ST. ANTHONY
FALLS LABORATORY

Project Report No. 579

Physical Model of the Broadway Pump Station
Mouse River Enhanced Flood Protection Project

Final

By

Matt Lueker, Rob Gabrielson, and Jeff Marr
University of Minnesota – St. Anthony Falls Laboratory

Prepared for:

MWH Americas, Inc.

MWH Project # 10508190

October 2016

Minneapolis, Minnesota

COLLEGE OF Science & Engineering
UNIVERSITY OF MINNESOTA

Executive Summary

The University of Minnesota – St. Anthony Falls Laboratory (SAFL) conducted a physical model study of the proposed Broadway Pump Station located in Minot, N.D. The pump station is designed to pump a total of 184,000 gpm with four vertical turbine pumps and three submersible pumps operating at 40,000 and 8,000 gpm each, respectively. The vertical turbine pumps can be upgraded to 50,000 gpm providing a total pump station capacity of 224,000 gpm. This pumping capacity requires a physical model study according to ANSI/HI 9.8-2012, *American National Standard for Rotodynamic Pumps for Pump Intake Design.*

SAFL conducted the model study in accordance with ANSI/HI 9.8-2012. The primary goal of the model study was to identify and mitigate unacceptable flow patterns at the pump suction to ensure anticipated pumping operation and reduced maintenance and repair costs. ANSI/HI 9.8-2012 describes methodology and acceptance criteria for model testing. Acceptance criteria include maximum allowable swirl angle, vortex type, and velocity criteria. The standard also provides mitigation methods for certain adverse flow conditions.

A testing matrix of 16 scenarios was created to test the full range of flow conditions anticipated in the pump station. However, preliminary testing found excessive swirl and vortices in one of the bays at a frequent event flow. Also, non-uniform flow entered the pump station under certain inflow conditions. The excessive swirl and vortices were mitigated by installing a 14 inch long and 9 foot tall splitter wall centered on the back wall of each vertical turbine pump bay. The non-uniform flow entering the station was somewhat mitigated by shortening the center wall of the double box culvert in the junction box.

Preswirl in all of the vertical turbine pumps was acceptable with the exception of vertical turbine pump 6 during extremely high flow events. However, the swirl only slightly exceeded the standard and operation of this pump may likely to be infrequent. This is acceptable by ANSI standards. Some Type 3 (dye core vortices) occurred during observation, but occurred less than 10% of the observed time with the exception of one tested scenario. No subsurface dye cores were observed.

Overall, testing with the addition of the back splitter wall shows the pump station complies with the ANSI/HI 9.8-2012 for frequent events and marginally exceeds acceptance criteria for some high flow events. The asymmetric inflow and design of the junction box may be a cause for the mild swirl and vortices in the pumping bays.

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1 Purpose

This report details the physical model testing carried out on the hydraulic performance of the Broadway Pump Station, which is a large pump pump station to be constructed as part of the *Mouse River Enhanced Flood Protection Plan*. The physical model testing program examined the hydraulics within the base design of the pump station, identified unfavorable hydraulic conditions, and developed design solutions to mitigate adverse flow entering the impeller section. The study followed the physical modeling standards from ANSI/HI 9.8-2012, *American National Standard for Rotodynamic Pumps for Pump Intake Design*, which requires physical modeling of pump stations if a single pump exceeds 40,000 gallon per minute (gpm) or the combined pumping capacity of the station exceeds 100,000 gpm. Both of these limits are exceeded for the Broadway Pump Station design. Numerous combinations of water surface elevations and pumping operations were considered and tested.

2 Background

In the summer of 2011, the City of Minot, North Dakota experienced a large flood that resulted in the evacuation of over 10,000 people and widespread destruction along the Souris (Mouse) River (Figure 1). In response to the flooding, the *Mouse River Enhanced Flood Protection Plan* was developed to provide additional flood protection along the Mouse River throughout North Dakota. In Minot, the most populated area along the river, this protection includes significant additional levees and large Pump stations to pump storm water from the city during flood and moderate rainfall events. A team of consultants is currently designing the levee protection systems and associated new pump stations that can manage future flood and storm water events to minimize damage to property and infrastructure. The University of Minnesota - St. Anthony Falls Laboratory (SAFL) was contracted to build a 1:7-scaled physical model of the proposed Broadway Pump Station in Minot, ND in order to have the design comply with ANSI/HI 9.8-2012.

3 Pump Station Description and Operation

The Broadway Pump Station can pump up to 224,000 gpm of stormwater using up to seven pumps. There are three submersible pumps which can pump 8,000 gpm each and four vertical turbine pumps which can pump up to 50,000 gpm each after impeller upgrades. The initial installation will have impellers designed for 40,000 gpm. Upstream of the pump station, a pair of box culverts connects the pump station to an upstream junction chamber. As shown in Figure 6, the junction chamber has two inlets (on the north and the west), one outlet to the pump station on the south, and an inclined access for maintenance equipment on the east. The two inlets allow flow from separate local watersheds into the pump station. The north inlet brings in stormwater from the east into the pump station. This stormwater will be blocked from naturally flowing into the river by the installed levees. The west inlet brings in water from a river meander which will be bypassed by a future diversion project during flood events. The maintenance ramp on the east side of the junction box will have stops logs installed during typical operation.

