.3 m.

Discharge from the pumps will be lifted vertically and discharged horizontally into a discharge chamber where it will then enter three UV disinfection channels.

1.3 STUDY OBJECTIVES

The main objective of the hydraulic model investigation was to determine if the proposed intake structure design provided adequate approach hydraulics and uniform distribution of flow to the pumps. If testing demonstrated that the intake structure did not meet acceptance criteria, the model was to be used to develop and test modifications to the intake structure layout until acceptable flow conditions were achieved.

1.4 FLOW HYDRAULICS AND ACCEPTANCE CRITERIA

Non-uniform flow within a pump sump can adversely impact the operation of circulating water pumps. This non-uniformity in flow approaching the pumps can result in excessive pre-swirl of flow approaching the impeller, free surface, and subsurface vortex formation in the vicinity of the pump bell, and non-uniform distribution of flow approaching the pump impeller. These flow phenomena, in turn, can lead to fluctuating loads on the pump impellers, vibration, accelerated bearing wear, cavitation damage and a reduction in pump efficiency.

In general, pump impellers are designed on the assumption that flow approaches the impellers axially. If the level of pre-swirl at the entrance to the pump is excessive, the flow will approach the impeller blades at an angle, which can lead to deviations in pump performance and a reduction in the minimum pressure on the impeller blades. In extreme cases, this minimum pressure can be low enough to generate cavitation and damage the impeller blades. With the level of flow pre-swirl usually fluctuating, there will be a loading and unloading on the impeller that can result in vibration and fatigue.

Similarly, free-surface vortices and subsurface vortices can also influence pump operation and life. These flow phenomena create a fluctuating load on the pump impeller blades of the pump impeller as each blade passes through the low-pressure vortex core. This can lead to vibration, increased bearing wear and potentially fatigue failure of the pump components. Strong free-surface vortices that are capable of entraining air could result in a reduction of the pump capacity and potentially the loss of prime. In addition, the low pressure at the core of the vortex could reduce the local pressure at the impeller to the point where localized cavitation damage develops.

A non-uniform distribution of flow entering the pump may generate non-uniform loading on the impeller that in turn leads to changes in the pressure distribution on the impeller blade. If excessive, cavitation can occur. Also, an imbalance in the flow velocities entering the pump will cause loading and unloading of the impeller blade, which could lead to fatigue failure. Excessive time-variations in the flow velocities approaching the impeller are capable of generating vibration, excessive noise, and flashes of cavitation.

Given these potential impacts on pump performance, the following performance criteria have been developed from the Hydraulic Institute's (HI) Pump Intake Design Standard (1998)[2] to evaluate the performance of the pump sump design for the current study:

- Free surface and subsurface vortices entering the pump should be less severe than vortices with coherent (dye) cores – less than Type 3. Figure 1-4 illustrates the Vortex Classification System that was utilized for this study.
- The average swirl angle, indicated by the swirl meter rotation, should be less than 5 degrees. The swirl meter rotation should be reasonably steady, with no abrupt changes in direction when rotating near the maximum allowable rate (angle).

[2] The Hydraulic Institute, American National Standard for Pump Intake Design, 1998.

- Time-averaged velocities at points in the throat of the bell should be within 10% of the cross-sectional area average velocity.
- Time-varying velocity fluctuations measured at a point should produce a standard deviation from the time-averaged signal of less than 10%.

In addition to the above criteria, it is necessary to minimize the amount of air entrainment at the pumps. Air entrainment is conservative in reduced scale models, because the rise rate of bubbles is similar between model and prototype and the energy in the fluid is much less in the model (i.e. bubbles rise faster in the model than in the prototype). Since there is no established criterion for the evaluation of air entrainment in physical models, the approach taken in this study was that if any air bubbles approach the modeled pumps, they would presumably enter the pump in the full size structure. This was not considered acceptable and modifications were developed to alleviate the problem.

2.0 MODEL DESCRIPTION

2.1 SIMILITUDE AND SCALE

Scale hydraulic models require that the force relationships in the model and prototype are dynamically similar. To achieve complete similarity, the ratio of the inertia to the gravitational, viscous, and surface tension forces must be the same between model and prototype. Only a 1:1 scale model can achieve all these criteria. Modeling at reduced scale involves identifying the primary force relationships to best simulate prototype conditions, then selecting a model scale to minimize any resulting scale effects.

Based on the assumption that there will be free surface flow in the sump and closed conduit flow in the intake piping, both Froude Number and Euler Number criteria must be satisfied in the model. For free surface flow phenomena, inertia and gravitational forces control fluid movement. A Froude-scaled, geometrically similar, undistorted, three-dimensional model is proposed for the sump model. In addition to using Froude scaling to provide proper simulation of gravity-driven flow phenomena, it is necessary to operate the model in a range of Reynolds numbers such that viscosity effects on vortex formation and energy losses in the sump structure will also be simulated. Research has shown that pump bell Reynolds numbers greater than 1×10^5 are required to simulate the formation of vortices in the pump sump model.

Flow phenomena in a completely closed conduit, such as inlet piping, are primarily controlled by inertia and pressure forces. Models of this type are typically operated at flow rates for which the Euler number is constant in both model and prototype. At higher Reynolds numbers, however, viscous forces become insignificant and the Euler number becomes almost entirely dependent on the geometry of the fluid boundaries. Research has shown that at pipe Reynolds numbers in excess of 1×10^5, where friction loss coefficients are constant, the Euler number will also be constant (Miller, 1978[3]).

In modeling flow in a pump sump to evaluate the potential for the formation of vortices, the geometric scale is selected to minimize viscous and surface tension scale effects. Also, the model should be large enough to allow flow visualization, accurate measurements of flow pre-swirl and velocities, and sufficient dimensional control. The Reynolds number defines viscous effects and the Weber number defines surface tension effects as defined below:

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[3] Miller, D.S. Internal Flow Systems. BHRA Fluid Engineering, 1978.

$$R_e = Reynolds\ number = \frac{UL}{\nu} = \frac{Inertial\ Force}{Viscous\ Force}$$

$$W_e = Weber\ number = \frac{\rho U^2 L}{\sigma} = \frac{Inertial\ Force}{Surface\ Tension\ Force}$$

Based on the available literature, the influence of viscous and surface tension forces are negligible if the model bell entrance Reynolds number and Weber number are above 6 x 10^4 and 240, respectively. **nhc** typically requires the Reynolds number be greater than 1 x 10^5 to ensure viscous and surface tension forces are negligible and that pressure forces, which are the controlling forces within the pump bell, are independent of Reynolds number.

Based on the above requirements, **nhc** selected a model scale of 1: 5. At this scale the model met the Reynolds number criterion with a pump bell Reynolds number of 1.2 x 10^5 and the Weber number criterion with a Weber number of 1,180 for the vertical pumps. Adherence to the Froude criterion for dynamic similarity leads to the following scale ratios:

Model Scale Relationships

Parameter	Relation	Ratio
Length	L_r	1 : 5
Velocity	$L_r^{1/2}$	1 : 2.24
Discharge	$L_r^{5/2}$	1 : 55.9

2.2 MODEL DESCRIPTION

The model, as shown in Figures 2-1 to 2-3 and Photo Plate 2-1, reproduced a portion of the effluent conduit with four lateral pipes extending from the side of the conduit to four can pumps and the internal and external geometry of the formed suction inlets up to the location of the prototype axial pump impellers.

At the selected scale of 1:5, the model effluent conduit was 460 mm wide. A 2.3 m section of the conduit extended from the headbox at El. 3.658m followed by a 1.66 m long section that sloped downward 12-degrees to El. 1.9 m and an additional length of 2.84 m to the bypass gate location. Flow within the inlet conduit was drawn to each pump can via four inlet laterals, which were each 240 mm in diameter and 1200 mm in length. The invert a of each lateral was set at El. 1.9 m, which was equal to the invert of the effluent conduit. The centerline spacing of each lateral was 560 mm, with the centerline of the most downstream lateral located 240 mm upstream from the bypass gate. The four pump cans were each 300 mm in diameter and set at a floor level of El. –1.0 m. The pumps were centered within the can and set 100 mm above the sump floor at El. –0.5 m.

The model effluent conduit was mounted on a raised wooden deck framed with dimensional lumber. The laterals, pump cans, draft tube piping and pump bells were fabricated from transparent acrylic plastic to permit visualization of the flow patterns. At the selected scale of 1:5, the model axial flow pump bell diameter was 184 mm and had a 200 mm vertical draft tube that incorporated the pump bell and pump bell column. The geometry of the model pump bells is illustrated in Figure 2-4 and Photo Plate 2-1.

Flow was circulated through the self-contained model using a centrifugal pump. At a scale of 1:5 the flow requirements ranged from 0.7 cubic foot per second (cfs) with one pump operating at its rated flow to 2.9 cfs with all four pumps operating. Total model inflow was controlled with a butterfly valve installed downstream from the laboratory pump; individual pump flow rates were adjusted with butterfly valves installed in each of the model pump suction lines.

Water levels were measured in the pump cans for initial design and in the effluent conduit near the laterals during design development testing and final design testing. Water levels were varied by changing the volume of water in the model.

2.3 MODEL MEASUREMENTS AND INSTRUMENTATION

The following measurements were required for the model:

> ***Flow Rates*** – The total model flow rate through the laboratory centrifugal pump was measured using an orifice-plate flow meter, installed in accordance with ASME Test Code Standards, with an air-water manometer used to measure the pressure differential. Individual pump flows were measured using elbow meters that measured the pressure differential between the inside and outside of an elbow installed in the discharge line for each pump. These elbow meters were calibrated in-place using the orifice-plate flow meter. Experience with these discharge measurement techniques has shown that the measured flows are accurate to within two percent.

Free-Surface and Subsurface Vortices – Free-surface and subsurface vortices were measured by visual observation using dye and were based on the free surface vortex strength scale of Type 1 to Type 5 (Figure 1-4).

Flow Pre-swirl – A swirl meter installed in each model pump bell, as shown in Figure 2-4, provided a measure of average intensity of swirl angle, θ, according to the following equation:

$$\theta = \tan^{-1}\left(\frac{\pi d n}{u}\right)$$

where: d = diameter of the pipe at the swirl meter

n = revolutions/second of the swirl meter

u = average axial velocity at the swirl meter

Experience with these meters indicates an accuracy of ±0.5 degrees.

Water Levels – Water levels in the sump were measured using staff gages referenced to a prototype elevation datum. Accuracy of the measurements was ±0.01 m prototype.

Flow Patterns – Colored dye was used to document flow patterns in the station and entering the pump suction bell.

Velocity Distribution at the Throat of the Pump Suction Bell – Pump inlet velocities were measured over a specified time period (typically 60 seconds model) using a miniature propeller velocity probe installed at the throat of one of the axial pump suction bells, as shown in Figure 2-4. Velocities were measured at eight locations at a constant radius from the pump axis around the circumference of the pump throat. The velocity probe was connected to a computer that recorded probe readings and computed statistical values such as average, minimum, and maximum velocity, minimum and maximum spatial variation and maximum temporal fluctuation. Experience with these velocity systems has indicated an accuracy of ±1 percent.

Photographs and Video – Still photographs and video footage were taken throughout the test program to provide visual documentation of model study progress and key results. Relevant photographs have been included in this report.

3.0 TEST PROGRAM

The test program consisted of the following three phases:

Initial Design Testing – Seven tests were conducted to evaluate the performance of the initial station design and determine the most severe operating condition. Results of the initial design tests are described in Section 4.1.

Design Development Testing – Tests were conducted to develop modifications to improve the performance of the proposed station structure. Results of the design development testing are described in Section 4.2.

Final Design Testing – A series of fourteen final design tests were conducted to confirm that the selected design met the specific operational criteria for the proposed station layout. The results of the final design tests are presented in Section 4.4.

4.0 TEST RESULTS

4.1 INITIAL DESIGN TESTING

Upon completion of model construction and shakedown (tests to ensure that the model was functioning effectively over the full range of operating conditions), model tests were conducted to evaluate the initial design. Seven operating conditions were tested, as indicated in the table below:

Initial Design Testing

Test No.	WL in Can (m)	Operating Pump Discharge (ML/d)				Total Flow (ML/d)	Comments
		Pump 1	Pump 2	Pump 3	Pump 4		
ID-1	4.30	100				100	Single pump operation
ID-2	“		100			100	“ “ “
ID-3	“				100	100	“ “ “
ID-4	“	100	100			200	Two-pump operation
ID-5	“	100	100	100		300	Three-pump operation
ID-6	“	100		100	100	300	“ “ “
ID-7	“	100	100	100	100	400	Four-pump operation

Results of the initial design tests are presented in Table 4.1 and summarized below. Photo Plate 4-1 presents typical hydraulic phenomena observed in the model.

With a water level in the pump cans of El. 4.3 m, the hydraulic losses through the laterals were small, thus the water level in the effluent conduit was only slightly higher. This resulted in a hydraulic jump forming in the effluent conduit at the sloping transition for three and four-pump operation. The hydraulic jump created a significant amount of turbulence and entrained air bubbles that entered the pumps. Additionally, under calmer one and two-pump operation, intermittent Type 4 air core vortices formed in the conduit carrying air through the laterals into the pump cans and ultimately into the pumps.

Flow separated from the sides of the laterals. The most adverse flow separation occurred in the lateral of Pump 1, where the separation extended approximately 50 cm model (2.5m prototype) into the lateral. The separation contributed to non-uniform flow approaching the pumps.

Circulation within the pump cans, as measured by the flow pre-swirl was acceptable with the maximum flow pre-swirl measurement of 3 degrees. This was observed for single pump operation (ID-1 and ID-3).

Flow pre-swirl was within the criterion for all tests, however the swirl rotation was erratic and was probably due to the formation of subsurface vortices.

Strong subsurface vortices were observed in the pump can for all tests. Vortices as strong as constant Type 5 originated from bell level on the pump can wall at locations approximately 60 degrees on either side of the pump can inlet. Constant Type 5 vortices also formed on the can floor, generally near the inlet side of the can. Additionally, double intermittent Type 3 vortices originated just below bell level from the pump can wall directly opposite from the inlet. Water surface within the pump cans was calm.

Velocity data recorded within the throat of the pump suction bell produced a maximum deviation of 34% below the mean (V_{min} / V_{ave} = 66%) and 54% above the mean (V_{max} / V_{ave} = 154%), which was well outside the specified criterion of ±10%. The temporal fluctuations were also well outside the performance criterion with the maximum fluctuation being ±51% from the time-averaged signal. The imbalance in the velocities and the turbulence was expected to be mostly attributed to the formation of subsurface vortices.

In summary, the levels of air entrainment, vortex activity, time-averaged velocity data, and velocity fluctuations were found to exceed the specified performance criteria.

4.2 DESIGN DEVELOPMENT TESTING

Following the initial design testing, design development testing was conducted. The objective of these tests was to develop and implement changes to the initial design that would reduce or eliminate the adverse flow observed for the initial design geometry. The majority of the design development testing was conducted at the one-pump operation of 100 ML/d in Pump 1.

Modifications examined in the model included the following:

- Raising water levels in the effluent conduit;
- Installing curtain wall in the effluent conduit;
- Installing grating platforms below the pump;
- Installing flow vanes in the laterals;
- Installing vane basket to the pump bell;
- Installing a cross on the bottom of the can below the pump;
- Installing a vertical oriented vanes at the bottom of the can around the periphery of the pump bell; and

- Installing floor cone below the pump bell.

Table 4.2 presents the data collected for various geometries tested. The following paragraphs describe the key findings for the various modifications.

WATER LEVEL

By raising water levels in the effluent conduit (measured in the vicinity of the laterals to the pump cans) to El. 4.80 m, the formation of a hydraulic jump in the conduit was prevented. Surface Type 4 air core vortices in the vicinity of the laterals were also eliminated. Standing waves still developed, however, at the sloping transition for three and four-pump operation and resulted in turbulence in the conduit near the laterals.

CURTAIN WALL

A curtain wall is an effective method of reducing or eliminating surface vortex activity and turbulence. For the present study, alternative elevations and locations for the curtain wall were tested in the conduit to reduce the downstream turbulence caused by the standing waves. At the recommended location, surface turbulence was minimized. On the basis of these results, the selected location was with the bottom set at El. 4.3 m with its height extending above high water level. The curtain wall was located 6.9 m downstream from the upper invert of the sloping transition in the conduit.

GRATING PLATFORMS

A grating platform is often used to dissipate vortex activity and to provide more uniform flow to the pump. Different locations were tested below the pump bell; the best being placed directly below the pump bell. In combination with various flow vanes, all criteria were met with the exception of velocity fluctuations, which were slightly outside the criterion. However, because of the risk of debris accumulating on the grating platform, which in turn could create non-uniform flow entering the pumps, the grating platform was not recommended.

FLOW VANES

Various flow vane configurations were tested as a method of improving the flow uniformity approaching the pumps. A turning vane was installed at the entrance to the lateral to reduce the separation in the lateral.

At the entrance to the pump can from the lateral, a flow vane was installed to redirect flow down the upstream portion of the can. This vane was effective in improving spatial velocities entering the pump.

Two vertical oriented flow vanes were also installed within the pump can 135-degrees on either side of the inlet. They were effective in providing a better distribution of flow to the pumps, however it was not required for the recommended design.

On the basis of this, the turning vane at the entrance to the laterals and the downward turning vane at the entrance to the pump cans are recommended.

Vane/ Grating Basket

A 36-vane basket with its bottom comprised of grating was suspended from the pump bell to dissipate subsurface vortices and provide more uniform flow to the pump. Although the vane basket was effective in dissipating floor vortices, it did not dissipate wall vortices or meet spatial velocity criteria. On the basis of these results, it was not recommended.

Floor Cross

A floor cross is sometimes used to reduce subsurface floor vortices, to provide more uniform flow to the pump, and to reduce flow pre-swirl entering the pump bell. In the present study, however, the floor cross was not effective in improving flow conditions to the pump, therefore, it was not recommended.

Installing a vertical oriented vanes at the bottom of the can around the periphery of the pump bell

Various configurations of a 72-vane ring surrounding the pump bell were tested. The proposed design included three horizontal rings that surrounded the vanes. The ring was effective in dissipating the severe Type 5 vortices that formed from the side of the pump can and provided better distribution of flow to the pumps. With the ring design installed in combination with other recommended modifications, the spatial velocity criterion was met, subsurface vortices were eliminated, and flow pre-swirl was well within the criterion. Based on these results, the vane ring is recommended.

Floor Cone

Floor cones are sometimes utilized to reduce subsurface vortex activity originating beneath pump suction bells. A floor cone designed on the basis of pump bell diameter and floor-to-bell clearance was tested.

With the cone installed, subsurface vortices originating from the floor were eliminated or reduced to general turbulence (from Type 5 in initial design). Based on these results, the installation of the floor cone is recommended.

PROPOSED PRELIMINARY MODIFICATIONS

On the basis of the design development testing, the following modifications were proposed in the Preliminary Modification Drawings:

- Water level in the conduit maintained at El. 4.8m or above;
- A curtain wall installed in the conduit;
- Flow turning vanes installed at the entrances to the laterals;
- Downward-turning vanes installed at the entrances to the pump cans;
- A ring of vertical oriented vanes surrounding the pump bells; and
- Floor cones centered beneath the pump bells.