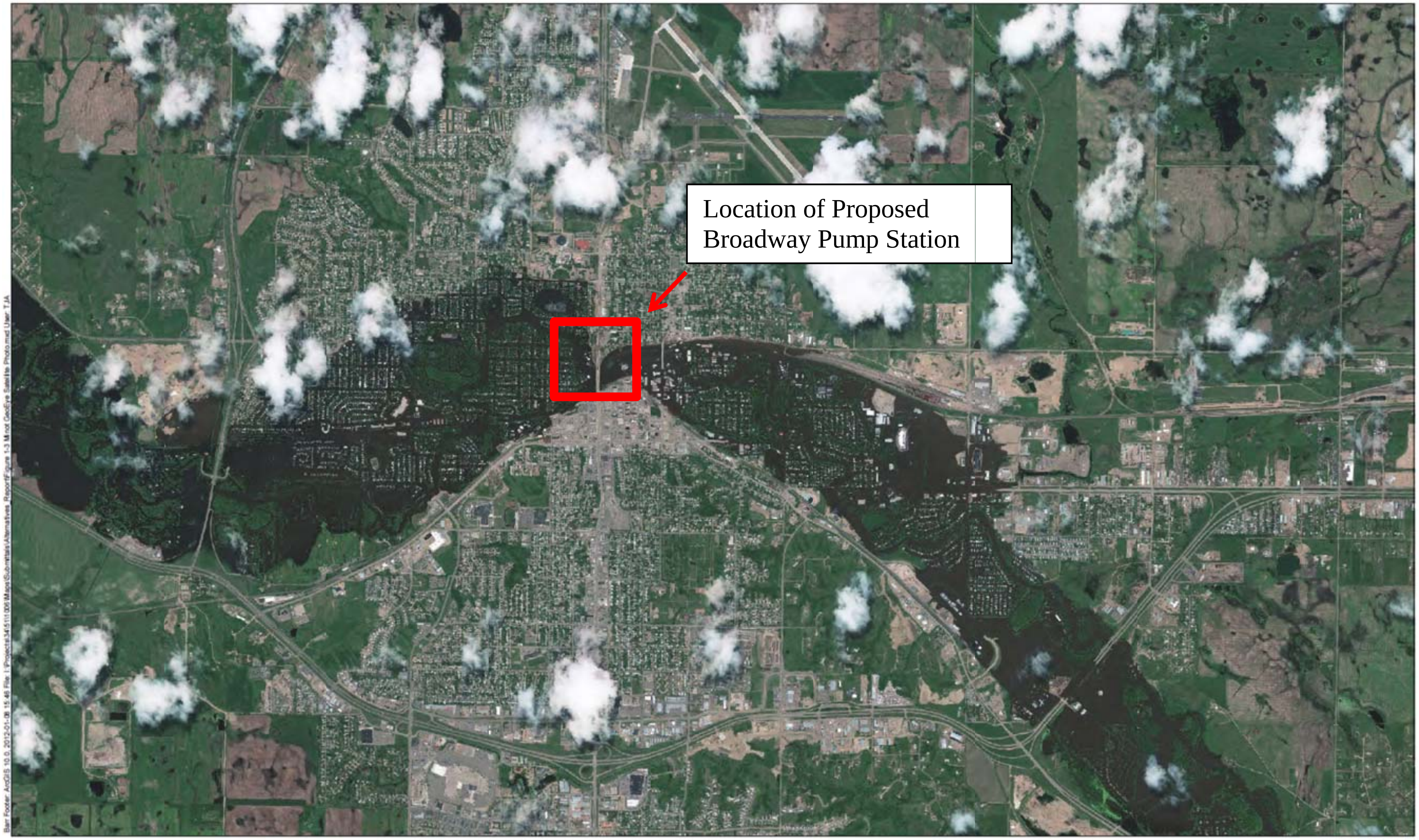


Figure 1: Minot Area Flooding, June 25, 2011

(Geoeye Satellite Photo)

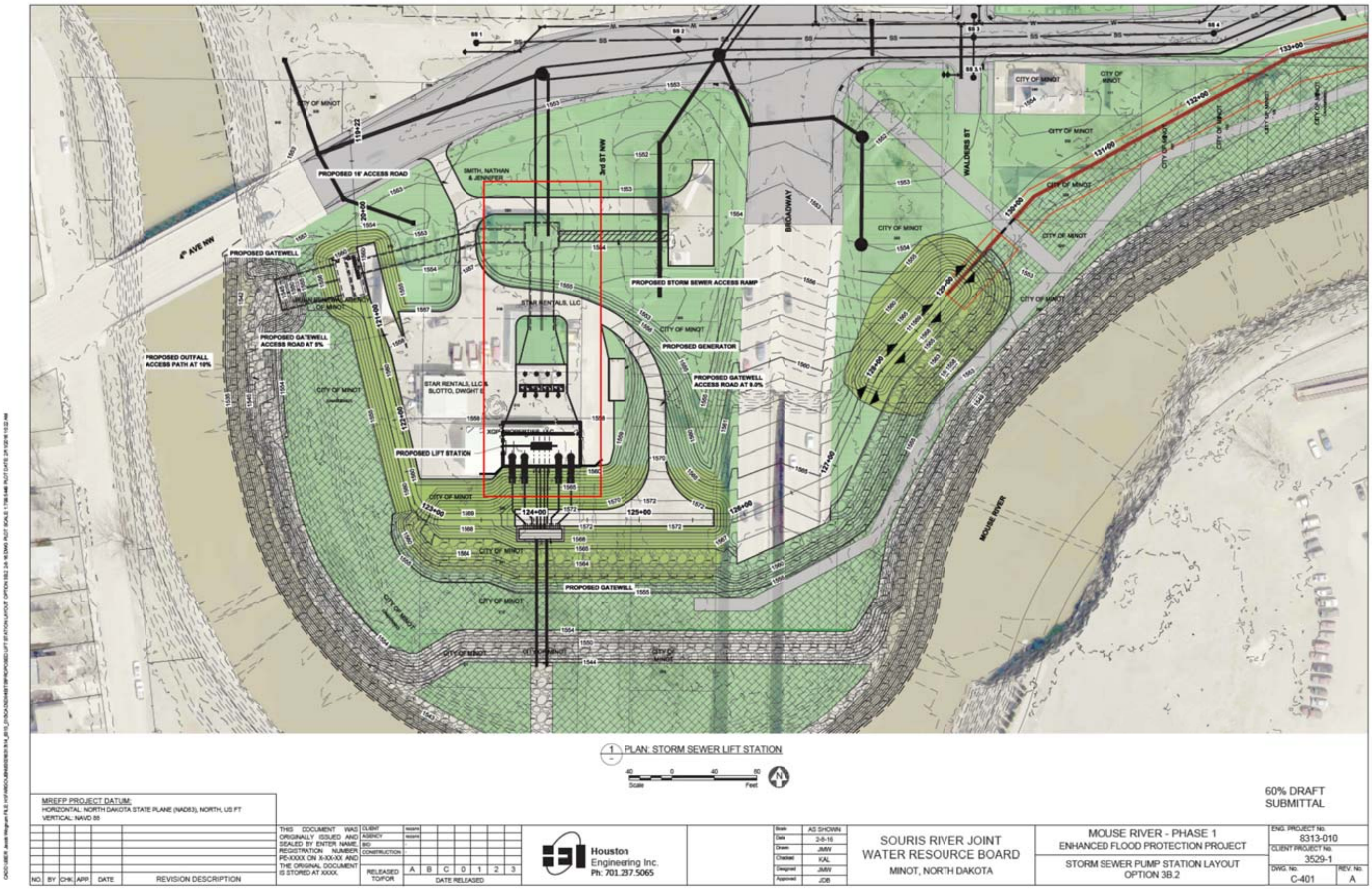


Figure 2: Proposed Broadway Pump Station in Minot, ND.

Image provided by Houston Engineering Inc.

4 Model Design

4.1 Scaling

The model is an undistorted geometric representation of the pump station and Froude similarity was used for scaling of the flow. Froude scaling is appropriate since gravitational and velocity forces are predominantly responsible for the flow field in the model and Froude scaling is prescribed in ANSI/HI 9.8-2012. The geometric scale of the model was governed by minimum Reynolds and Weber number at the bell mouth to ensure negligible viscous and surface tension effects, respectively.

Table 1: Froude Scaled Quantities

Quantity	Scale Model : Prototype
Length	1:7
Flow Rate	1:129.6
Velocity	1:2.65
Time	1:2.65

Table 2: 1:7 Scaled Reynolds and Weber Numbers for Vertical Intake Pump Bell Mouth

	ANSI/HI 9.8-2012 standard	40,000 gpm*	50,000 gpm*
Reynolds Number	> 6 x 10^4	1.2 x 10^5	1.5 x 10^5
Weber Number	> 240	226	1284

* water temperature at time of testing was ~70°F

Trash racks were modeled in the physical model but required modified geometric scaling to create fully turbulent flow through the trash racks. These were fabricated and installed after the May 18, 2016 physical model site visit. Fully turbulent flow is required to ensure that the head loss is correctly scaled through the trash racks. To correctly scale head loss, velocity must follow Froude scaling requiring the same percentage open area in both the prototype and the model. Furthermore, losses through trash racks are mostly a result of turbulent structures due to flow separation rather than skin friction. Thus, the length of the modeled trash racks is not critical for scaling (Clark, et al, 2010).

Table 3: Dimensions and Reynolds number of the trash racks for a conservative low flow scenario.

	Bar Width (in)	Bar Spacing (in)	Bar Length (in)	% Open Area	Re at 50,000 gpm
Prototype	1	2	3	67%	6,500
Model	1.5	3	4.5	67%	3,800

4.2 Boundary Conditions

All of the interior walls affecting flow patterns in the pump station were included in the model. The flow boundary conditions (model extents for inflow and outflow) for the physical model are listed below.

- Upstream Entrance
    - North channel extending 40 feet from junction box.
    - West channel extending 40 feet from junction box.
    - Maintenance channel on east side of junction box.
- Downstream Entrance
    - The approximate location of the impeller of the vertical intake. For the physical model, this was approximated as the bell mouth section 21.7 inches (prototype) into the bell mouth.
    - The bell mouth of the three submersible pumps.

For the upstream inflow boundaries, flow straighteners were used in the model north and west supply channels, as needed. On the east side of the junction box, the portion of the maintenance channel constructed in the physical model was blocked with a flat steel plate during testing to approximate stop logs.

Determining the hydraulics (flow distribution and swirl) at the location of the impellers for the four vertical pumps was one of the primary objectives of the physical hydraulic model. In order to accurately measure swirl, a straight, clear pipe having the same cross sectional shape and area as the inner diameter of the bellmouth was extended downstream of (vertically above) the bellmouth. Because the pipe diameter was the same as the bellmouth, the swirl at the inlet was maintained with the pipe and through the swirl meter location.

For the downstream boundary representing the three submersible pumps in the center bay, the exterior pump, motor, and plumbing dimensions were not geometrically scaled as these pumps were not a primary concern. Instead, a simplified geometry of three vertical pipes was used to create a flow sink in the center bay to ensure correct flow patterns in the remainder of the pump station. However, the location, diameter, and flow rate of the submersible pump inlets were correctly located and scaled.