4.3 REVIEW OF PRELIMINARY MODIFICATIONS

Mr. Chris Lipscombe of Earth Tech reviewed the recommended preliminary modifications and approved all of the recommendations, except the increase in water levels. Because prototype station water level may vary up to ±0.5 m, a low water level (measured in the conduit near the laterals) of El. 4.3 m may be required for operation. Further design development testing was undertaken to improve flow approaching the laterals at El. 4.3 m.

RELOCATION OF SLOPING TRANSITION IN THE CONDUIT

In order to reduce the impact of the hydraulic jump on the pump performance, the sloping transition relocated 19.6 m upstream from its location. In the model (which was constructed to represent 11.5 m, prototype, length of conduit upstream of the slope), the slope was completely removed so that the floor at the headbox was at El. 1.9 m. The results of this modification indicated that the flow in the conduit was relatively calm. Because of this, the recommended curtain wall was not required. Relocation of the sloping transition 19.6 m upstream is recommended.

VORTEX BREAKER BARS

With the deeper channel flow velocities were significantly less, thus the energy to develop strong surface vortices was less. However, reasonably strong surface vortices did form and needed to be addressed.

Additional testing was conducted and seven square beams were developed with their tops placed at El. 4.25m to break up the formation of the vortices. The vortex breaker bars were effective in dissipating all surface vortices so that no air was entrained. Therefore, the vortex breaker bars are recommended.

4.4 FINAL DESIGN TESTING

The objective of the final design testing was to ensure that the proposed modifications would perform satisfactorily for a range of operating conditions. The modifications that were tested included the following (refer to Figures 4-1 to 4-3 and Photo Plate 4-2):

- The sloping transition in the conduit relocated 19.6m upstream;
- Vortex breaker bars installed across the width of the conduit in the vicinity of the laterals;
- Flow turning vanes installed at the entrances to the laterals;
- Downward turning vanes installed at the entrances to the pump cans;
- A ring of vertical oriented vanes surrounding the pump bells; and
- Floor cones centered beneath the pump bells.

The fourteen final design tests listed below were conducted with the above modifications installed in the model.

Final Design Test Program

Test No.	Conduit WL El. (m)	Operating Pump Discharge (ML/d)				Total Flow (ML/d)	Comments
		Pump 1	Pump 2	Pump 3	Pump 4		
1*	4.8	100				100	One-pump operation
2*	4.8		100			100	" " "
3*	4.8				100	100	" " "
4*	4.8	100	100			200	Two-pump operation
5	4.8			100	100	200	" " "
6	4.8	100			100	200	" " "
7*	4.8	100	100	100		300	Three-pump operation
8	4.8		100	100	100	300	" " "
9*	4.8	100		100	100	300	" " "
10*	4.8	100	100	100	100	400	Four-pump operation
11	4.3	100				100	One-pump operation
12	4.3	100	100				Two-pump operation
13	4.3	100	100	100		300	Three-pump operation
14	4.3	100	100	100	100	400	Four-pump operation

* Initial Design Tests

Table 4.3 summarizes the results from these tests and Photo Plate 4-3 shows the final design flow patterns. In all cases, the recommended modifications to the station were successful in providing acceptable flow to the pump.

For all tests, the water surface in the effluent conduit was relatively calm. For low water tests, Type 1 surface dimples formed in the conduit near the laterals. Intermittent Type 2 surface vortices were observed at the downstream end of the conduit for the four-pump operation at the low water level (Test 14), however the vortices did not extend to the laterals.

Flow through the laterals and down the can was more uniform that observed in initial design testing. More uniform flow in the laterals and can plus passing through the vanes at the base of the can resulted in flow pre-swirl being within the acceptance criterion for all cases. The maximum flow pre-swirl angle was 2 degrees.

The ring of vanes at the base of the can and the floor cone were effective in dissipating subsurface vortices originating from the side of the pump can and from the floor. Although no defined vortices formed, there was still some general turbulence at the locations where vortices had formed on the side of the can. This resulted in slightly elevated levels in the velocity fluctuations.

Velocities at the throat of Pump 1were recorded for ten tests. In all cases, spatial velocities were within the criterion and temporal fluctuations were slightly outside the criterion. The maximum spatial deviation in the average flow velocity was 10% and the maximum temporal fluctuation recorded was 15%. Although temporal fluctuations were outside the specified criterion, this was a vast improvement from the initial design (fluctuations of up to 51%).

4.5 SUBSEQUENT DESIGN CONSIDERATIONS (POST TESTING)

Following the completion of the model testing, two potential changes were identified regarding the pump station design:

1. The pumps may be downsized from 100 ML/d to 86 ML/d and the number of pumping units increased from four to five. The inlet sump would be lengthened to accommodate the change, so approach conditions would not change. All other dimensions would remain the same.

The maximum flow in the effluent conduit will increase slightly from 400 ML/d to 430 ML/d. This increase in flow may have a small affect on the increase the strength and length of the hydraulic jump that will form on the sloping transition in the effluent conduit. With the sloping transition located at the entrance to the effluent channel, some 32.5 m upstream of the laterals to the pump station, the hydraulic jump should still be sufficiently far upstream so that turbulence and the entrainment of air bubbles should not be an issue. Surface vortex formation in the conduit in the vicinity of the laterals may also be influenced by the increase flow capacity, however, if additional vortex breaker bars are installed in the effluent conduit at the fifth pumping unit, it is unlikely that surface vortices with capacity to entrain air to the pumps will form. The decrease in flow per pump should not have a significant influence on the flow patterns in the laterals and pump cans, thus the recommended modifications should still provide acceptable flow conditions to the pumps.

2. The size of the pump discharge columns may be smaller than modeled. Depending upon the pump manufacturer the pump discharge tube with the smaller capacity pumps may be 800 mm in diameter rather than 1000 mm. All other dimensions would remain the same.

   With a smaller pump discharge column diameter, the flow velocities in the can will be significantly slower and thus the potential for strong submerged vortices will be less. The recommended modifications should have the same positive effect on the flow conditions entering the smaller pump. The turbulence levels in the flow that influenced the temporal velocities may be less, which may reduce the velocity fluctuations entering the pumps.

5.0 CONCLUSIONS

Physical model testing conducted for the initial design of the City of Winnipeg North End Water Pollution Control Centre Pump Station demonstrated that the flow within the station susceptible to strong subsurface vortices originating from the floor beneath the pump bell and from the side of the can. Air entraining surface vortices that developed in the conduit near the laterals pulled air into the pumps. A hydraulic jump that formed on the sloping transition in the conduit during three and four-pump created a significant amount of turbulence and entrained air bubbles that entered the pumps. Time-averaged and time-varying velocity fluctuations at the pump impeller location were also well outside the specified criteria.

Several modifications to the initial design were developed and tested in the model. The objectives of the modifications were to improve the uniformity of flow approaching the pump, minimize turbulence, reduce the vortex activity in the vicinity of the pump inlet, and improve the velocity distribution at the pump impeller location. Modifications developed in the model and tested for Final Design included the following:

- The sloping transition in the conduit relocated 19.6m upstream;
- Vortex breaker bars installed across the width of the conduit in the vicinity of the laterals;
- Flow turning vanes installed at the entrances to the laterals;
- Downward turning vanes installed at the entrances to the pump cans;
- A ring of vertical oriented vanes surrounding the pump bells; and
- Floor cones centered beneath the pump bells.

With these modifications installed, flow pre-swirl, surface, and subsurface vorticity, and the spatial velocities at the impeller location were all within the specified performance criteria. The temporal velocity fluctuations were 5 percent outside the specified criterion. Typically, high fluctuations in the velocities may cause minor performance issues such as slightly elevated levels of vibration and noise, and possibly flashes of cavitation. Since all the other criteria have been met, we do not foresee this being a significant problem.

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.1

Summary of Initial Design Testing

Test No.	Water Level in Cans	Pump	Operating Discharge (ML/d)	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
				CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
ID-1	El. 4.3m	Pump 1	100	0	0	17	3	0	3(C)	3(C)	67%	154%	49%	Type 4(I) vortices occurred on the floor on the inlet side of the can and on the wall of the can at two locations; approximately 60 degrees either side of the inlet, at bell level. A double Type 3(I) vortex occurred on the walll of the can directly across from the inlet, at bell level. Water surfaces in the conduit and can were calm. A Type 4(I) surface vortex formed in the conduit and entered the Pump 1 lateral pipe.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
ID-2	El. 4.3m	Pump 1	x	x	x	x	x	x	x	x	x	x	x	Vortices occurred at the same locations within the can as ID-1. A Type 5(I) surface vortex formed in the conduit and entered the Pump 2 lateral pipe.
		Pump 2	100	0	0	11	2	0	5(I)	5(I)				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
ID-3	El. 4.3m	Pump 1	x	x	x	x	x	x	x	x	x	x	x	Vortices occurred at the same locations within the can as ID-1 and ID-2. A Type 4(I) surface vortex formed in the conduit and entered the Pump 4 lateral pipe.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	100	0	0	16	3	0	5(I)	5(I)				
		Total	100											
ID-4	El. 4.3m	Pump 1	100	8	1	0	0	0	3(C)	3(C)	69%	149%	48%	Strong constant Type 3 vortices occurred on the floor and on the wall of the cans at aproximately 60 degrees either side of the inlets. A double Type 3(I) vortex occurred on the wall of the can opposite the inlet location, at bell height. A hydraulic jump formed at the entrance to the conduit from the headbox. Standing waves and turbulence occurred in the conduit. Type 4(I) surface vortices formed in the conduit at the entrance to the Pump 1 and 2 laterals.
		Pump 2	100	0	0	15	3	0	3(C)	3(C)				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	200											
ID-5	El. 4.3m	Pump 1	100	11	2	0	0	0	5(C)	5(C)	66%	147%	50%	Similar vortices were observed within the cans as previous tests. With three pumps operating, the hydraulic jump in the conduit occurred on the sloping transition (approx 2.42 m model upstream from the centerline of lateral 1). The hydraulic jump entrained air bubbles into the flow. Some bubbles entered Pump 1, less entered Pump 2, and an occasional bubble entered Pump 3.
		Pump 2	100	0	0	13	2	0	5(I)	5(I)				
		Pump 3	100	8	1	0	0	0	3(C)	4(I)				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	300											

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.1 (continued)

Summary of Initial Design Testing

Test No.	Water Level in Cans	Pump	Operating Discharge (ML/d)	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
				CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
ID-6	El. 4.3m	Pump 1	100	2	0	8	1	0	5(C)	5(C)	71%	147%	51%	Similar observations as ID-5, however more air bubbles entered lateral 1, a small amount of bubbles entered lateral 3, and no bubbles entered lateral 4.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	100	12	2	0	0	0	5(I)	5(I)				
		Pump 4	100	13	2	0	0	0	5(I)	5(I)				
		Total	300											
ID-7	El. 4.3m	Pump 1	100	10	2	0	0	0	5(C)	5(C)	74%	147%	50%	Vortices within the cans occurred at similar locations as previous tests. With all four pumps operating, the hydraulic jump was slightly farther downstream than with three pumps, but still occurred on the sloping transition in the conduit. Significant amounts or air bubbles from the hydraulic jump entered Pump 1, with decreasing amounts in the downstream pumps.
		Pump 2	100	1	0	10	2	0	5(C)	5(C)				
		Pump 3	100	4	1	4	1	0	5(I)	5(I)				
		Pump 4	100	12	2	1	0	0	5(I)	5(I)				
		Total	400											

NOTES:

1. Clockwise (CW) and counter-clockwise (CCW) directions, as viewed from above.
2. I = Intermittent; C = Constant
3. Throat velocities were recorded using a Nixon propeller meter at eight locations in the throat of Pump 1 (most upstream pump).

Legend:

x Pump was not operating

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.2
Summary of Design Development Testing

Test No.	Water Level in Conduit	Pump	Operating Discharge	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
			(ML/d)	CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
Modification 1- Water level was maintained at El. 4.8m in the conduit.														Two pump operation: no hydraulic jump or standing waves formed in the conduit. Type 3 surface vortices formed at the entrance to the Pumps 1 and 2 laterals.
MOD-1A	El. 4.8m	Pump 1	100	-	-	-	-	-	-	-	-	-	-	
		Pump 2	100	-	-	-	-	-	-	-				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	200											
MOD-1B	El. 4.8m	Pump 1	100	-	-	-	-	-	-	-	-	-	-	Three pump operation: no hydraulic jump formed. Small standing waves formed in the conduit from the sloping transition to the first lateral.
		Pump 2	100	-	-	-	-	-	-	-				
		Pump 3	100	-	-	-	-	-	-	-				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	300											
MOD-1C	El. 4.8m	Pump 1	100	-	-	-	-	-	-	-	-	-	-	Four pump operation: no hydraulic jump formed. Larger standing waves formed in the channel from the sloping transition to the first lateral creating significant turbulence in the conduit. Separation in the lateral of Pump 1 extended approximately .5 m model (2.5 m proto).
		Pump 2	100	-	-	-	-	-	-	-				
		Pump 3	100	-	-	-	-	-	-	-				
		Pump 4	100	-	-	-	-	-	-	-				
		Total	400											
Modification 2 - A grating platform the diameter of the can was placed two-thirds of the floor-to-bell distance above the floor. Water level for all subsequent tests was set in the conduit (El. 4.8m).														Flow within the conduit was calm. Type 3(I) surface vortices formed in the channel and entered the Pump 1 lateral. Wall vortices formed in the can at locations approximately 60 degrees either side of the inlet at the grating level and entered the bell. The double vortex located opposite the inlet formed below the grating and was dissipated by the grating. The floor vortex was also dissipated by the grating.
MOD-2	El. 4.8m	Pump 1	100	8	1	0	0	0	3(I)	0	63%	140%	37%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.2 (continued)

Summary of Design Development Testing

Test No.	Water Level in Conduit	Pump	Operating Discharge	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
			(ML/d)	CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
Modification 3- A vertical curtain wall was installed at El. 4.3m at a location 1.2 m model (6.0 m proto) upstream from the centerline of the Pump 1 lateral.														Upstream of the curtain wall, standing waves developed to the same extent as Mod-1C. Dowstream of the curtain wall, the flow was relatively calm.
MOD-3	El. 4.8m	Pump 1	100	-	-	-	-	-	-	-	-	-	-	
		Pump 2	100	-	-	-	-	-	-	-				
		Pump 3	100	-	-	-	-	-	-	-				
		Pump 4	100	-	-	-	-	-	-	-				
		Total	400											
Modification 4 - A grating platform the diameter of the can was installed directly below the bell. Other modifications (curtain wall, the lower grating platform) remained.														Strong wall vortices formed on either side of the inlet at the elevation of the lower grating. The grating eliminated wall vortices, though turbulence from the wall was observed.. Floor vortices that began on the inlet side of the can and wall vortices that formed opposite the inlet were dissipated by the grating. Flow pre-swirl was reduced and fluctuated less. Velocity fluctuations were reduced to 11%. Spatial velocities were improved.
MOD-4	El. 4.8m	Pump 1	100	0	0	1	0	0	0	0	84%	117%	11%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 5- A vertical vane was installed at the entrance to the lateral and a downward turning vane was installed at the entrance to the can. Other modifications (curtain wall, 2 grating platforms) remained.														Spatial velocities were improved, however Vmin/Vave remained 5% outside criteria due to a low velocity point 90 degrees counterclockwise (as viewed from above) from the inlet location. Turbulence from the wall was observed.
MOD-5	El. 4.8m	Pump 1	100	0	0	0	0	0	0	0	85%	108%	10%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 6- The lower grating was removed. Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane, grating platform under bell) remained.														Fluctuations were slightly higher than Mod-5 (two grating platforms). Spatial velocities were within 3% of criteria. Turbulence was observed from the wall.
MOD-6	El. 4.8m	Pump 1	100	0	0	0	0	0	0	0	89%	113%	13%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.2 (continued)

Summary of Design Development Testing

Test No.	Water Level in Conduit	Pump	Operating Discharge	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
			(ML/d)	CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
Modification 7- Vertical flow vanes were attached to the can 135 degrees on either side of the inlet. Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane, grating platform under bell) remained.														Turbulence was observed from the wall. Velocity fluctuations were 2% outside criteria. All other criteria were met.
MOD-7	El. 4.8m	Pump 1	100	0	0	0	0	0	0	0	92%	106%	12%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 8- Vertical flow vanes and the grating platform were removed. A 36-vane basket with grating attached beneath it was suspended from the pump bell. Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane) remained.														Type 3 vortices passed through the vanes and entered the bell. Spatial and temporal velocities were outside criteria.
MOD-8	El. 4.8m	Pump 1	100	-	-	-	-	0	3(I)	0	73%	136%	34%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 9- Vane basket was removed and floor cross was installed. Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane) remained.														Type 3 vortices formed between extents of the floor cross. Spatial velocity distribution and fluctuations were well outside criteria.
MOD-9	El. 4.8m	Pump 1	100	0	0	0	0	0	3(C)	2(C)	65%	199%	39%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 10- Floor cross was removed. A floor cone was installed beneath the bell. A 1.2 m (proto, ID) diameter ring of 72-vanes was installed on the floor surrounding the bell . Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane) remained.														Type 2 vortices from the wall entered the bell through the vane ring. Type 2 floor vortices were observed. Spatial and temporal velocities were outside criteria.
MOD-10	El. 4.8m	Pump 1	100	3	1	0	0	0	2(C)	2(C)	52%	125%	43%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.2 (continued)

Summary of Design Development Testing

Test No.	Water Level in Conduit	Pump	Operating Discharge	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
			(ML/d)	CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
Modification 11 - 3 horizontal rings (10mm model depth) were added to the outer diameter of the 72-vane ring. Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane, cone) remained.														Velocity fluctuations were 3% outside criteria. All other criteria were met. Turbulence was observed from the wall.
MOD-11	El. 4.8m	Pump 1	100	0	0	8	1	0	0	0	92%	104%	13%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 12 - An additional 4 horizontal rings were added to the outer diameter of the 72-vane ring (for 7 horizontal ring total). Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane, cone) remained.														Velocity fluctuations were slightly worse. All other criteria were met. Turbulence was observed from the wall.
MOD-12	El. 4.8m	Pump 1	100	0	0	13	2	0	0	0	95%	106%	15%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 13 - The 4 additional horizontal rings were removed, the top ring was reduced to 5mm depth (model), the second ring was reduced to 7.5mm, and the third ring was 10mm. Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane, cone) remained.														Velocity fluctuations were outside criterion. All other criteria were met. Turbulence was observed from the wall.
MOD-13	El. 4.8m	Pump 1	100	0	0	0	0	0	0	o	91%	110%	14%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 14 - The floor cone was removed. A grating platform the diameter of the ring of vanes was installed 70mm model from the floor. Other modifications (curtain wall, lateral entrance vane, can entrance downward turning vane, 72-ring vane with 3 horizontal outer rings) remained.														Velocity fluctuations were outside criterion. All other criteria were met.
MOD-14	El. 4.8m	Pump 1	100	0	0	1	0	0	-	-	88%	107%	16%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.2 (continued)

Summary of Design Development Testing

Test No.	Water Level in Conduit	Pump	Operating Discharge	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
			(ML/d)	CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
Modification 15 - The grating platform was removed and floor cone was reinstalled. The downward turning vane at the entrance to the can was removed. Other modifications (curtain wall, lateral entrance vane, 72-ring vane with 3 horizontal outer rings) remained.														Without the downward turning vane, both spatial velocities and temporal fluctuations were outside criteria.
MOD-15	El. 4.8m	Pump 1	100	0	0	5	1	-	-	-	88%	109%	21%	
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
Modification 16 - The sloping transition in the conduit was relocated upstream (beyond the model) . The downward turning vane at the entrance to the can was replaced. Other modifications (curtain wall, lateral entrance vane, 72-ring vane with 3 horizontal outer rings, floor cone) remained.														The low water level in the conduit was specified at El. 4.3m. With the sloping transition relocated upstream, conditions in the vicinity of the laterals were relatively calm. With the calmer conditions, the curtain wall was no longer required, however, Type 4(I) surface vortices (capable of entraining air to the pumps) were observed entering the laterals.
MOD-16	El. 4.3m	Pump 1	100	-	-	-	-	-	-	-	-	-	-	
		Pump 2	100	-	-	-	-	-	-	-				
		Pump 3	100	-	-	-	-	-	-	-				
		Pump 4	100	-	-	-	-	-	-	-				
		Total	400											
Modification 17 - Seven square vortex breaker bars were installed across the width of the conduit in the vicinity of the laterals. The curtain wall was removed. Other modifications (relocated slope, lateral entrance vane, can entrance downward turning vane, 72-ring vane with 3 horizontal outer rings, floor cone)														With the vortex breaker bars installed, a maximum Type 2(I) surface vortex was observed in the conduit in the vicinity of the laterals, however, the vortex did not enter the laterals.
MOD-17	El. 4.3m	Pump 1	100	-	-	-	-	-	-	-	-	-	-	
		Pump 2	100	-	-	-	-	-	-	-				
		Pump 3	100	-	-	-	-	-	-	-				
		Pump 4	100	-	-	-	-	-	-	-				
		Total	400											

NOTES:

1. Clockwise (CW) and counter-clockwise (CCW) directions, as viewed from above.
2. I = Intermittent; C = Constant
3. Throat velocities were recorded using a Nixon propeller meter at eight locations in the throat of Pump 1 (most upstream pump).