4.3 Model Construction

The Broadway Pump Station model was built on the model floor at the University of Minnesota - St. Anthony Fall Laboratory. MWH Americas provided annotated and dimensioned PDF drawings which were used to create a 3D AutoCAD drawing of the scaled model. Model wall vertices were laid out before construction and verified after construction with a computer controlled data acquisition carriage outfitted with a laser pointer. Elevated floors were measured from the leveled deck and verified with a surveying transit.

The walls and floor of the model and associated head tanks were constructed of dimensional lumber and primarily 3/4” plywood, sealed with a polyurethane caulking, and then painted with a two-part epoxy paint for waterproofing. Outer walls surrounding the pumping bays were sheeted with ¾” clear Plexiglas in place of plywood to allow better view of flow at the intakes. The model was built on a plywood and lumber deck constructed and leveled prior to construction of the walls. This overall construction method has an accuracy of 1/8”.

The vertical intake pumps were constructed of concentric clear pipes with an overall outer and inner dimension of 6” and 4”, respectively, to match the prototype dimensions of 42” and 28”. See Figure 3. The bell mouth was constructed with a rapid prototyping machine. Documentation of the prototype pumps and consultation with the pump manufacturers ensured that this was an accurate representation of the vertical intake pumps. This overall construction method of the vertical intake pumps has an accuracy of 1/16”.

Figure 3: Modeled Vertical Turbine Pump

The submersible pumps in the center bay were approximated by vertical 2” PVC pipes which closely matched the scaled submersible intake prototype dimension of 350 mm (13.78”). The PVC pipes were positioned such that the end of the pipes were located at the submersible pump mouths in the prototype to ensure the flow sinks in the model were correct. The impeller/pump housing and discharge pipe in the prototype were not modeled.

4.4 Plumbing

The model used non-recirculated Mississippi River water for testing. A single variable frequency drive (VFD) 14” pump was used to draw water from the laboratory’s supply channel to 12” piping to both the west and north supply headboxes. Pumping lines to each headbox had a valve for isolation and throttling. Valves were used for rough flow control and the VFD was used for fine tuning the total inflow. A 6.5” orifice plate was used in the shared supply line to the north and west head tank to measure total inflow.

The pump station used siphons/gravity driven flow to operate all of the modeled pumps. Flow from the four vertical turbine pumps were individually diverted into a single constant head tank on a lower laboratory floor providing an elevation head of approximately 18 feet. The discharge pipes from each of the modeled vertical turbine pumps had 3” orifice plate inside of 4” PVC pipes and were throttled with gate valves to allow individual flow control. See Figure 4.

Figure 4: Vertical Turbine Pump Discharge Plumbing

The three submersible pumps located in the center bay were collectively controlled by identical individual siphons diverted into a variable head tank. See Figure 5. The total flow out of the tank, representing the combined flow of the three submersible tanks, was gravity driven. A ball valve on a lower laboratory floor was used to maintain full pipe flow. The discharge was also throttled with a gate valve. A 2.5” orifice plate was located in the 4” PVC discharge pipe to measure combined flow rate out of the submersible pumps.

Figure 5: Combined Submersible Pump Discharge Plumbing

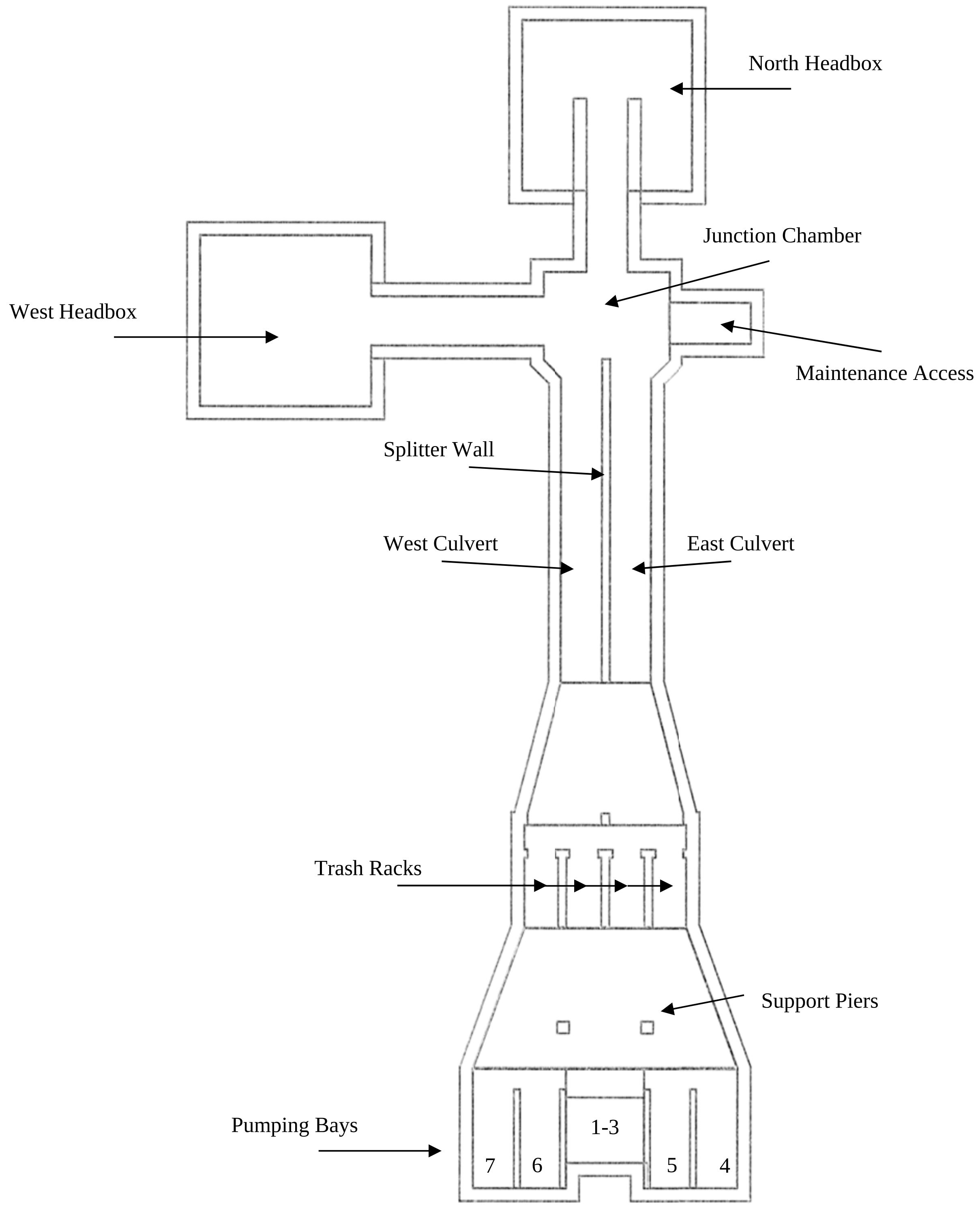


Figure 6: Plan View of Model with Pump Bays Numbered

4.5 Instrumentation

4.5.1 Flow Measurement and Logging

The following orifice plates were used to measure flow into and out of the model.

- 6.5” orifice in the 12” supply line feeding both the north and west head tanks
- 3” orifices in the 4” pipe discharge pipe for each of the vertical turbine pipes
- 2.5” orifice in the 4” discharge pipe for the combined flow of the three submersible pumps

All orifice plates were constructed to conform to ASME standards, thus no calibration was required. Differential pressures across all orifices were measured with Rosemount 3051S differential pressure transducers. Dedicated transducers were connected to i) the inflow meter and ii) the meter measuring combined submersible pump flow. A single transducer was used to measure flow through a single vertical intake pump and was switched to each discharge pipe using a series of valves.

Water surface elevations were measured using ultrasonic sensors (Massa M300 series) immediately upstream of the center bay, in the center of the east and west culverts 34 feet from the start of the box culverts, and the north and west supply channels 17.5 feet upstream of the junction box.

All data was displayed, logged, and time stamped via a specialized LabVIEW™ program to aid the model operator with control and logging all flow and water surface elevations in prototype units.

4.5.2 Velocity

Velocity was measured using a Vectrino+ Acoustic Doppler Velocimeter (ADV). The ADV was placed to sample from each of the supply channels and the east and west culverts for some of the tested scenarios. A single point along the centerline approximately two feet (prototype) above the invert of each channel and approximately three feet downstream of the ultrasonic sensors was measured for five minutes in the model. Velocity was sampled at 20 Hz and further subsampled at 1 Hz for reporting. The primary purposes of the velocity measurements were to: 1) quantify flow distribution inflow from north and west supply channel for scenarios with inflow from both locations and 2) quantify flow distribution in east and west culverts.

4.5.3 Pump velocity

Velocity measurements at the approximate location of the pump impeller utilized a pitot tube installed in one of the vertical pumps 26.25” (prototype) downstream from the plane of the opening to the bellmouth intake (Figure 7). The pitot tube was connected to a differential pressure transducer, adjustable to various locations in the cross section, and recorded in LabVIEW™.

Figure 7: Installed pitot tube in vertical pump for velocity measurements.

4.5.4 Flow swirl

Flow swirl was measured by installing a swirl meter at the location recommended by ANSI/HI 9.8-2012 in all vertical intake pumps (Figure 8). Location of the swirl meter is referenced to the model bellmouth throat diameter, *d*. This swirl meter location was 16” (4d) from bell mouth opening and aligned with the centerline of the pump. The swirl meters were 2.6” (0.6d) tall with a diameter of 3” (0.75d). The swirl meters were mounted on a shaft and low friction bearings below and above the swirl meter. The inner diameter of the impeller section was continued inside of the discharge pipe to maintain flow rotation through the location of the swirl meter. This allows swirl approximation at the impeller location.

One fin of the swirl meter was painted red and rotations were manually counted with the aid of a MATLAB program which logged the model operator’s button pushes each time the painted fin made a full rotation. Swirl was continuously logged and timestamped for 10 minutes for each pump. Predominant swirl direction as well as any pertinent notes was collected over the duration of the 10-minute observation. The 10 minute data was parsed into 10 second bins to determine short term swirl as dictated by ANSI/HI 9.8-2012. The average, standard deviation, maximum, and percentage of time swirl was above 5° was calculated from these 10 second bins over the entire 10 minute total sampling period.

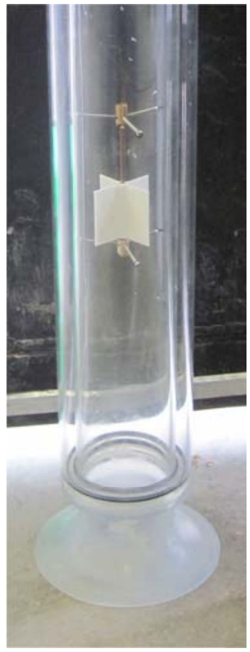


Figure 8: Swirl Meter

4.5.5 Observations and Video

Written observations were noted on diagrams of the following locations and views during testing.