Legend:

x Pump was not operating

\- Data was not recorded

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.3

Summary of Final Design Testing

Test No.	Water Level in Conduit	Pump	Operating Discharge (ML/d)	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
				CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
1	El. 4.8m	Pump 1	100	0	0	7	1	0	0	0	94%	107%	14%	Conduit water surface was calm. Turbulence was observed from the can wall.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
2	El. 4.8m	Pump 1	x	x	x	x	x	x	x	x	x	x	x	Conduit water surface was calm. Turbulence was observed from the can wall.
		Pump 2	100	0	0	10	2	0	0	0				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
3	El. 4.8m	Pump 1	x	x	x	x	x	x	x	x	x	x	x	Conduit water surface was calm. Turbulence was observed from the can wall.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	100	3	1	0	0	0	0	0				
		Total	100											
4	El. 4.8m	Pump 1	100	0	0	4	1	0	0	0	96%	104%	14%	Conduit water surface was calm. Turbulence was observed from the can wall.
		Pump 2	100	0	0	8	1	0	0	0				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	200											
5	El. 4.8m	Pump 1	x	x	x	x	x	x	x	x	x	x	x	Type 1 surface dimples were observed in the conduit. Turbulence was observed from the can wall.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	100	10	2	0	0	0	0	0				
		Pump 4	100	6	1	0	0	0	0	0				
		Total	200											

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.3 (continued)

Summary of Final Design Testing

Test No.	Water Level in Cans	Pump	Operating Discharge (ML/d)	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
				CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
6	El. 4.8m	Pump 1	100	0	0	11	2	0	0	0	94%	107%	14%	Conduit water surface was calm. Turbulence was observed from the can wall.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	100	5	1	0	0	0	0	0				
		Total	200											
7	El. 4.8m	Pump 1	100	0	0	5	1	0	0	0	96%	103%	14%	Conduit water surface was calm. Turbulence was observed from the can wall.
		Pump 2	100	0	0	9	2	0	0	0				
		Pump 3	100	0	0	1	0	0	0	0				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	300											
8	El. 4.8m	Pump 1	x	x	x	x	x	x	x	x	x	x	x	Type 1 surface dimples occurred near the downstream conduit wall. Turbulence was observed from the can wall.
		Pump 2	100	0	0	14	2	0	0	0				
		Pump 3	100	14	2	0	0	0	0	0				
		Pump 4	100	6	1	0	0	0	0	0				
		Total	300											
9	El. 4.8m	Pump 1	100	0	0	9	2	0	0	0	90%	106%	15%	Type 1 surface dimples occurred near the downstream conduit wall. Turbulence was observed from the can wall.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	100	0	0	0	0	0	0	0				
		Pump 4	100	6	1	0	0	0	0	0				
		Total	300											
10	El. 4.8m	Pump 1	100	0	0	13	2	0	0	0	94%	107%	12%	Type 1 surface dimples occurred near the downstream conduit wall. Turbulence was observed from the can wall.
		Pump 2	100	0	0	9	2	0	0	0				
		Pump 3	100	4	1	0	0	0	0	0				
		Pump 4	100	7	1	0	0	0	0	0				
		Total	400											

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

TABLE 4.3 (continued)
Summary of Final Design Testing

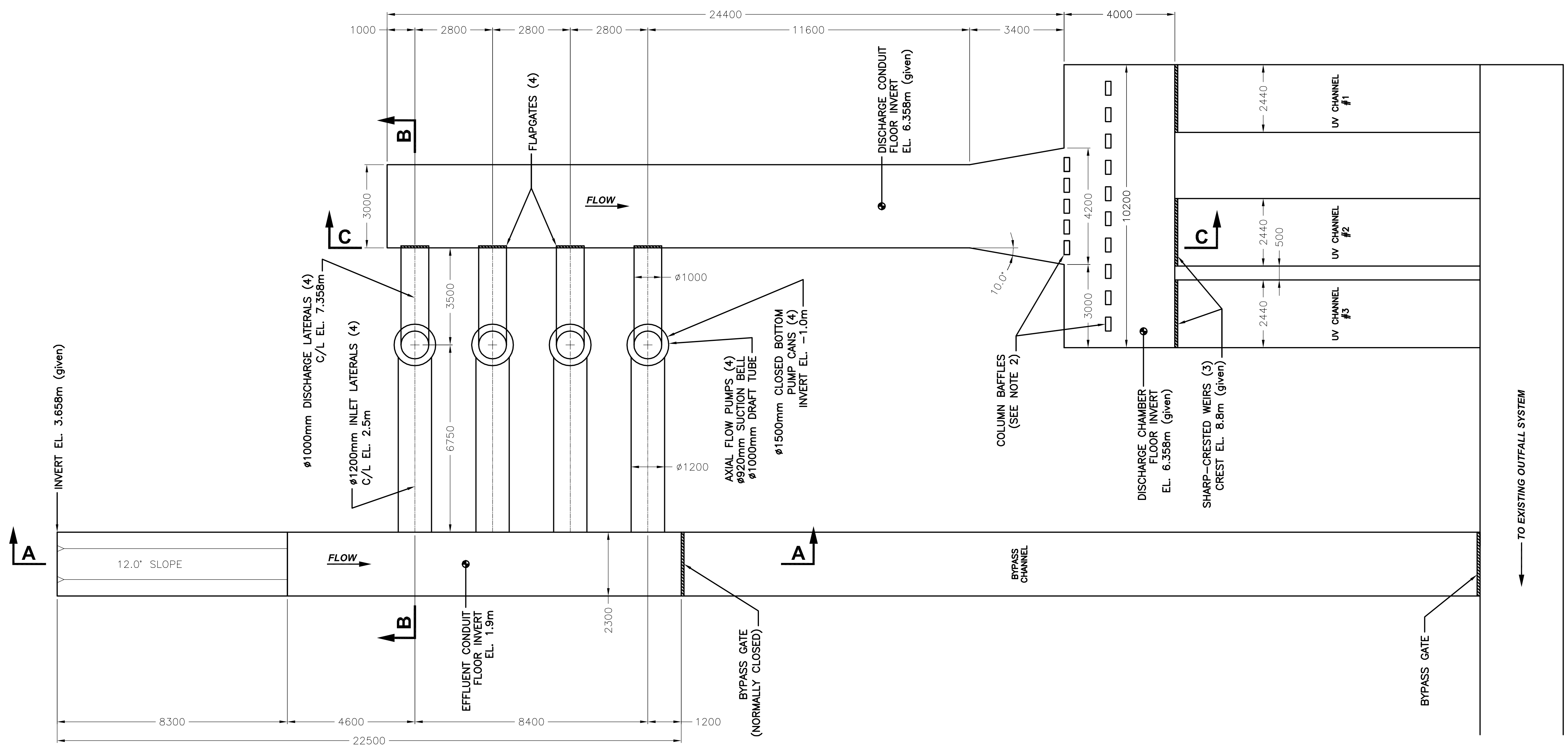
Test No.	Water Level in Cans	Pump	Operating Discharge (ML/d)	Pre-swirl[1]				Vortex Activity[2]			Throat Velocity[3]			Comments
				CW (rpm)	CW (deg)	CCW (rpm)	CCW (deg)	Surface	Wall	Floor	V_{min}/V_{ave}	V_{max}/V_{ave}	Maximum Fluctuation	
11	El. 4.3m	Pump 1	100	0	0	8	1	0	0	0	92%	110%	15%	Conduit water surface was calm. Turbulence was observed from the can wall.
		Pump 2	x	x	x	x	x	x	x	x				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	100											
12	El. 4.3m	Pump 1	100	0	0	6	1	0	0	0	92%	106%	15%	Type 1 surface dimples occurred in the conduit near the operating pumps' laterals. Turbulence was observed from the can wall.
		Pump 2	100	0	0	8	1	0	0	0				
		Pump 3	x	x	x	x	x	x	x	x				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	200											
13	El. 4.3m	Pump 1	100	0	0	2	0	0	0	0	91%	107%	15%	Type 1 surface dimples occurred in the conduit near the operating pumps' laterals. Turbulence was observed from the can wall.
		Pump 2	100	0	0	7	1	0	0	0				
		Pump 3	100	6	1	0	0	0	0	0				
		Pump 4	x	x	x	x	x	x	x	x				
		Total	300											
14	El. 4.3m	Pump 1	100	0	0	4	1	0	0	0	90%	105%	14%	Type 2 vortices occurred in the conduit near the downstream end, however, they did not enter the laterals. Turbulence was observed from the can wall.
		Pump 2	100	0	0	10	2	0	0	0				
		Pump 3	100	1	0	0	0	0	0	0				
		Pump 4	100	7	1	0	0	0	0	0				
		Total	400											

NOTES:

1. Clockwise (CW) and counter-clockwise (CCW) directions, as viewed from above.
2. I = Intermittent; C = Constant
3. Throat velocities were recorded using a Nixon propeller meter at eight locations in the throat of Pump 1 (most upstream pump).
4. All final design testing was conducted with the following modifications installed: seven square vortex breaker bars in the conduit near the laterals, a flow turning vane at the entrance to each lateral, a downward turning vane at the entrance to each pump can, a 72-vane ring , with 2 horizontal rings surrounding each bell, and a floor cone centred beneath each pump bell.

Legend:

x Pump was not operating



NOTES:

1) ALL DIMENSIONS GIVEN IN PROTOTYPE MILLIMETRES UNLESS STATED OTHERWISE. ALL ELEVATIONS GIVEN IN PROTOTYPE METRES.
2) THE NEED FOR COLUMN BAFFLES AND OTHER DEVICES REQUIRED TO MEET PERFORMANCE CRITERIA CAN BE DETERMINED THROUGH PHYSICAL MODELLING OF THE DISCHARGE SYSTEM.

0 2000 4000 6000
DISTANCE IN MILLIMETRES
1: 60 (prototype)

EARTH TECH (CANADA) INC.

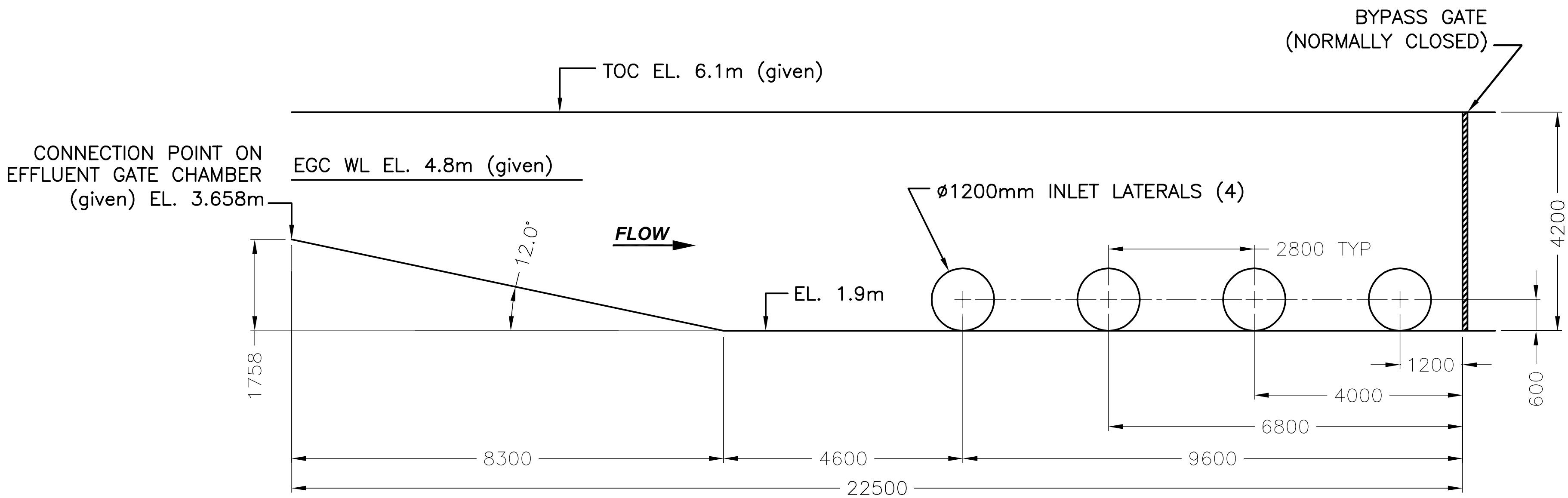
CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Proposed Pump Station Layout
Plan View

Dwg. 6506–001	Rev. No. 3	27–Sep–2004

northwest hydraulic consultants

FIGURE 1-1



SECTION A-A

NOTES:
1) ALL DIMENSIONS GIVEN IN PROTOTYPE MILLIMETRES UNLESS STATED OTHERWISE. ALL ELEVATIONS GIVEN IN PROTOTYPE METRES.

0 2000 4000 6000
DISTANCE IN MILLIMETRES
1: 80 (prototype)

EARTH TECH (CANADA) INC.

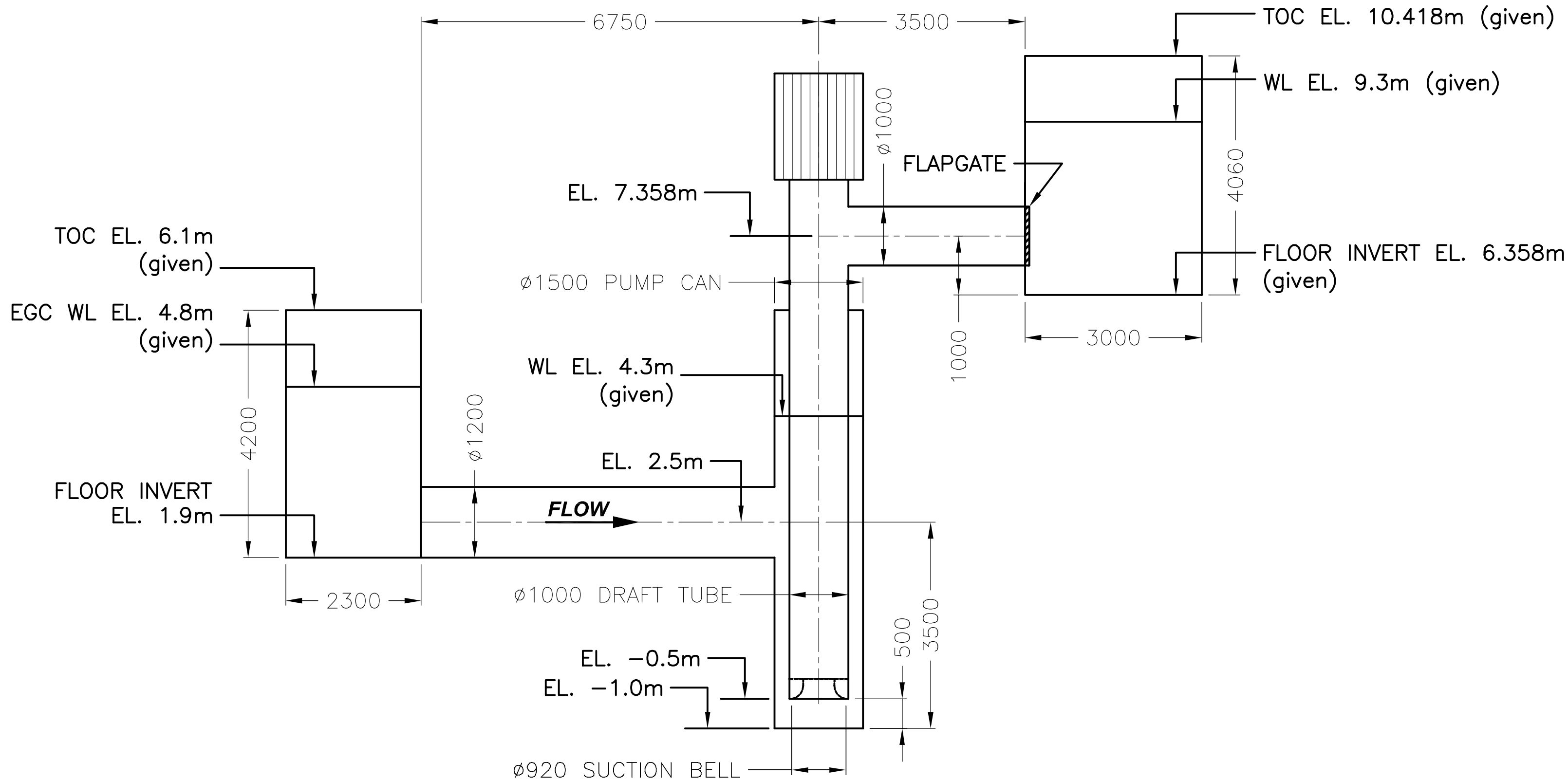
CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Proposed Pump Station Layout
Section A-A

Dwg. 6506–001	Rev. No. 3	27–Sep–2004

northwest hydraulic consultants

FIGURE 1-2



SECTION B-B

NOTES:

1) ALL DIMENSIONS GIVEN IN PROTOTYPE MILLIMETRES UNLESS STATED OTHERWISE. ALL ELEVATIONS GIVEN IN PROTOTYPE METRES.