- Plan view of junction box and east and west box culverts
- Plan view pump station from end of culverts to bays
- Plan view of center pumping bay
- Plan, side, and end view of operating pumping bays four through seven

The purpose of the written observations and video was to help determine the upstream causes of adverse flow conditions at the pump intakes, if any were found. These observations are shown in Appendix B.

Video of these location and views were also collected. Video was used for determining percentage of time swirl occurred as well as for general qualitative information.

5 Testing

5.1 Test Matrix

The testing matrix was provided on May 11, 2016 from MWH Americas via email and is shown in Table 4 along with collected data sets.

The matrix was developed to minimize the number of tests necessary while ensuring any potential adverse flow effects would be found. The testing utilizes the planned operational low WSEL set points for pump operation. That is, scenarios represent the lowest WSEL that will be encountered for each pump scenario.

Four additional flows (7A, 7B, 8A, and 8B) were tested using the maximum discharge possible in the model while maintaining the WSEL of the base conditions. These tests were performed to exaggerate swirl conditions for the final tested configuration. ANSI/HI 9.8-2012 describes using 1.5 times the Froude scaled flow; however the model was only capable of flow in the range of the 1.28 to 1.38 times the 50,000 gpm Froude scaled flow in the vertical turbine pump. For this testing, each of the vertical intakes were operated individually with the center bay operating at the prescribed Froude scaled flow.

Scenario	Pumps Operating	Flowrate per Vertical pump (gpm)	Flowrate per Submersible pump (gpm)	Total Station Flowrate (gpm)	Wet Well WSEL (ft)	Influent Water Source – Box Culvert Branch	Flow Log Data - 5 sec Interval	Flow Log Data - 0.5 Sec Invterval	Velocity Data	Swirl Pump 4	Swirl Pump 5	Swirl Pump 6	Swirl Pump 7	Video	Observation Notes
1	1 – 3		7,000	21,000	1536	North	X		N/A	N/A	N/A	N/A	N/A	X	X
2	4	40,000		40,000	1542	North	X	X	X	X	N/A	N/A	N/A	X	X
2A	4	50,000		50,000	1542	North	X	X	X	X	N/A	N/A	N/A	X	X
3	5	50,000		50,000	1542	North		X		N/A	X	N/A	N/A	X	X
4	4, 5	50,000		100,000	1542.75	North	X			X	X	N/A	N/A	X	X
5	4, 6	50,000		100,000	1542.75	North	X	X		X	N/A	X	N/A	X	X
6	4, 7	50,000		100,000	1542.75	North	X	X		X	N/A	N/A	X	X	X
7	1 – 3, 4	50,000	8,000	74,000	1542	North	X			X	N/A	N/A	N/A	X	X
8	1 – 3, 5	50,000	8,000	74,000	1542	North	X			N/A	X	N/A	N/A	X	X
9	1 – 5	50,000	8,000	124,000	1542.75	North	X			X	X	N/A	N/A	X	X
10	1 – 6	50,000	8,000	174,000	1543.5	North	X	X	X	X	X	X	N/A	X	X
11	1 – 7	50,000	8,000	224,000	1544.25	North	X	X	X	X	X	X	X	X	X
11A	1 – 7	50,000	8,000	224,000	1544.25	West	X	X	X	X	X	X	X	X	X
12	1 – 7	50,000	8,000	224,000	1545	25% North / 75% West		X	X	X	X	X	X	X	X
13	1 – 7	50,000	8,000	224,000	1545	50% North / 50% West		X	X	X	X	X	X	X	X
14	1 – 7	50,000	8,000	224,000	1545	75% North / 25% West		X	X	X	X	X	X	X	X
7A	1 – 3, 4	69,000	8,000	93,000	1542	North	X			X	N/A	N/A	N/A	X	X
7B	1-3, 7	64,000	8,000	88,000	1542	North	X			N/A	N/A	N/A	X	X	X
8A	1-3, 5	67,000	8,000	91,000	1542	North	X			N/A	X	N/A	N/A	X	X
8B	1-3, 6	64,000	8,000	88,000	1542	North	X			N/A	N/A	X	N/A	X	X

Table 4: Test Matrix and Collected Datasets.

*collected datasets are indicated with X's

5.2 Model Operation

The model was operated at steady state inflow for all of the conditions tested. The following procedure was used to operate the model.

1. Purge air from the supply line and associated differential pressure measurement tubes to ensure accurate inflow measurement.
2. Fill model with water to submerge all pump intakes.
3. Purge air from all vertical intakes and submersible pump discharge lines and associated differential pressure tubes.
4. Set approximate target inflow discharge by throttling valve and using variable frequency drive.
5. Set pump discharge(s) for all pumps as prescribed in the testing matrix for each scenario while monitoring water surface elevation (WSEL) in model. Ensure pump discharges are correct while WSEL is near target value.
6. Modify the inflow with VFD as needed to set WSEL to target value.
7. Monitor flows and WSEL over the duration of data collection.

Scenarios 12 through 14 utilized the velocity measurement in the north and west supply channels to approximate the flow split. The inflow orifice plate only measured total flow into the model and the inlet valves were throttled as need to reach the approximate target flow split between the west and north inlet.

5.3 Data Collection

Water surface elevation data, pump inlet velocity, inflow, and outflows were logged during data collection using the LabVIEW program. Inflow/WSEL datasets were recorded at frequencies of 0.5 or 5 Hz, depending on if ADV velocity measurements were collected for that run.