0 2000 4000 6000

DISTANCE IN MILLIMETRES
1: 80 (prototype)

EARTH TECH (CANADA) INC.

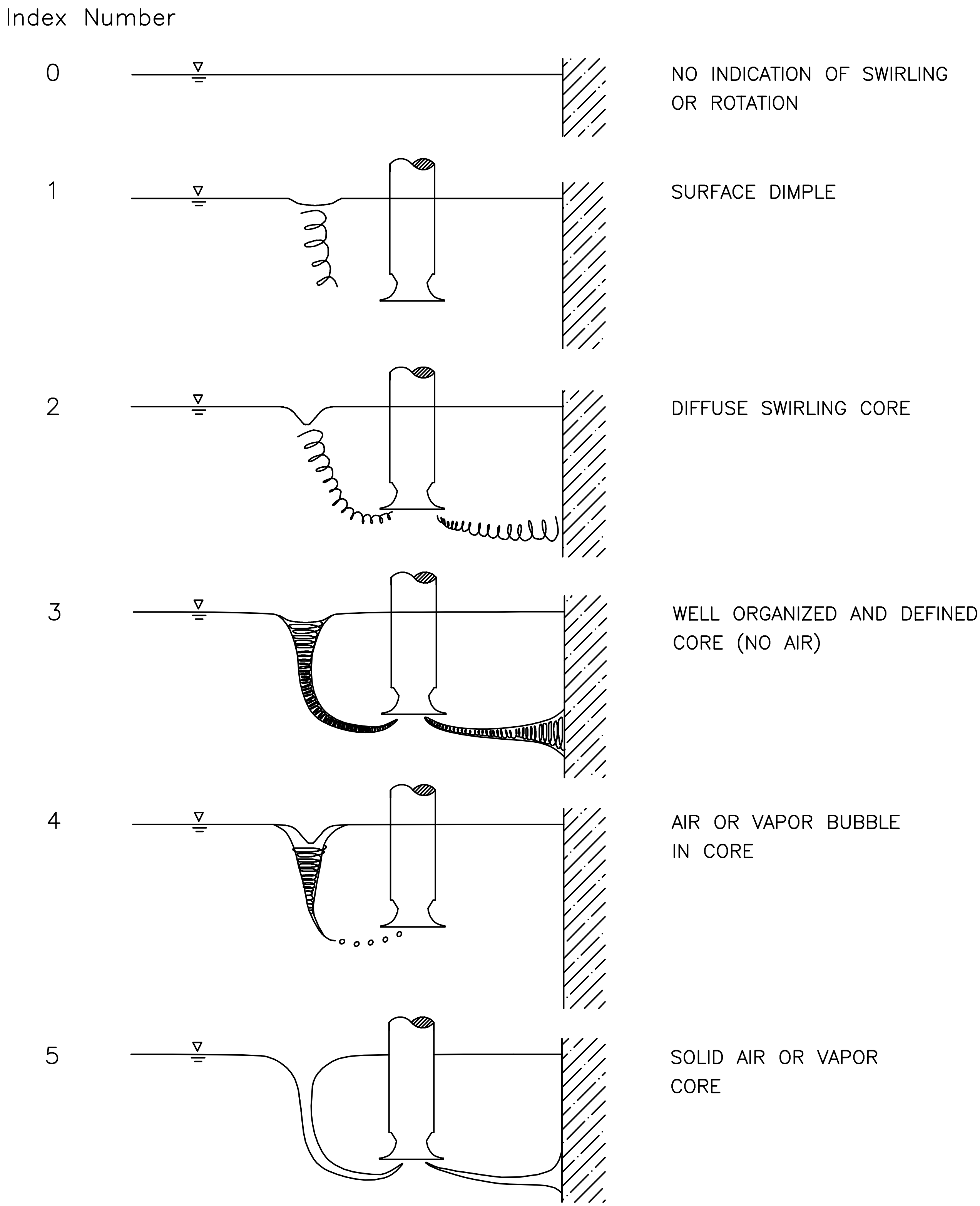
CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Proposed Pump Station Layout
Section B-B

Dwg. 6506−001	Rev. No. 3	27−Sep−2004

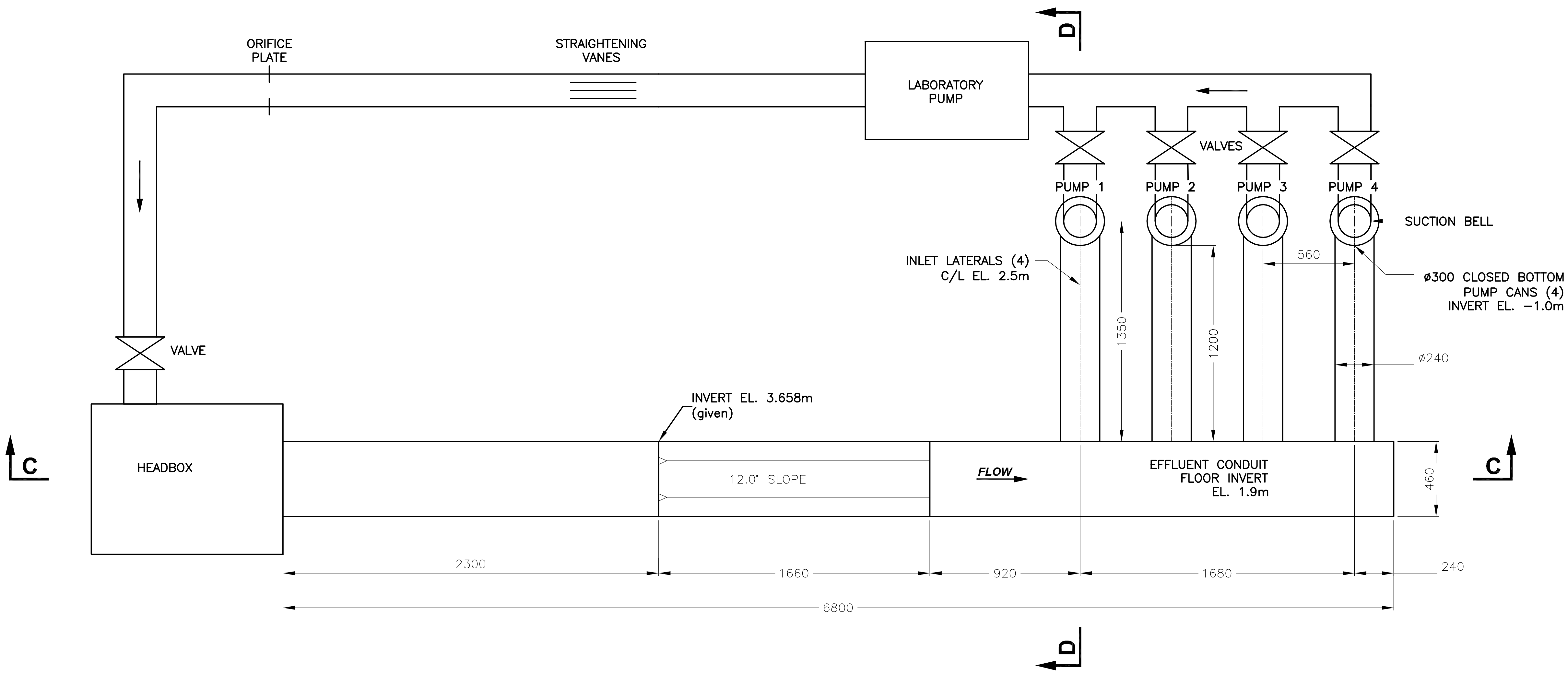
northwest hydraulic consultants

FIGURE 1-3



EARTH TECH (CANADA) INC.		
CITY OF WINNIPEG, NEWPCC PUMP STATION MODEL TEST		
Vortex Classification System		
Dwg. 6506–004	Rev. No. 1	18–Nov–2004
northwest hydraulic consultants		

FIGURE 1-4



NOTES:

1) DIMENSIONS ARE GIVEN IN MODEL MILLIMETRES.
   ALL ELEVATIONS ARE GIVEN IN PROTOTYPE METRES.
2) MODEL SCALE: 1mm MODEL = 5mm PROTOTYPE

0 300 600 900 1200 1500
DISTANCE IN MILLIMETRES
1: 30 (model)

EARTH TECH (CANADA) INC.

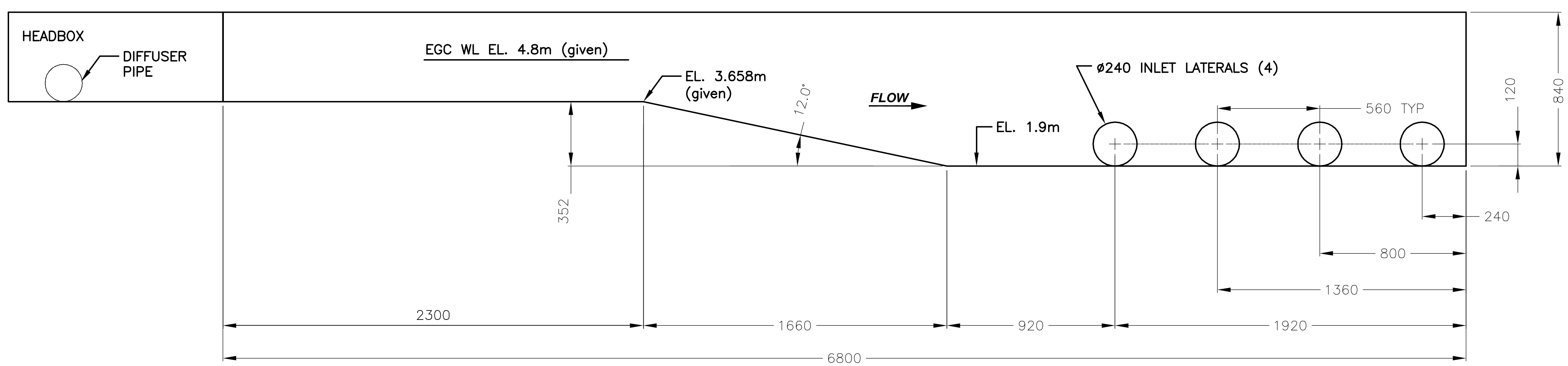
CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Model Layout
Plan View

Dwg. 6506–002	Rev. No. 3	14–Dec–2004

northwest hydraulic consultants

FIGURE 2-1



SECTION C-C

NOTES:
1) DIMENSIONS ARE GIVEN IN MODEL MILLIMETRES.
ALL ELEVATIONS ARE GIVEN IN PROTOTYPE METRES.
2) MODEL SCALE: 1mm MODEL = 5mm PROTOTYPE

0 300 600 900 1200 1500
DISTANCE IN MILLIMETRES
1: 30 (model)

EARTH TECH (CANADA) INC.

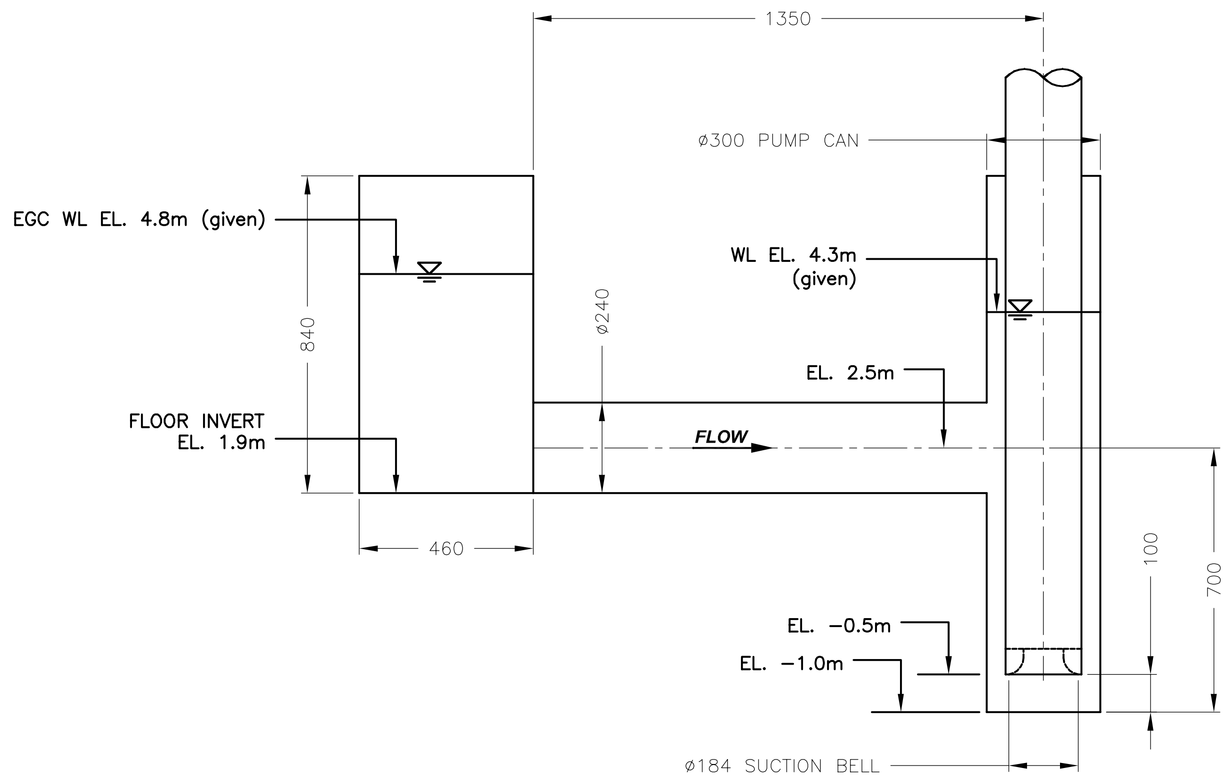
CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Model Layout
Section C-C

Dwg. 6506–002	Rev. No. 2	30–Nov–2004

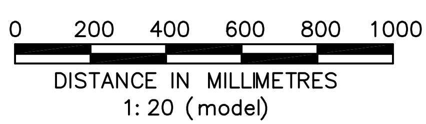
northwest hydraulic consultants

FIGURE 2-2



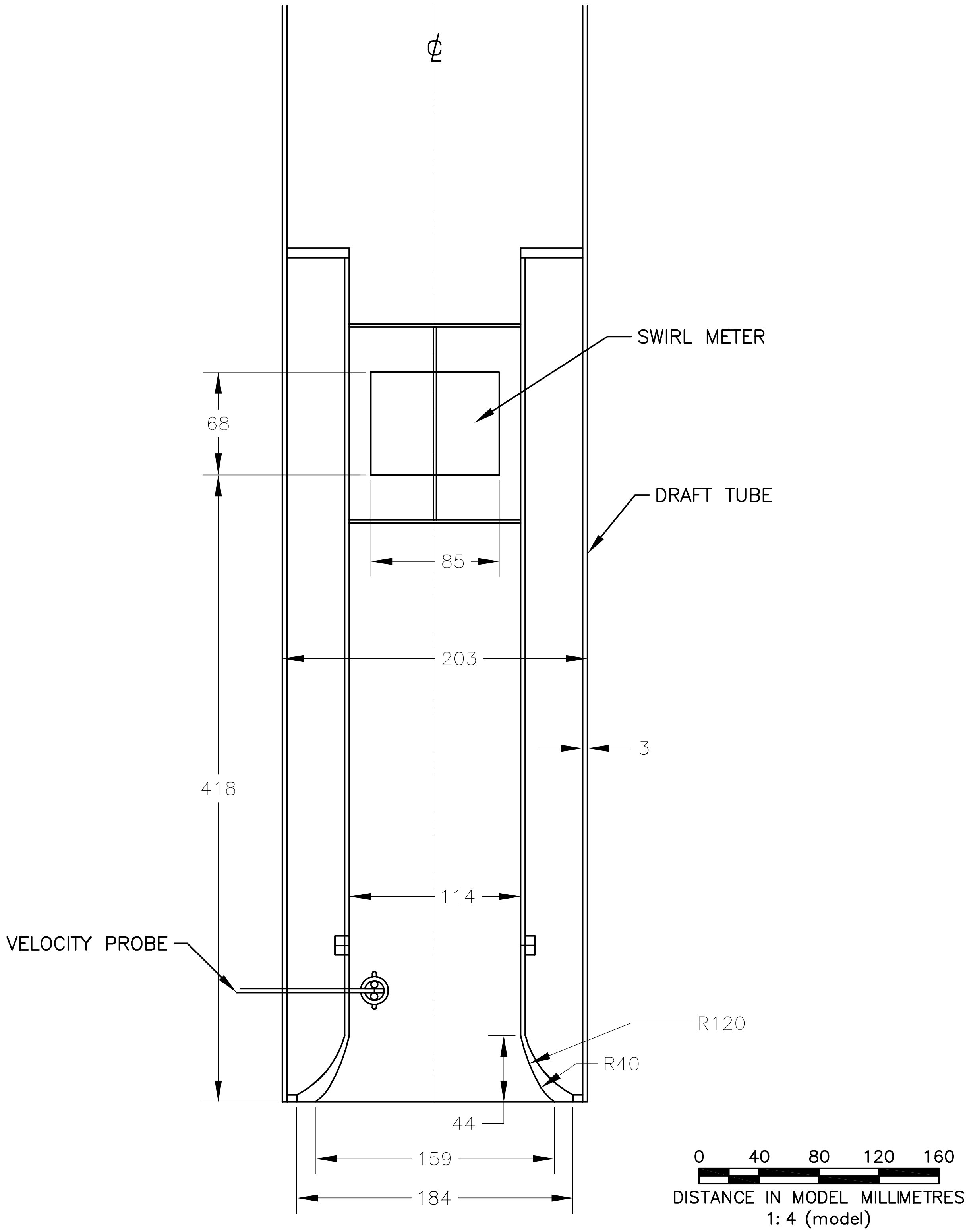
SECTION D-D

NOTES:
1) DIMENSIONS ARE GIVEN IN MODEL MILLIMETRES.
ALL ELEVATIONS ARE GIVEN IN PROTOTYPE METRES.
2) MODEL SCALE: 1mm MODEL = 5mm PROTOTYPE



EARTH TECH (CANADA) INC.		
CITY OF WINNIPEG, NEWPCC PUMP STATION MODEL TEST		
Model Layout **Section D-D**		
Dwg. 6506−002	Rev. No. 3	14−Dec−2004
northwest hydraulic consultants		

FIGURE 2-3



NOTES:

1) PRIMARY DIMENSIONS ARE GIVEN IN MODEL MILLIMETRES.
2) MODEL SCALE: 1mm MODEL = 5mm PROTOTYPE

EARTH TECH (CANADA) INC.