Velocities were recorded using the ADV for five minute durations at a sampling frequency of 20 Hz. Velocities were boxcar averaged to 1 Hz for reporting.

Swirl angle was logged and measured continuously for 10 minutes for each of the operating vertical turbine pumps. During swirl angle measurements, the flow in the specific vertical turbine pump of interest was logged at the same time.

Observations of surface flowlines were recorded with the aid of paper confetti to show flow phenomenon. Video of paper confetti on the surface of the water was also collected. Dye injection was used to visualize the subsurface flow approaching and inside each of the pumping bays. Video of dye injections through the Plexiglas panels was also collected. Surface and subsurface vortices were monitored and classified according to ANSI/HI 9.8-2012.

Velocities at the impeller were measured in selected vertical turbine pumps for scenarios with adverse flow conditions.

5.4 ANSI Acceptance Criteria

ANSI/HI 9.8 – 2012 contains the following applicable acceptance criteria for testing. This criteria provided guidelines for testing, analysis, and reporting for this project.

5.4.1 Vortices

Both free surface and subsurface vortices can cause localized low pressure in the flow at the location of the impeller if the vortices are severe enough. This may cause damage to the impeller or degrade performance in the pump. Vortices also indicate general rotational flow in the bay and surface vortices may entrain debris or air degrading pump performance. ANSI states:

> "Free surface and subsurface vortices entering the pump must be less severe than vortices with coherent (dye) cores (free surface vortices of Type 3 and the subsurface vortices of Type 2 in Figure 9.8.4.5a). Dye cores vortices may be acceptable only if they occur for less than 10% of the time or only for infrequent pump operating conditions."

5.4.2 Flow Swirl

Flow swirl was measured in each of the operating vertical turbine pumps for each testing scenario. Flow swirl is used to evaluate the rotation of the flow at the impeller section. This may affect long or short term pump performance if there are rapid changes in rotation or excessive swirl at the impeller section. ANSI states:

> "Swirl angles, both the short-term (10- to 30- second model) maximum and the long-term (10-minute model) average indicated by the swirl meter rotation, must be less than 5 degrees. Maximum short-term (10- to 30- second model) swirl angles up to 7 degrees may be acceptable, only if they occur less than 10% of the time or for infrequent pump operating conditions. The swirl meter rotation should be reasonable steady, with no abrupt changes in direction when rotating near the maximum allowable rate (angle)."

5.4.3 Velocity Profiles at Pump Section

A constant velocity profile at the impeller section is important to ensure the pump operates as designed. Uneven velocities at different locations or times can cause uneven loading on the impeller or pump leading to vibration and other adverse symptoms. ANSI states:

> "Time-averaged velocities at points in the throat of the bell or at the pump section in a piping system shall be within 10% of the cross sectional average velocity. Time-varying fluctuations at a pump shall produce a standard deviation from the time-averaged signal of less than 10%."

5.5 Preliminary Testing

Preliminary testing was performed in order to finalize test procedures, develop best practices for model operation, and identify any adverse flow conditions requiring immediate mitigation before final data collection. This allowed researchers to take qualitative observations and make alterations and decisions quickly to solve any adverse flow conditions encountered.

5.5.1 Pump Bay Modifications

During preliminary tests focusing on test scenario 7, it was found that the average swirl angle was greater than 5° and Type 5 vortices (pulling bubbles to intake) were present. To mitigate this, the following modifications described in Appendix A of ANSI/HI 9.8-2012 were tested:

- Hydrocone only
- Hydrocone and back wall splitter plate
- Back splitter wall plate only

The cone was rapid prototype printed at SAFL and installed underneath the bellmouth intake. The hydrocone caused swirl and surface vortices to worsen. Hydrocones are generally used to mitigate subsurface vortices which were not found during project testing.

The back wall splitter plate decreased the average swirl angle as well as lessened the severity of the surface vortex. However, extending the splitter plate through free surface created symmetric smaller vortices on either side of the splitter wall. To mitigate these smaller vortices, the top of the splitter wall was lowered to an elevation of 1540 which is two feet lower than any WSEL at which the vertical turbine pumps will operate. The lowered top elevation created a shear zone near the surface that decreased the frequency of dye cores and surface swirl. Once the final wall baffle was installed, the occurrence of the dye core and surface swirl greatly decreased. See Figure 9.

The final design of the back splitter wall took into consideration the recommendations of SAFL, ANSI standards, and the needs of the client for operation and maintenance purposes. The final design was a splitter wall connected perpendicularly to the center of the rear wall and extending 14” (prototype) to the edge of the bellmouth intake. This allows the pump to be removed vertically without impinging on the splitter wall. The splitter wall originated at the floor and extended vertically 9 feet (prototype).

The back splitter walls were fabricated and installed in all the vertical turbine pumping bays and the floor cone was removed before executing the full test matrix.