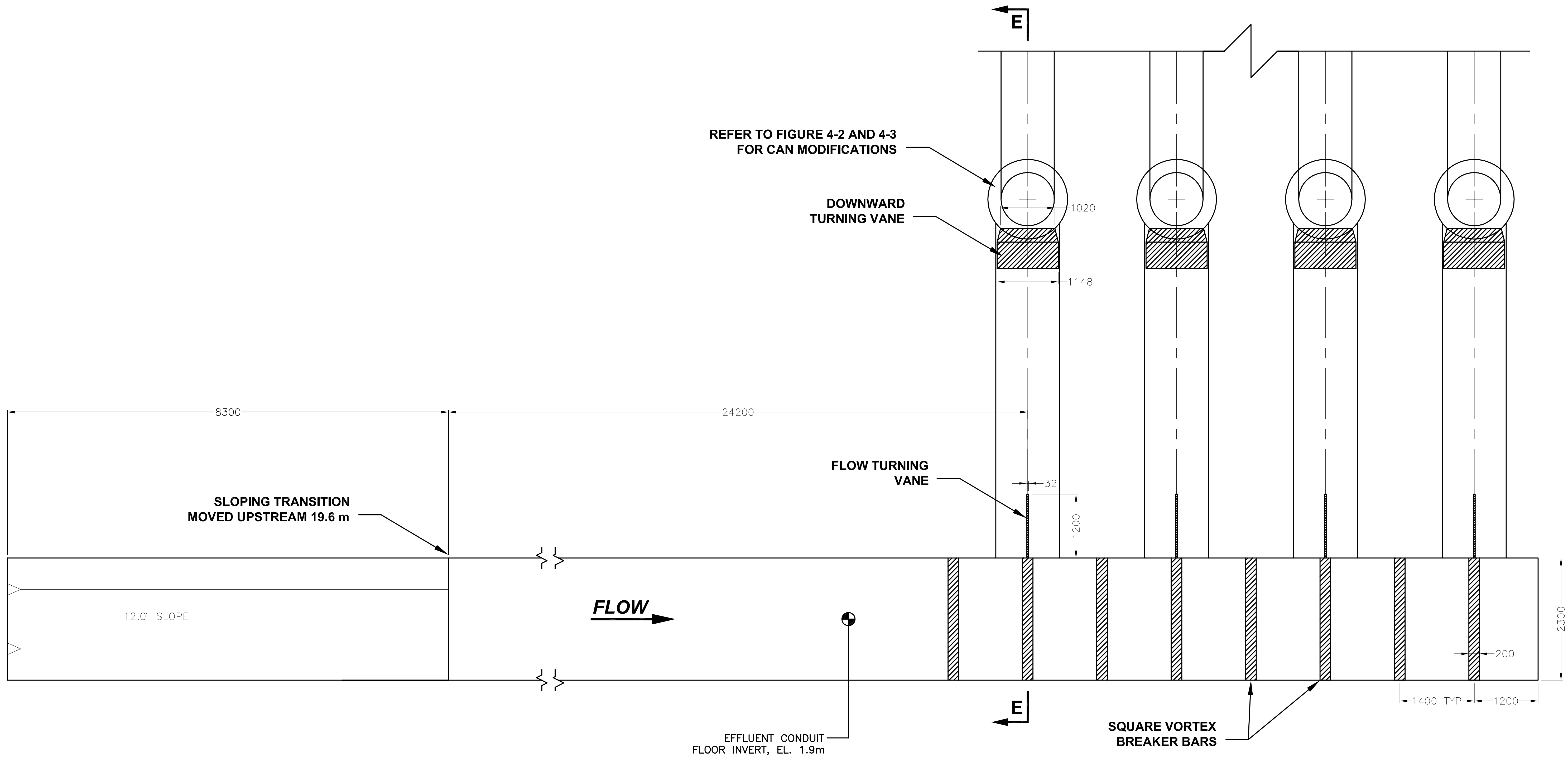
CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Model Pump Bell

Dwg. 6506–003	Rev. No. 2	14–Dec–2004

northwest hydraulic consultants

FIGURE 2-4



NOTES:

1) ALL DIMENSIONS ARE GIVEN IN PROTOTYPE MILLIMETRES. ALL ELEVATIONS ARE GIVEN IN PROTOTYPE METRES.
2) PROPOSED MODIFICATIONS ARE TYPICAL FOR ALL FOUR PUMPING UNITS.

0 750 1500 2250 3000
DISTANCE IN MILLIMETRES
1: 75 (prototype)

EARTH TECH (CANADA) INC.

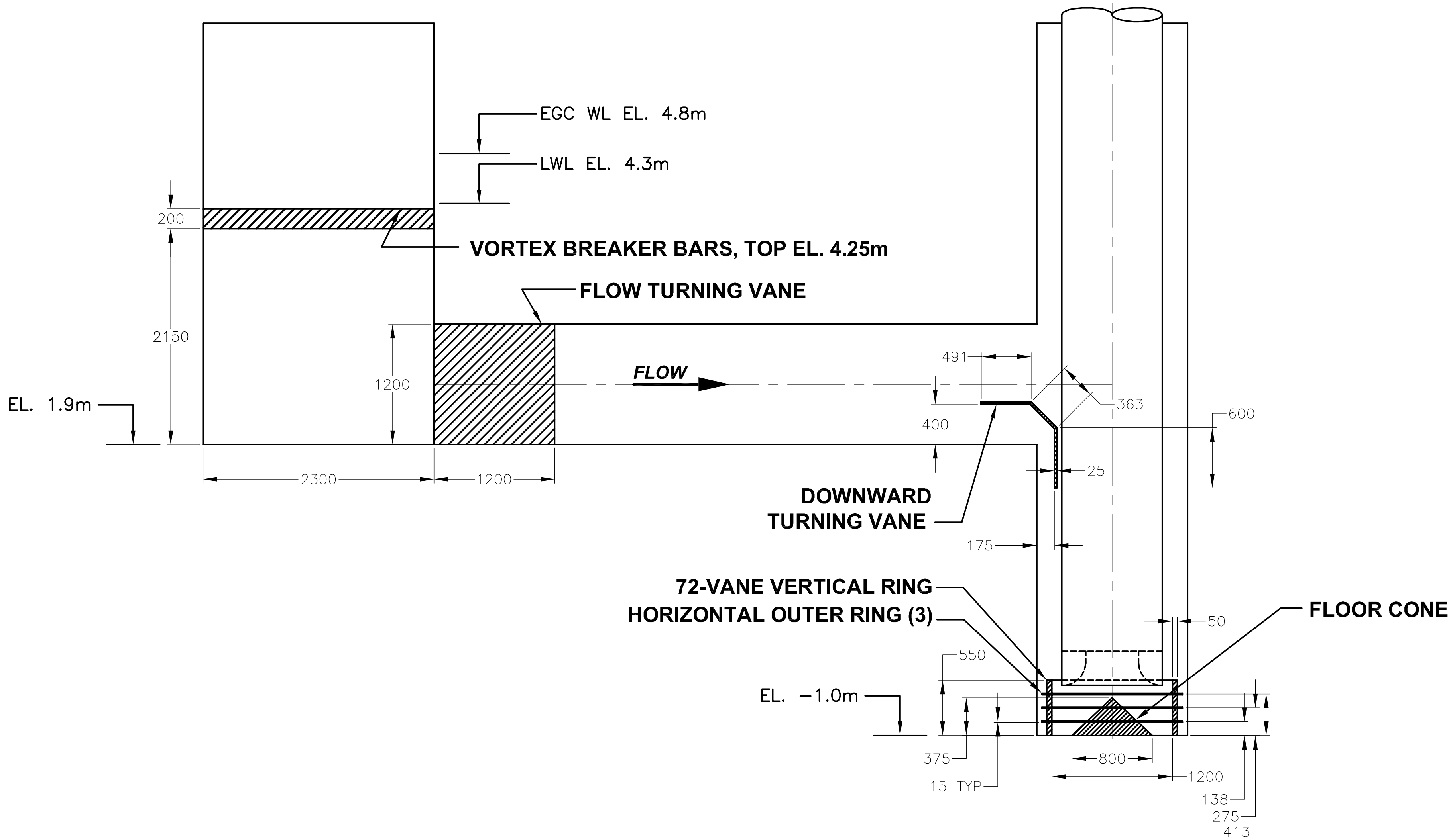
CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Recommended Modifications Plan View

Dwg. 6506–501	Rev. No. 1	30–Nov–2004

northwest hydraulic consultants

FIGURE 4-1



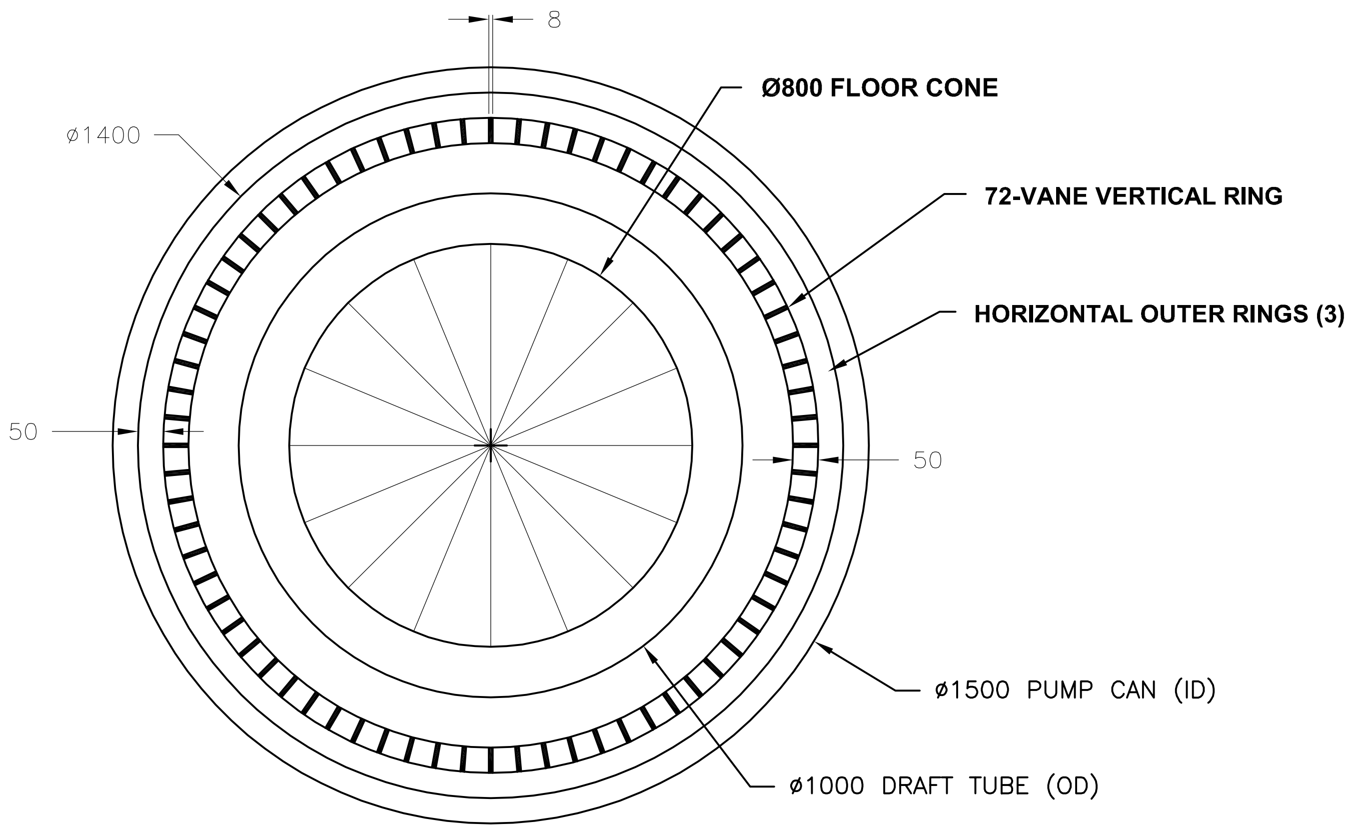
NOTES:

1) ALL DIMENSIONS ARE GIVEN IN PROTOTYPE MILLIMETRES. ALL ELEVATIONS ARE GIVEN IN PROTOTYPE METRES.
2) PROPOSED MODIFICATIONS ARE TYPICAL FOR ALL FOUR PUMPING UNITS.

0 600 1200 1800 2400
DISTANCE IN MILLIMETRES
1: 60 (prototype)

EARTH TECH (CANADA) INC.		
CITY OF WINNIPEG, NEWPCC PUMP STATION MODEL TEST		
Recommended Modifications Section E-E		
Dwg. 6506−501	Rev. No. 1	30−Nov−2004
northwest hydraulic consultants		

FIGURE 4-2



NOTES:

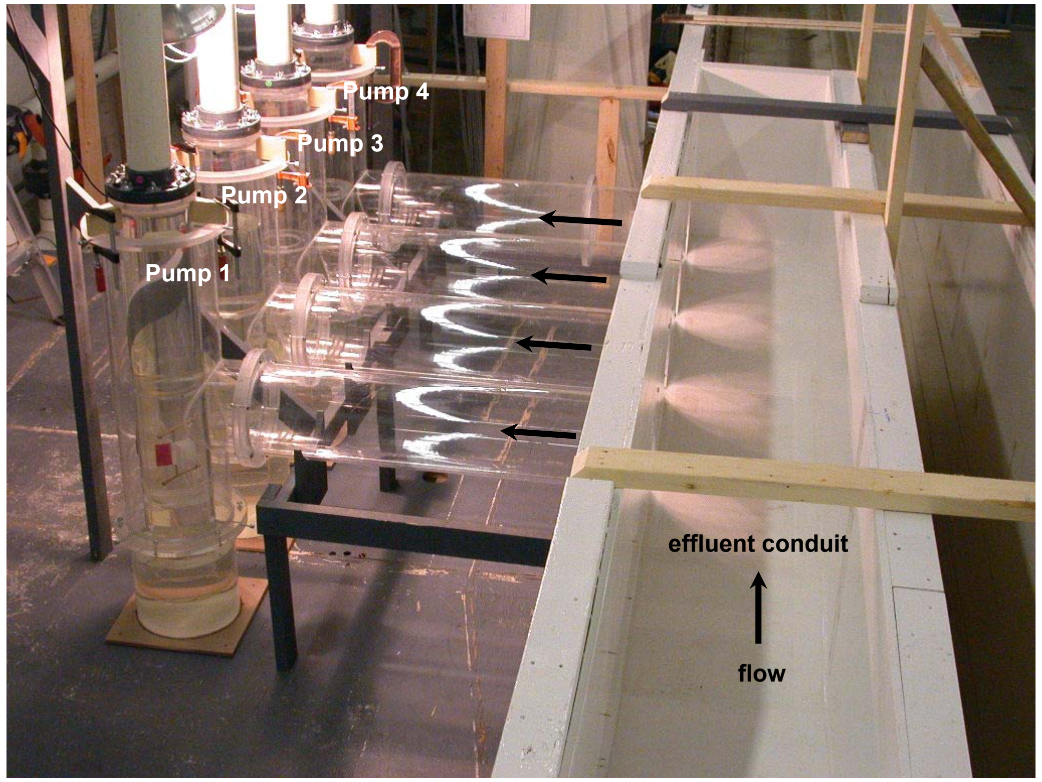
1) ALL DIMENSIONS GIVEN IN PROTOTYPE MILLIMETRES.
2) PROPOSED MODIFICATIONS ARE TYPICAL FOR ALL FOUR PUMPING UNITS.

0 150 300 450 600

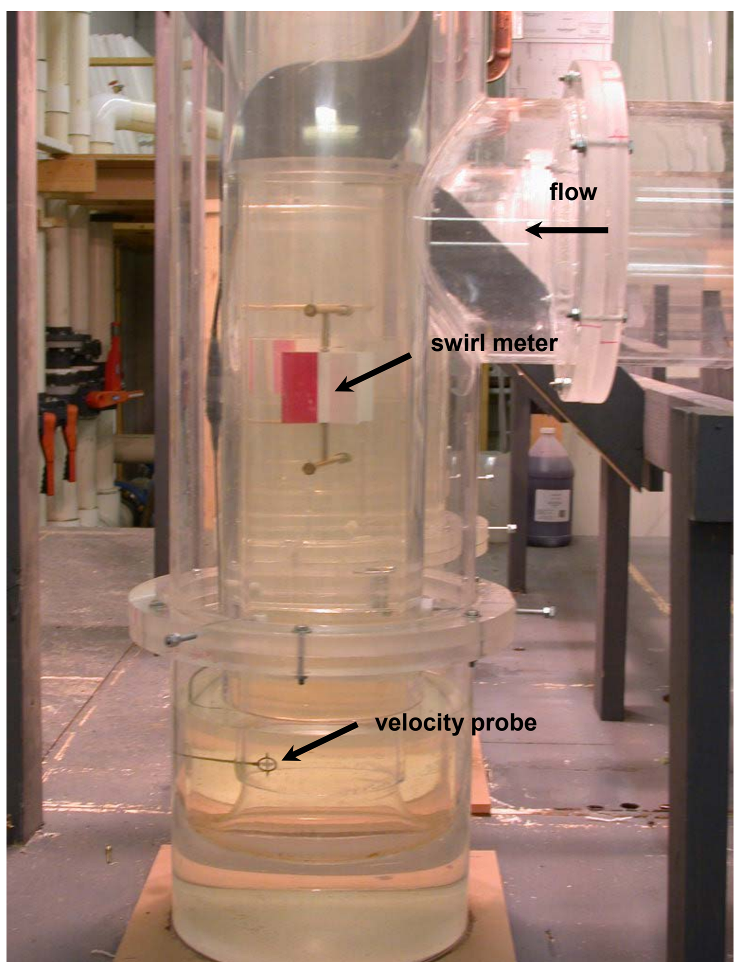
DISTANCE IN MILLIMETRES
1: 15 (prototype)

EARTH TECH (CANADA) INC.		
CITY OF WINNIPEG, NEWPCC PUMP STATION MODEL TEST		
Recommended Modifications Pump Can Details		
Dwg. 6506–501	Rev. No. 1	30–Nov–2004
northwest hydraulic consultants		

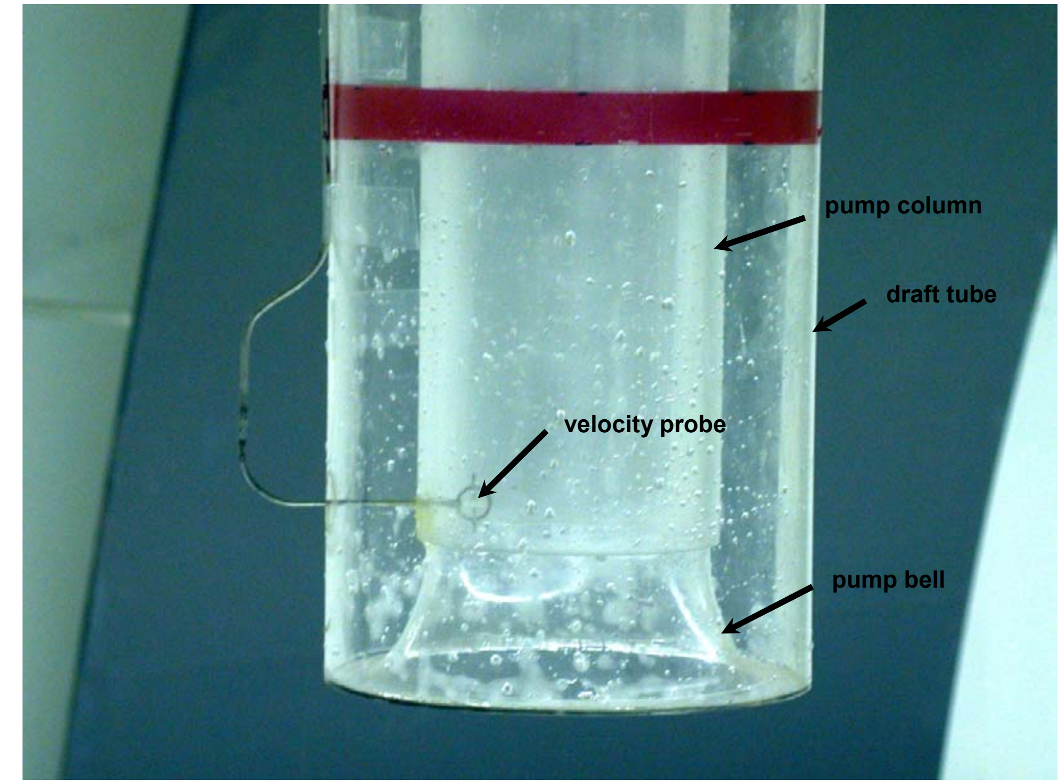
FIGURE 4-3



1) View looking downstream at the model. The model reproduced the effluent conduit with four lateral pipes extending from the side of the conduit to four can pumps. *(16506-001)*



2) Side view of the Pump 1 can. The pump was centred within the can and placed 100 mm model above the can floor. Swirl angles were computed from the angular velocity of the swirl meter and axial flow velocity. The miniature propeller velocity probe connected the frequency meter and computer data acquisition system to measure pump inlet velocities in Pump 1. *(16506-002)*

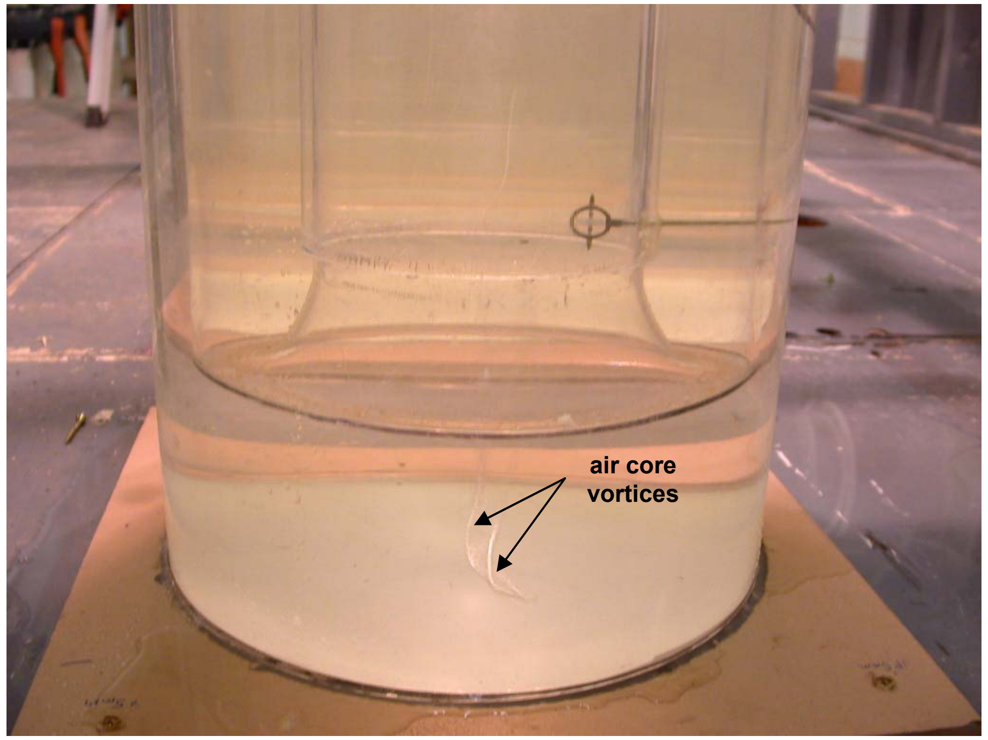


3) Close-up view of Pump 1 (removed from the can). The model pump bells were made from transparent plastic and connected to an acrylic tube representing the pump column. A clear acrylic draft tube surrounded the pump bell and pump column. *(16506-003)*

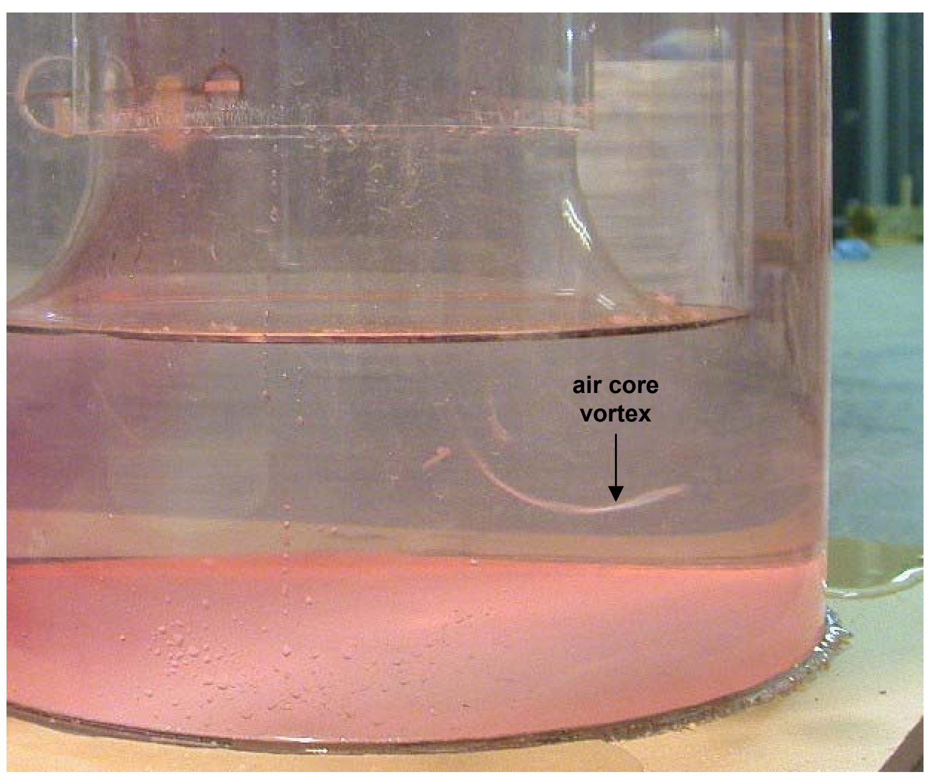
CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

Model Layout

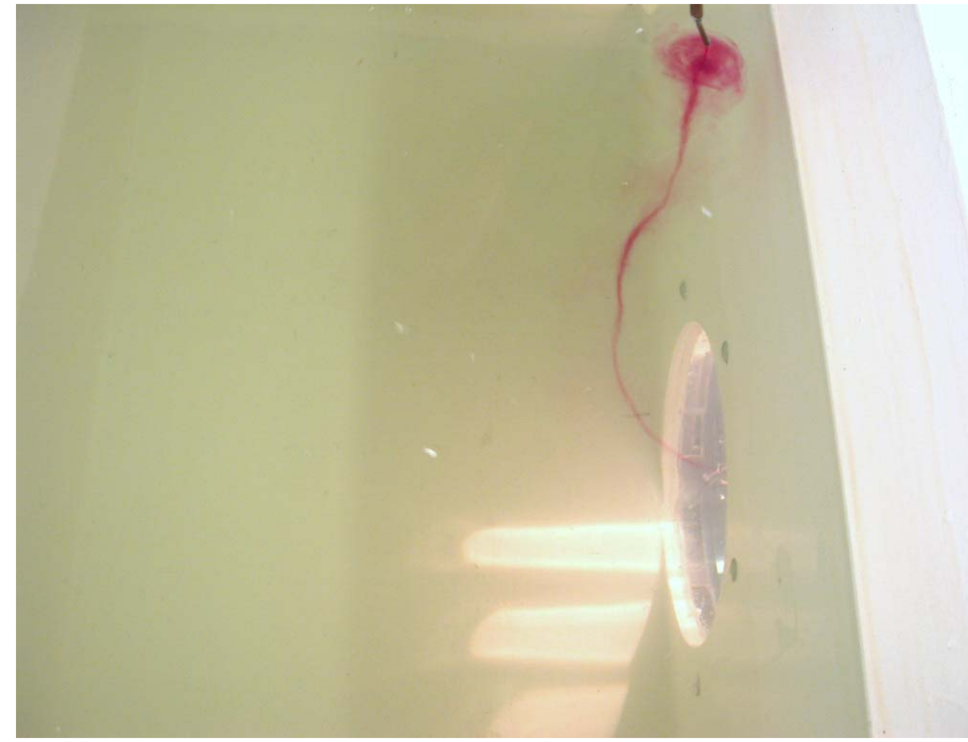
PHOTO PLATE 2-1



1) View of Type 5 subsurface air core vortices that formed on the floor of the pump can beneath the pump bell. *(16506-006)*



2) View of a Type 5 subsurface air core vortices that formed on the sidewall of the pump can at locations approximately 60 degrees on either side of the inlet. Type 3 subsurface vortices also formed on the can wall directly opposite the inlet at approximately bell level. *(16506-007)*



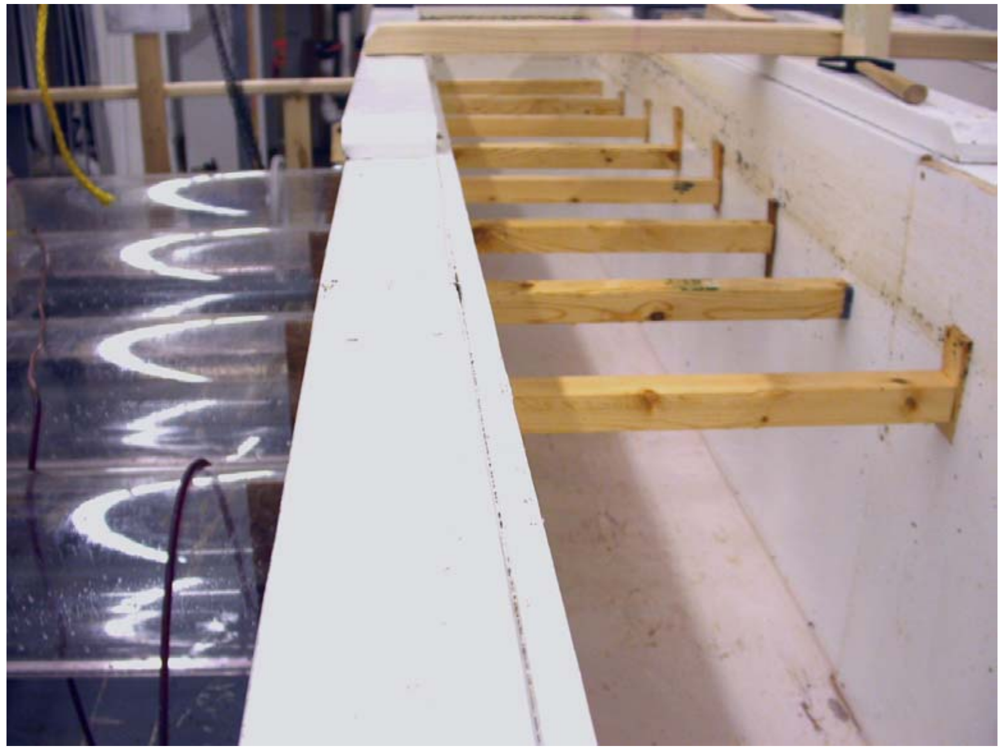
3) View looking upstream at the effluent conduit and Pump 4 lateral entrance. Type 3 (shown) and Type 4 (air core) vortices formed and entrained air to the pumps during operations at low water level (El. 43.0 m). *(16506-005)*

4) View looking upstream at the effluent conduit. For three and four-pump operation at low water level, a hydraulic jump formed on the sloping transition. The hydraulic jump created a significant amount of turbulence and entrained air bubbles that entered the pumps. *(16506-004)*

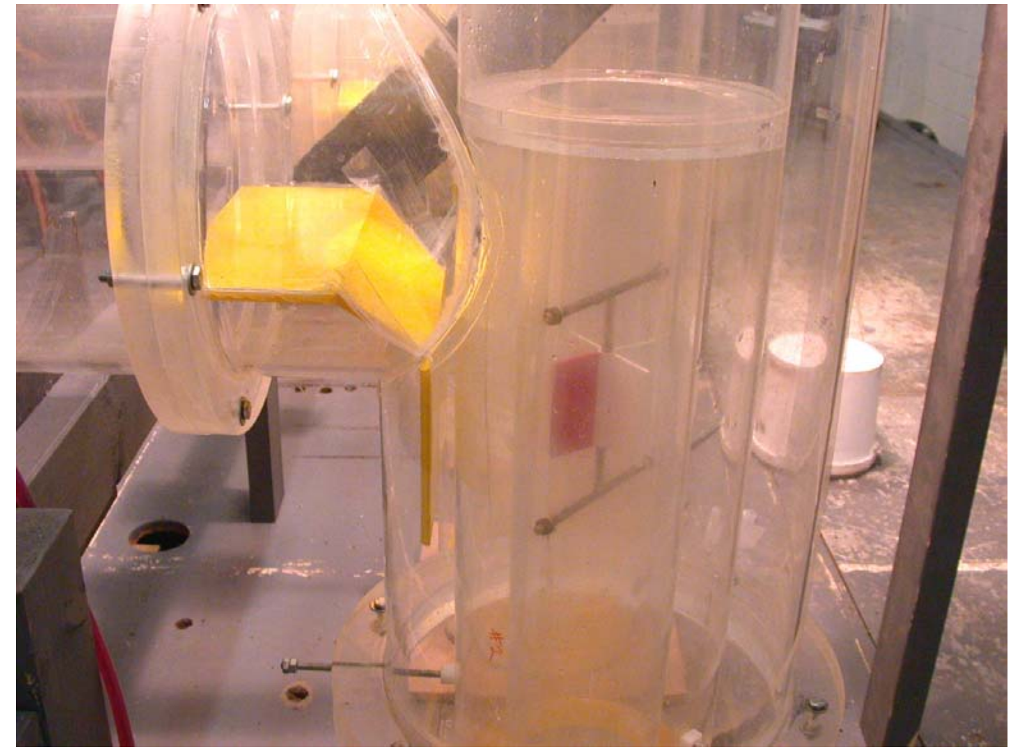
CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

Flow Patterns – Initial Design

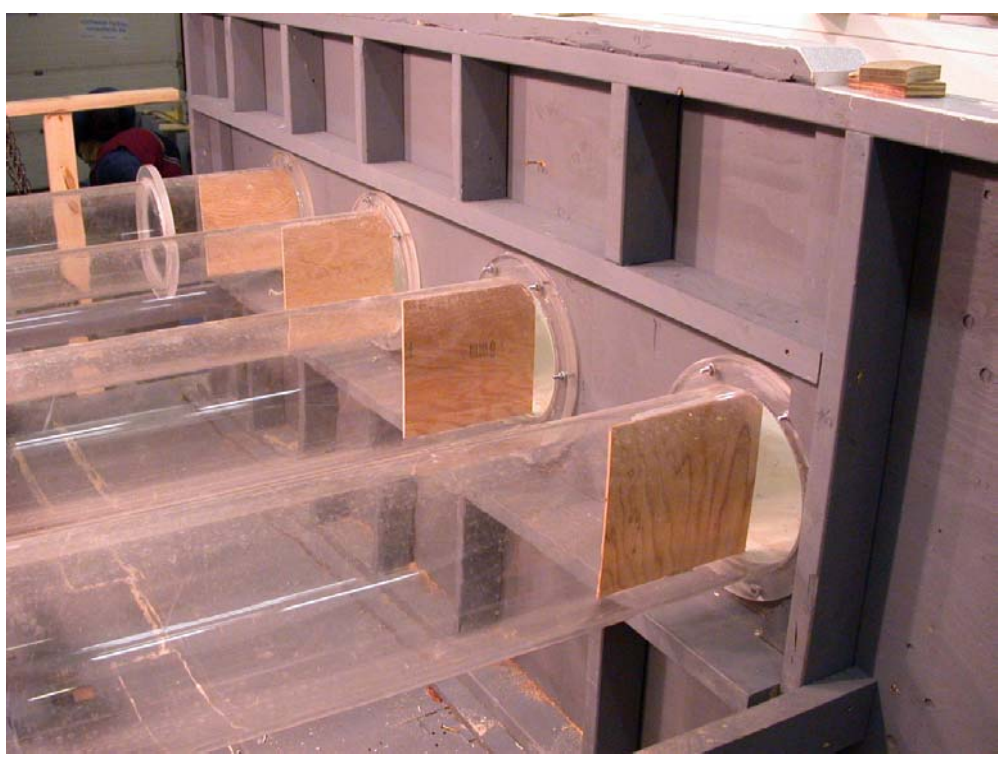
PHOTO PLATE 4-1



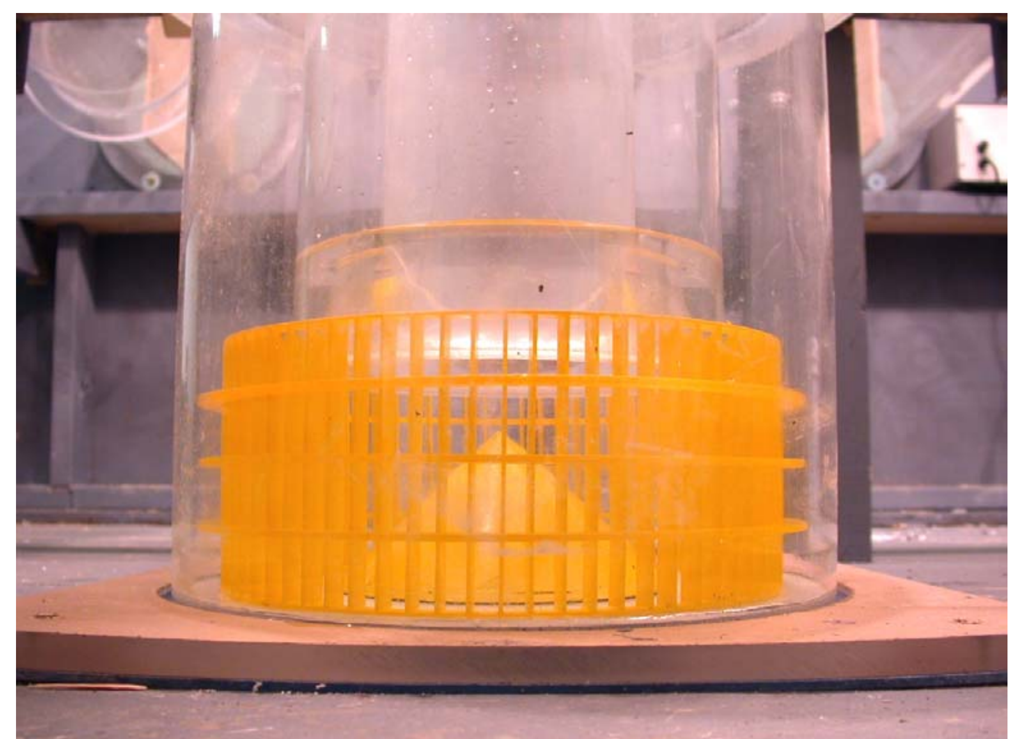
1) View looking downstream in the conduit at the recommended seven square vortex breaker bars that were installed with their tops at El. 4.25 m. *(16506-008)*



3) View of the recommended downward turning vane at the entrance to the pump can *(16506-010)*



2) Oblique view of the flow turning vane that was installed at the entrance to each lateral to reduce the flow separation in the laterals. *(16506-009)*

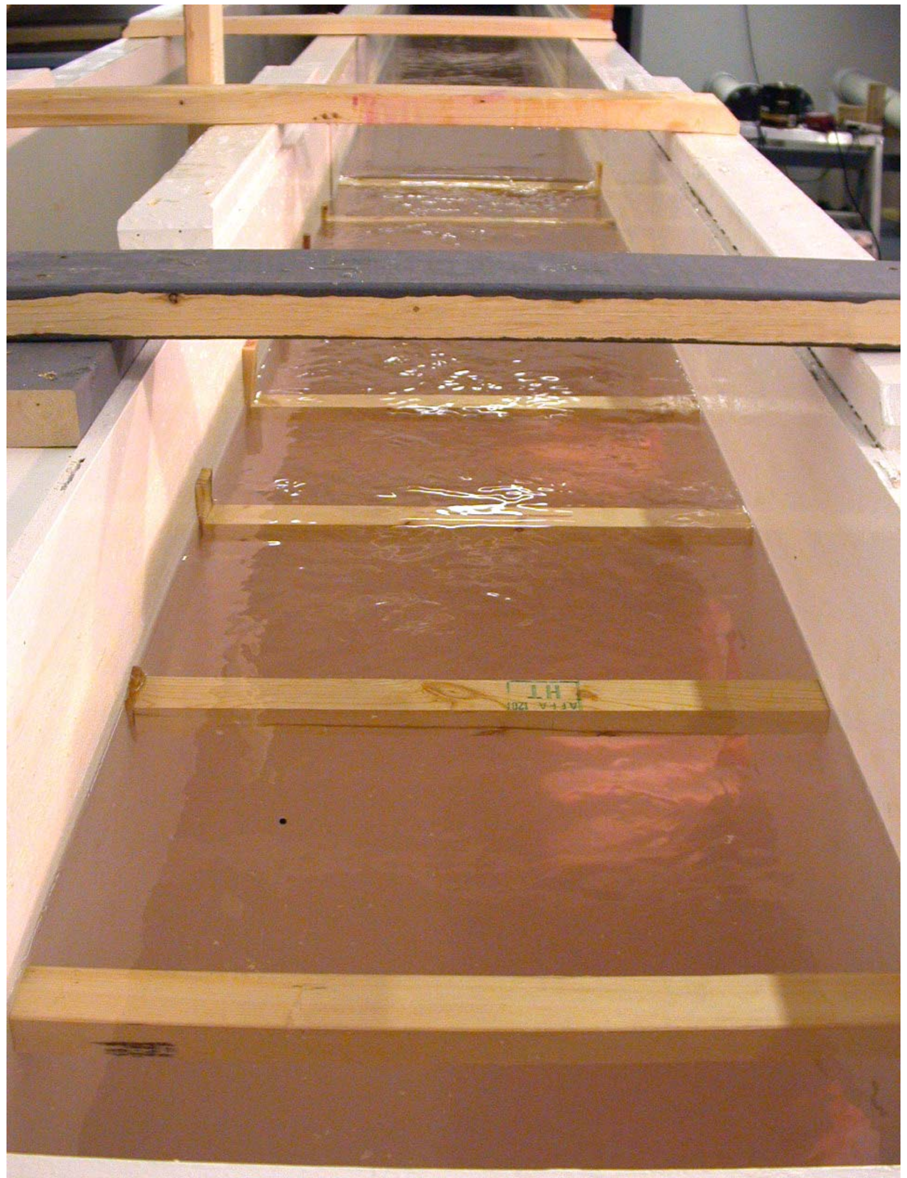


4) View of the recommended pump can modifications. A 72-vane ring surrounded the pump bell, with three horizontal outer rings. A floor cone was centred beneath each pump bell. *(16506-011)*

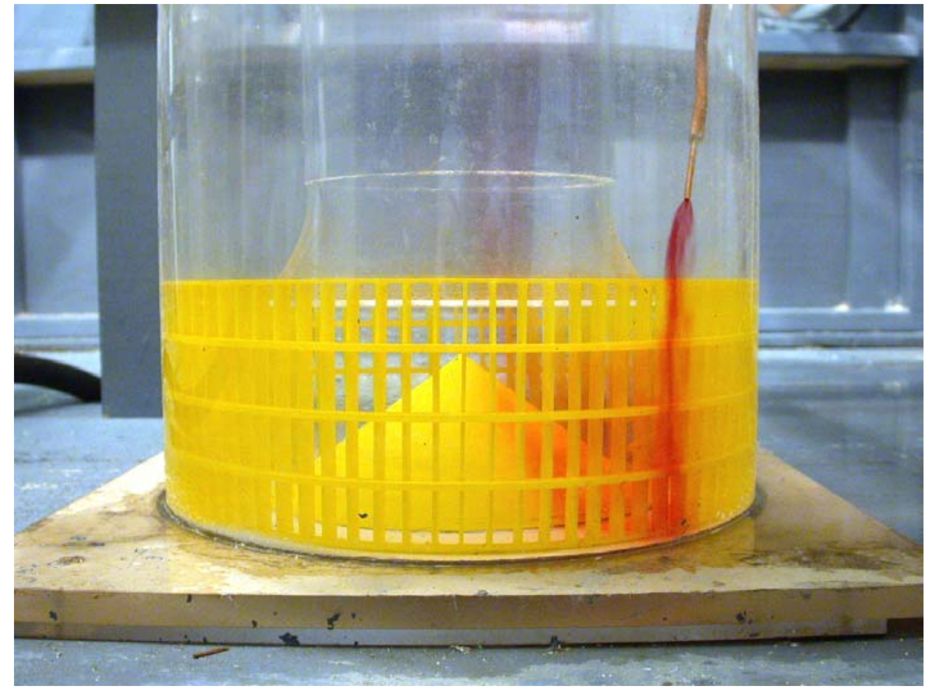
CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

Recommended Modification

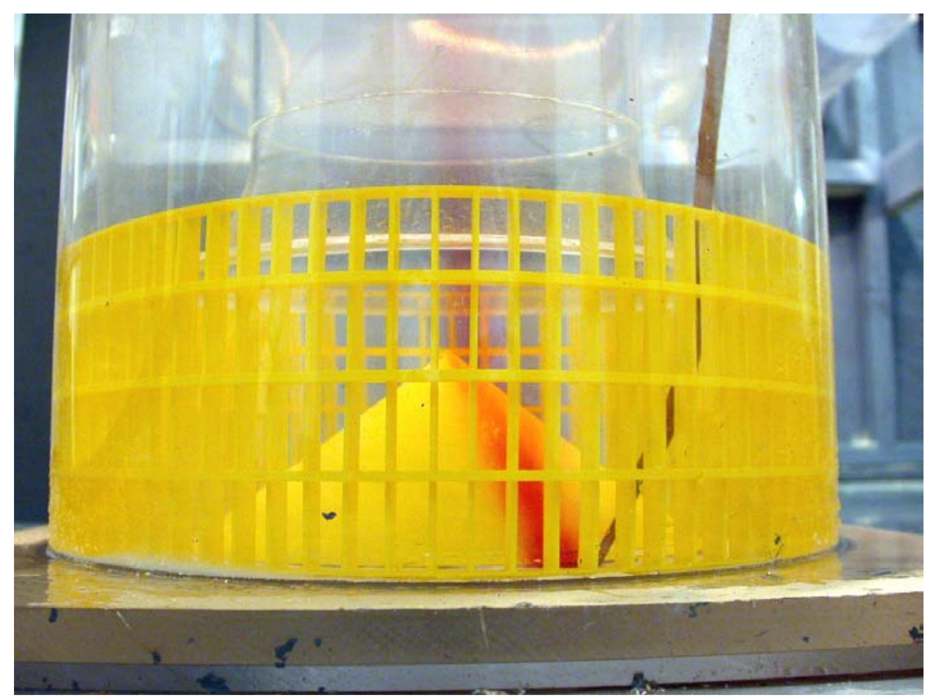
PHOTO PLATE 4-2



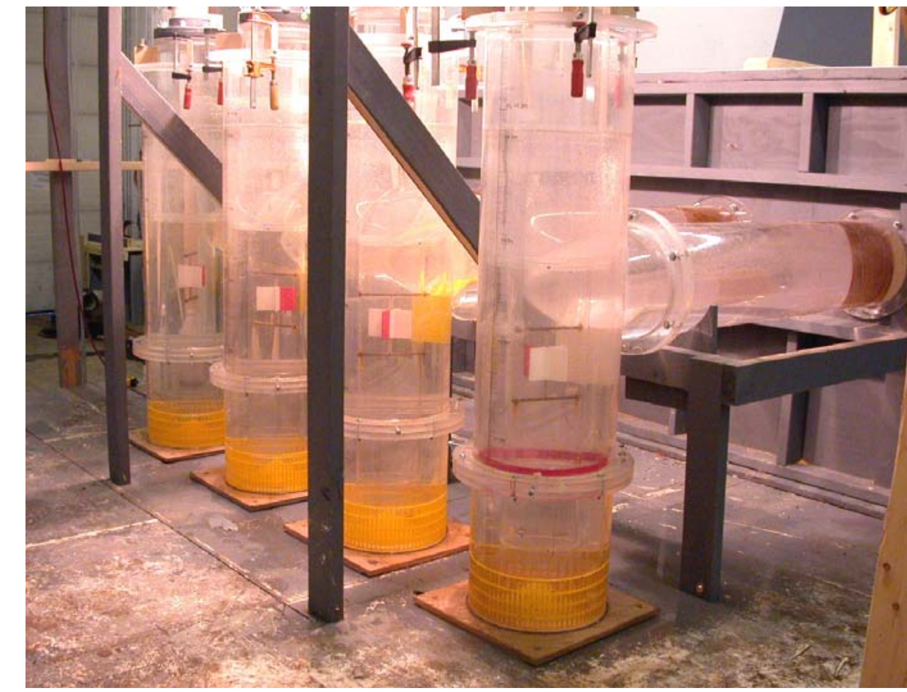
1) View looking upstream in the conduit with all four pumps operating at low water level. With the sloping transition moved 19.6 m (proto) upstream, flow conditions within the conduit were calm. The vortex breaker bars were effective in reducing strong vortices in the vicinity of the laterals. *(16506-012)*



2) View of flow patterns near the pump can wall. The vane ring was effective in eliminating the wall vortices and in better distributing flow to the pump, as indicated by significantly improved velocity data. *(16506-013)*



3) View of flow patterns on the floor of the pump can. The floor cone was effective in eliminating floor vortices. *(16506-014)*



4) Oblique view of all four pump cans with the recommended modifications installed. All four pumps were operating at low water level. *(16506-015)*

CITY OF WINNIPEG
NORTH END WATER POLLUTION CONTROL CENTRE
PUMP STATION MODEL TEST

Flow Patterns – Final Design

PHOTO PLATE 4-3

Leaders in
water resource
technology

Ref. No. 6506-4708

nhc

27 September 2004

EARTH TECH (CANADA) INC.
850 Pembina Highway
Winnipeg, MB R3M 2M7

Attention: **Mr. Chris Lipscombe, P.Eng.**
Project Manager

Via email: chris.lipscombe@earthtech.ca

Dear Mr. Lipscombe:

Subject: City of Winnipeg, North End Water Pollution Control Centre
Pump Station Model Test – Conceptual Design Review (REVISED)

1.0 INTRODUCTION

Earth Tech (Canada) Inc. is designing the interim pump station for the City of Winnipeg's North End Water Pollution Control Centre. **northwest hydraulic consultants** (**nhc**) have been retained by Earth Tech to conduct a design review of the proposed pump inlet and discharge system. This letter report summarizes our review and conclusions. Information contained herein supersedes that presented in our original document dated 23 September 2004.

2.0 BACKGROUND INFORMATION

In **nhc**'s proposal dated 3 September 2004, it was noted that the original proposed design and layout of the new effluent pumping station, as outlined in your Request for Quotation (RFQ), would likely result in adverse flow to the pumps and contained extraneous features that could be eliminated to reduce the overall size and cost of the installation (given that the station will only be required in the short term before a permanent pump station is built further upstream as part of the future secondary process upgrade). A brief description of three options for improving the layout of the pump station was included as part of our proposal. Upon review, Earth Tech decided to pursue the option that consisted of an effluent conduit with four lateral pipes extending from the side of the conduit to four can pumps. The discharge from the can pumps would enter the side of a rectangular conduit that would direct flow to a discharge chamber, located directly upstream of three UV channels.

Earth Tech prepared a schematic plan drawing to illustrate how **nhc**'s proposed arrangement would tie into the existing outfall system. This drawing indicates that flow entering the effluent gate chamber (EGC) will either be transported to the existing outfall (continuing along its same path) or be redirected to the proposed effluent pumping station via a 2.3 m wide effluent conduit that is aligned 53 degrees to the existing system. The invert of the EGC at the connection point to

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consultants

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canada T6E 4Y1

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fax (780) 436-1645

nhc@nhc-edm.com
www.nhcweb.com

the proposed effluent conduit is at El. 3.658 m. A bypass gate will be installed in the effluent conduit downstream of the four inlet laterals such that, if necessary, flow can bypass the effluent pumping station and head directly to the existing outfall system. A second gate located at its downstream end would prevent flow which exits the UV channels from entering the bypass channel.

3.0 CONCEPTUAL DESIGN REVIEW

3.1 GENERAL

The Hydraulic Institute (HI) 1998 Standards[1] provided the basic design guidance used for the conceptual design review, and were supplemented with **nhc**'s practical experience from other successful pump station designs.

As part of this design review, **nhc** has determined the configuration, dimensions and elevations of the effluent conduit, inlet laterals, pump can, discharge laterals, and discharge system leading to the weir structures. In exception, the following parameters were provided by Earth Tech and have not been altered:

- Connection point on EGC, El. 3.658 m
- Floor invert of discharge conduit, El. 6.358 m
- Weir crests within discharge chamber, El. 8.80 m
- Effluent conduit top of concrete, El. 6.1 m
- Discharge conduit top of concrete, El. 10.418 m
- Water level within effluent conduit, El. 4.8 m
- Water level within pump cans, El. 4.3 m (estimated by Earth Tech based on hydraulic losses within the system)
- Water level within discharge system, El. 9.3 m
- Width of effluent conduit at EGC connection point, 2.3 m
- Width of discharge conduit, 3.0 m (minimum)
- Width of discharge chamber, 10.2 m

As stated by Earth Tech, the proposed pump station is based on the operation of four Flygt P7081 pumps, each having a rated discharge of 100 million litres per day (ML/d) and a 920 mm diameter suction bell. Each pump will be housed within a draft tube that has a constant diameter of 1000 mm for its entire height, including the discharge portion of the pipe. The firm capacity of the station will be approximately 400 ML/d with all four pumps in operation, and has been used as the criterion for sizing the inlet and discharge conduits. Our review is based on the assumption that the diameters of the pump column and pump bowl(s) do not exceed the dimension of the suction bell (as noted above); otherwise, it may be necessary to revise the pump can configuration.

The pumps and pump suction laterals will need to be housed within a sump structure that provides an adequate amount of submergence on the pumps to minimize the formation of strong air core vortices. According to the HI Standards, the minimum submergence required (assuming uniform flow approaching the intake) is defined as:

[1] Hydraulic Institute. American National Standard for Pump Intake Design, ANSI/HI 9.8, 1998.

$$S = D (1 + 2.3 F)$$

where: *S = submergence, m*
D = suction bell diameter, m
F = suction bell Froude number, and $F = V (g D)^{-1/2}$
V = suction bell velocity, m/s
g = acceleration due to gravity, m/s^2

3.2 EFFLUENT CONDUIT

It is important to establish reasonably uniform flow conditions within the effluent conduit in order to minimize inflow irregularities in the inlet laterals leading to each pump can. Such conditions are more likely to be achieved if the depth-averaged velocity within the conduit is maintained below 1.0 m/s.

As shown in Figures 1, 2 and 3, the effluent conduit will be 2.3 m wide (given) by 22.5 m long by 4.2 m deep (given) with four inlet laterals extending from its side. A 12.0-degree sloping transition extending downstream from the connection point to the EGC lowers the floor to El. 1.9 m over a horizontal distance of 8.3 m, thereby reducing the velocity within the downstream portion of the effluent conduit to approximately 0.7 m/s when all four pumps are operating at normal water level.

Based on the equation shown in Section 3.1, minimum submergence within the effluent conduit at the entrance to each inlet lateral is 2.0 m (measured with respect to pipe centreline) and was computed using a 1.2 m inlet lateral diameter and an inlet flow rate of 100 ML/d (1.16 m^3/s). This value corresponds to a minimum water level of El. 4.5 m, which is 0.3 m below the EGC water level of El. 4.8 m.

3.3 INLET LATERALS

The HI Standards recommend that any source of flow disturbance (i.e., pipe openings, sharp bends, etc.) be located at least five times the predominant dimension of the flow-disturbing element away from the pump. It is also recommend that pipe velocity be maintained at or below 1.2 m/s. In order to minimize the occurrence of air entrainment within the pump cans, **nhc** recommends that surcharged conditions be maintained along the length of the inlet piping under all expected pump operating conditions.

As shown in Figures 1, 2 and 3, flow within the effluent conduit is drawn to each pump can via four inlet laterals, which are each 1.2 m in diameter (all recommended diameters mentioned herein are given with respect to inside dimensions) and 6.0 m in length. At this diameter, velocity within each suction pipe will be approximately 1.0 m/s. The invert of each lateral is set at El. 1.9 m, which is equal to the invert of the effluent conduit. The centreline spacing of each lateral is 2.8 m, with the centreline of the most downstream lateral located one pipe diameter (1.2 m) upstream from the bypass gate (it has been assumed that the gate will remain closed during operation of the proposed pump station). The crown of each lateral is set at El. 3.1 m, which is 1.2 m below the expected operating water level within the pump cans (El. 4.3 m).

3.4 PUMP CANS

The HI Standards recommends that the maximum velocity between the can and the pump should be 1.5 m/s, and assumes that the diameters of the pump column, pump bowl(s) or any flange do not exceed that of the suction bell. It is also recommended that the centreline of the inlet laterals be a minimum of two times the can diameter above the elevation of the pump bell, and that the pumps be situated 0.5 times the bell diameter above the can floor.

As shown in Figures 1 and 3, the four pump cans are each 1.5 m in diameter and set at a floor level of El. -1.0 m. The diameter of the can in relation to the draft tube diameter results in a maximum velocity of 1.5 m/s approaching the suction bell at design flow. The distance between the centreline of the inlet laterals and the can floor is 3.5 m. The pumps are centred within the can and set 0.5 m above the sump floor at El. -0.5 m.

Based on the equation shown in Section 3.1, minimum submergence within the pump can is 2.2 m and was computed using a 0.92 m suction bell diameter and a pump discharge of 100 ML/d (1.16 m^3/s). This value corresponds to a water level of El. 1.7 m, which is well below the expected normal operating water level within the pump can (El. 4.3 m).

3.5 Discharge Laterals

As shown in Figures 1, 3 and 4, the four discharge laterals will each be 1.0 m in diameter (given) and 3.0 m in length. At this diameter, velocity within the pipe will be approximately 1.5 m/s. The centreline of each lateral is set 1.0 m above the conduit floor at El. 7.358 m. The centreline spacing of each lateral is 2.8 m, with the centreline of the most upstream lateral located one pipe diameter (1.0 m) from the endwall. As indicated in the drawing from Earth Tech, flapgates will be installed at the exit to each lateral to prevent backflow through idle pumps.

3.6 Discharge Conduit

It is important to establish reasonably uniform hydraulic conditions as flow approaches the discharge chamber so that the flow expands uniformly in the discharge chamber. Therefore, **nhc** recommends that the discharge conduit be sized to achieve a depth-averaged velocity of less than 1.0 m/s.

As shown in Figures 1, 3 and 4, the discharge conduit will be 3.0 m wide (given) by 24.4 m long by 4.06 m deep (given) with four discharge laterals supplying flow at the upstream end. The conduit length extending from the centreline of the most downstream pump to the discharge chamber entrance is 15.0 m, which equates to five times the conduit width; this portion of the channel can be longer if required. The channel floor is set at El. 6.358 m, as specified by Earth Tech. A 10-degree expansion at the downstream end of the discharge conduit widens the channel symmetrically by 1.2 m over a longitudinal distance of 3.4 m. Theoretically, this expansion will reduce the depth-averaged velocity within the conduit from approximately 0.5 m/s to 0.4 m/s (with all four pumps operating at normal water level).

3.7 Discharge Chamber

Uniform flow distribution to each of the three UV channels is required, thus flow approaching the weirs needs to be uniform. In order to achieve this, the flow within the discharge chamber needs to be evenly dispersed with a relatively tranquil water surface immediately upstream of the weir structures.

As shown in Figures 1 and 4, the discharge chamber will be 10.2 m wide (given) by 4.0 m long by 4.06 m deep. The channel floor is set at El. 6.358 m, as specified by Earth Tech. The three weir structures leading to the UV channels are situated at the downstream end of the discharge chamber; weir crests will be set at El. 8.80 m, as specified by Earth Tech.

Column baffles placed within the discharge chamber are included in Figure 1 for illustrative purposes. The need for column baffles or other devices required to meet the performance criteria can be determined through physical modelling of the discharge system, which is discussed in the following section.

4.0 THE NEED FOR PHYSICAL MODELLING OF THE DISCHARGE SYSTEM

Although various ways to reduce approach velocities within the discharge conduit and dissipate flow energy within the discharge chamber have been considered by **nhc**, uncertainty remains as to whether the conceptual design of the discharge system will result in uniform flow distribution to each UV channel. It is likely that some form of energy dissipater will be required within the discharge chamber; however, its exact placement and geometry cannot be accurately determined through desktop evaluation.

nhc recommends that a physical model study of the discharge system be conducted to optimize its design and to ensure that the necessary criteria are achieved. The model would reproduce the discharge piping for all four pumps, the full length of the discharge conduit, the discharge chamber and the three sharp-crested weir structures. Our proposal dated 3 September 2004 includes a scope of work, cost estimate and schedule to conduct a model study of the discharge chamber on the basis of the original design (as outlined in the RFQ). A revised proposal to construct and test a scale hydraulic model of the discharge system, as described herein, can be provided upon your request.

Please do not hesitate to contact me directly at (780) 436-5868 if you have any questions or require additional information.

Respectfully submitted,

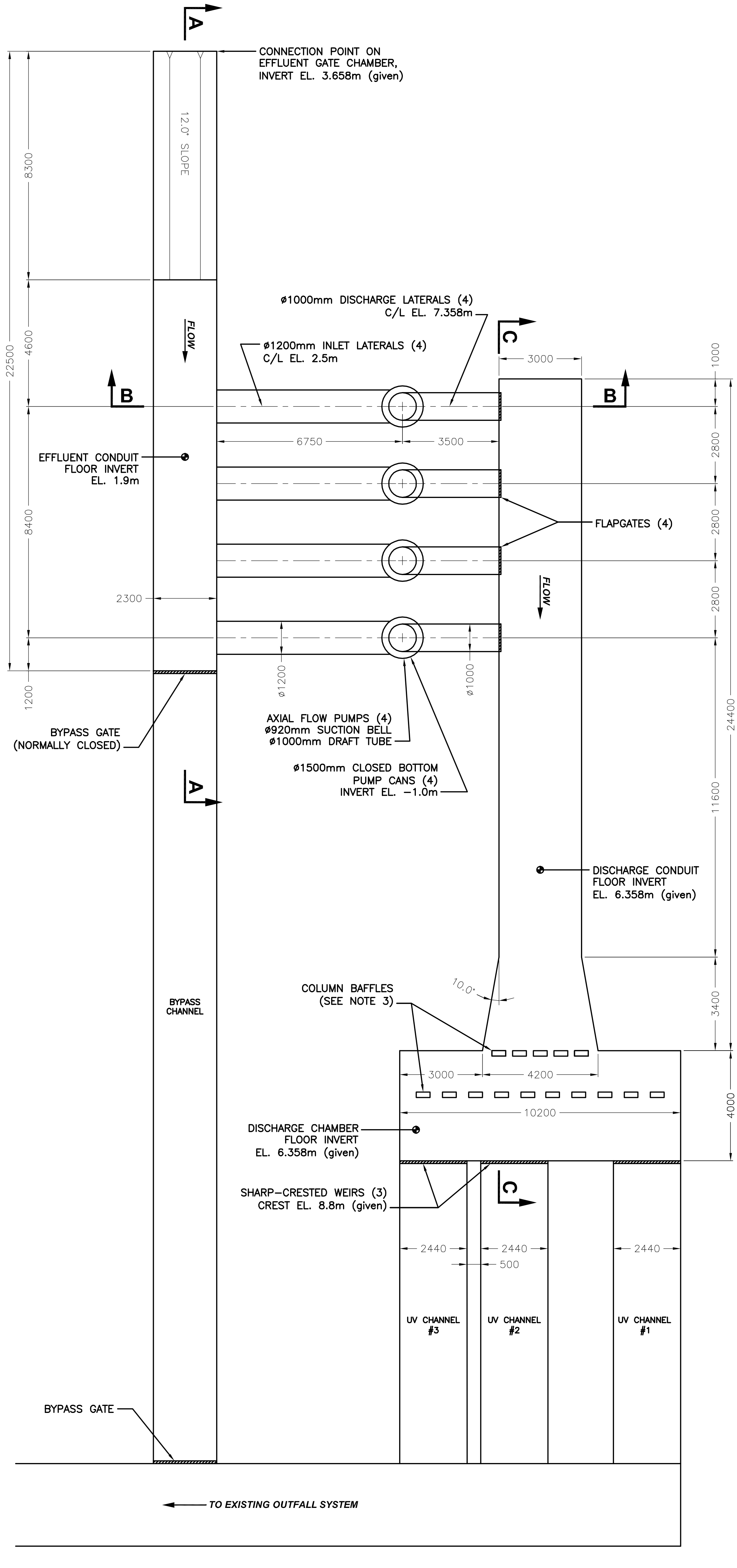
northwest hydraulic consultants

original signed by

Darren Shepherd, M.Sc., P.Eng.
Associate

ATTACHMENTS

cc: Mr. Tom Demlow, P.E. (**nhc** Seattle, tdemlow@nhc-sea.com)
Mr. Brian Hughes, P.Eng. (**nhc** Vancouver, bhughes@nhc-van.com)



NOTES:

1) ALL DIMENSIONS GIVEN IN PROTOTYPE MILLIMETRES UNLESS STATED OTHERWISE. ALL ELEVATIONS GIVEN IN PROTOTYPE METRES.
2) THE NEED FOR COLUMN BAFFLES AND OTHER DEVICES REQUIRED TO MEET PERFORMANCE CRITERIA CAN BE DETERMINED THROUGH PHYSICAL MODELLING OF THE DISCHARGE SYSTEM.

EARTH TECH (CANADA) INC.		
CITY OF WINNIPEG, NEWPCC PUMP STATION MODEL TEST		
Proposed Pump Station Layout **Plan View**		
Dwg. 6506−001	Rev. No. 3	27−Sep−2004
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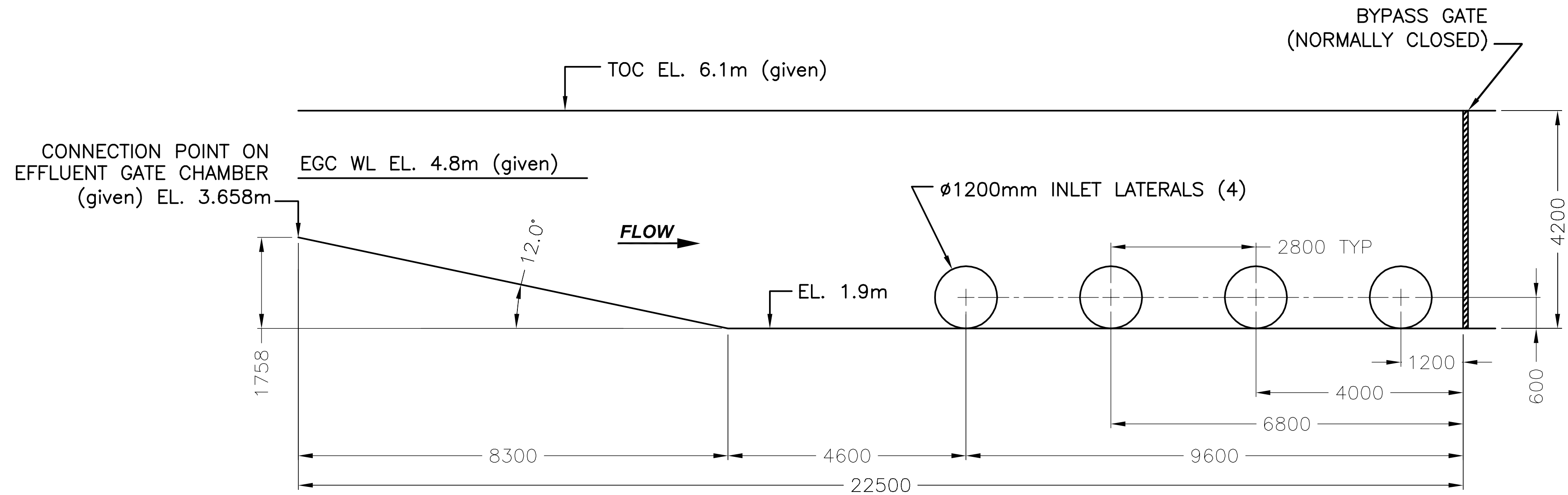
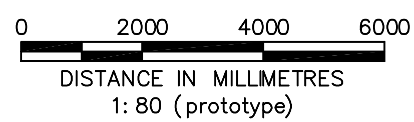
FIGURE 1



SECTION A-A

NOTES:

1) ALL DIMENSIONS GIVEN IN PROTOTYPE MILLIMETRES UNLESS STATED OTHERWISE. ALL ELEVATIONS GIVEN IN PROTOTYPE METRES.



EARTH TECH (CANADA) INC.

CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Proposed Pump Station Layout
Section A-A

Dwg. 6506–001	Rev. No. 3	27–Sep–2004

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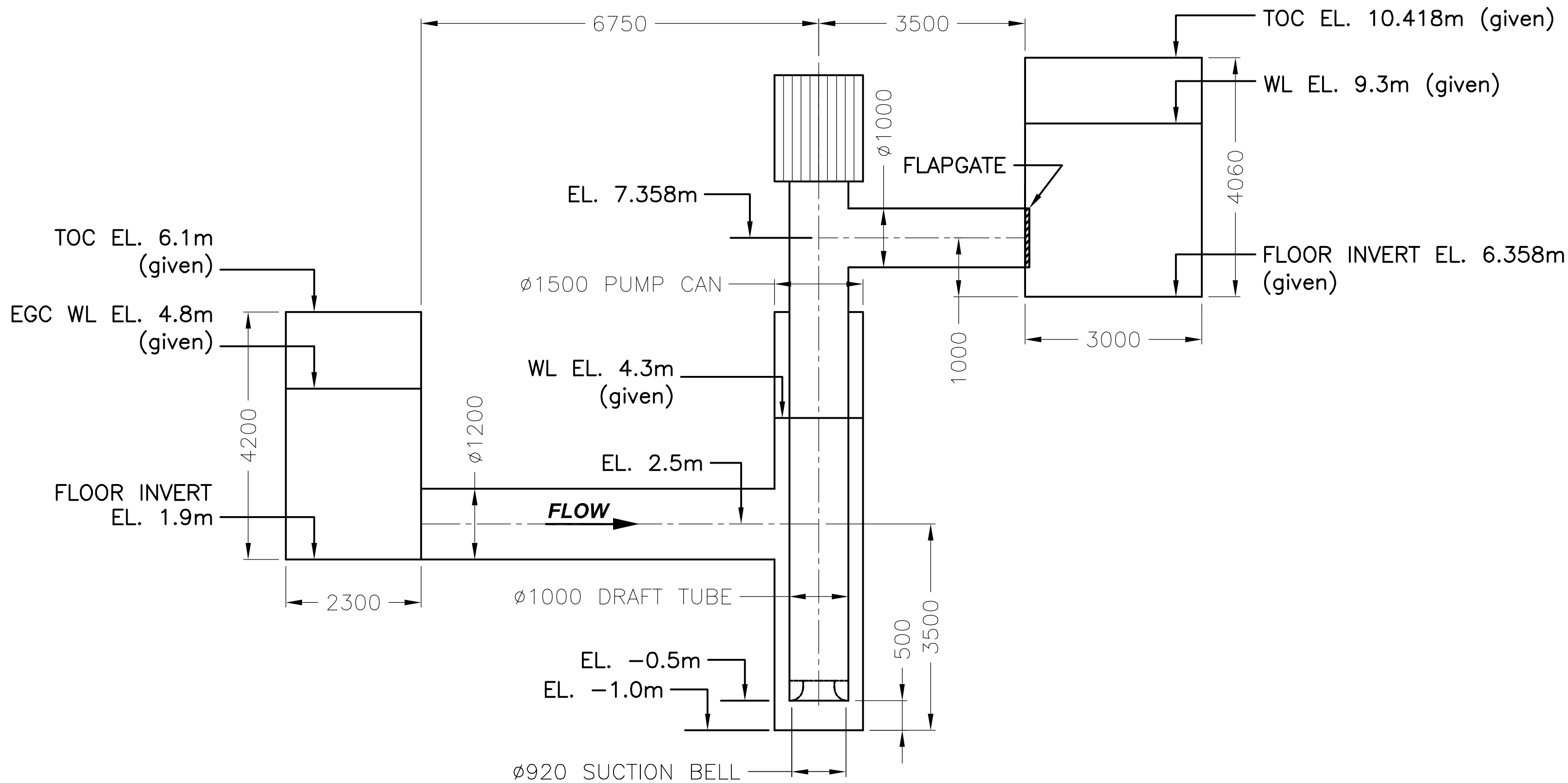
FIGURE 2



SECTION B-B

NOTES:

1) ALL DIMENSIONS GIVEN IN PROTOTYPE MILLIMETRES UNLESS STATED OTHERWISE. ALL ELEVATIONS GIVEN IN PROTOTYPE METRES.

0 2000 4000 6000

DISTANCE IN MILLIMETRES
1: 80 (prototype)

EARTH TECH (CANADA) INC.

CITY OF WINNIPEG, NEWPCC
PUMP STATION MODEL TEST

Proposed Pump Station Layout
Section B-B

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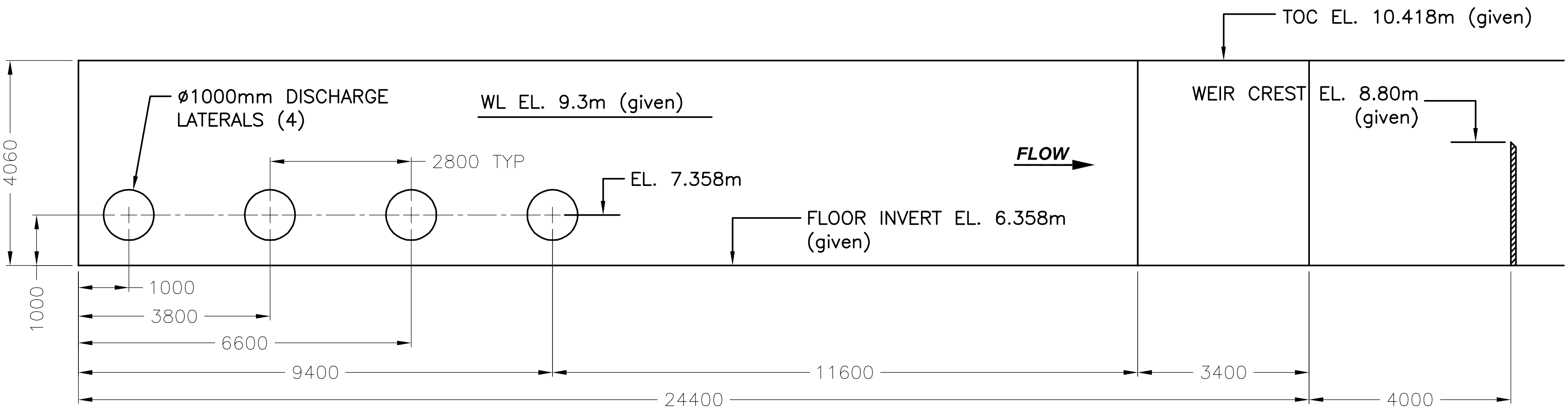
FIGURE 3



SECTION C-C

NOTES:

1) ALL DIMENSIONS GIVEN IN PROTOTYPE MILLIMETRES UNLESS STATED OTHERWISE. ALL ELEVATIONS GIVEN IN PROTOTYPE METRES.

0 2000 4000 6000

DISTANCE IN MILLIMETRES
1: 80 (prototype)

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Proposed Pump Station Layout
Section C-C

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FIGURE 4