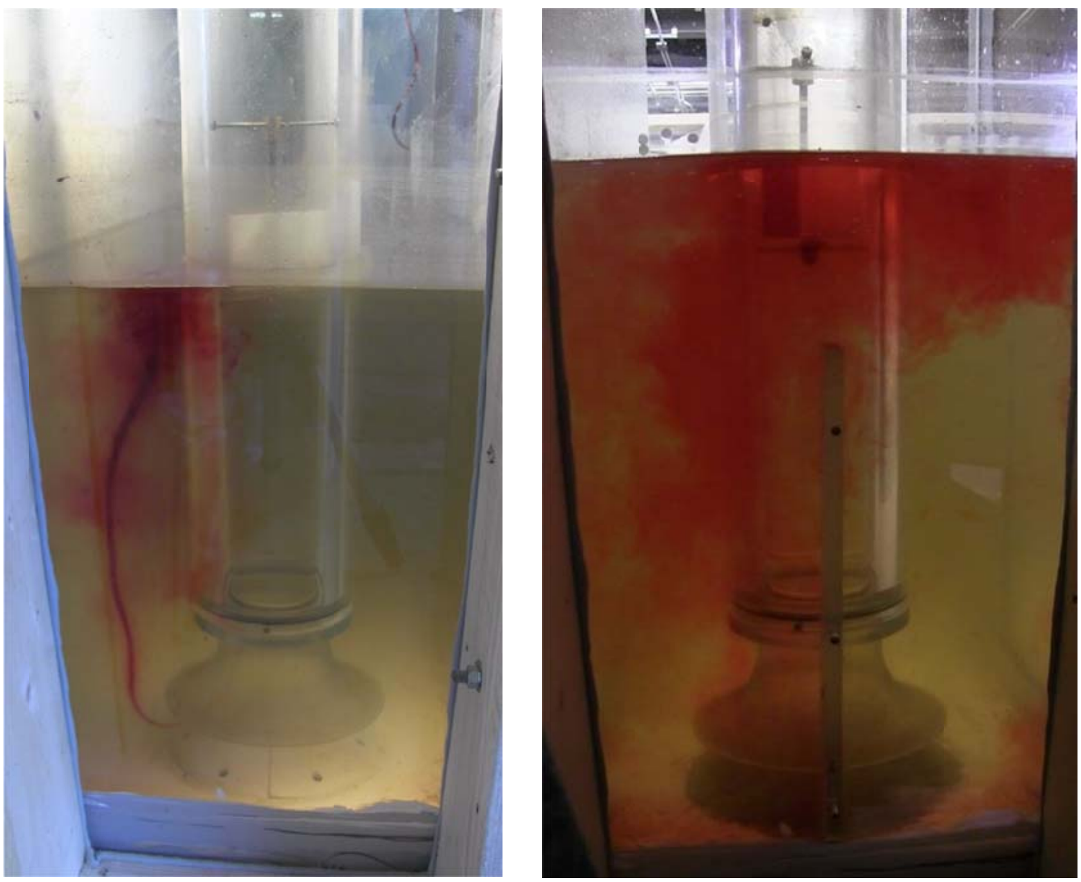


Figure 9: Rear view of vertical turbine pumping bay with hydrocone (left) and splitter wall (right)

5.5.2 Junction Box Modifications

The following two flow issues were found during preliminary testing at the junction box.

- Flow surging in the west supply channel and east culvert was observed during high flow rates from the north supply (Scenarios 9-11).
- There was uneven distribution of flow between west and east culverts during high in-flow from west supply (Scenario 11A).

For the surging, the alteration to improve the flow conditions was isolating the maintenance channel off from the junction chamber with a sheet of metal. See Figure 10. This alteration greatly reduced, but did not fully remove, the surging in the west supply and east culvert when the flow was from north. This isolation of the maintenance channel from the junction more closely approximates final prototype design of the junction box.

To resolve the flow split when water approached the junction chamber from the western supply, the center culvert wall was shortened by five feet such that it projected less into the junction box creating a near-even flow split for scenario 11A.

Figure 10: Tested Configuration of Junction Box

5.5.3 Other Modifications

Two additional changes were made to the model that were not intended to affect the flow but were made at the request of the client. In the pump station, two conservatively sized structural piers were added (Figure 11). The second change was the addition of the trash rack to more correctly model the pump station (Figure 12).

Figure 11: Installed Structural Piers

Figure 12: Modeled Trash Racks

6 Final Testing Results and Discussion

6.1 Flowrate, Velocity, and Water Surface Elevation

Table 5 and 6 summarize the hydraulic characteristics measured in the model for applicable scenarios. Evenly distributed flow into the pumping bays was a general pump station design goal. Cross flow in front of the pumping bays is a source of swirl and vortices entering the pump section according the ANSI/HI 9.8-2012.

Table 5 shows a summary of modeled hydraulics and flow distribution in inlets and west and east culverts. Percentage of flow was calculated using the measured velocities and cross sectional information of the flow in the channels. Inflow distribution for scenarios 12 through 14 was close to target values. The distribution between the east and west culvert was close to even for all scenarios with exception of scenario 14.

Table 6 shows the velocity and water surface statistics. The highest standard deviations for both velocity and water surface elevations were generally observed for scenario 11. This was due to the surging in the west supply channel and east culvert for this scenario.

The maximum recorded water surface in the culverts was 1544.5 feet. The elevation of the crown of the culvert is 1546 so culvert flow will always maintain a free surface condition and transitions from open channel to closed channel flow should not occur.

Table 5 : Flow Splits in Model

Scenario	Pumps Operating	Flowrate per Vertical pump (gpm)	Flowrate per Submersible pump (gpm)	Total Station Flowrate (gpm)	Target Wet Well WSEL (ft)	Influent Water Source – Box Culvert Branch	% Inflow from North	% Inflow from West	% Flow in West Culvert	% Flow in East Culvert
1	1 – 3		7,000	21,000	1536	North	100%	0%		
2	4	40,000		40,000	1542	North	100%	0%	43%	57%
2A	4	50,000		50,000	1542	North	100%	0%	44%	56%
3	5	50,000		50,000	1542	North	100%	0%	44%	56%
4	4, 5	50,000		100,000	1542.75	North	100%	0%		
5	4, 6	50,000		100,000	1542.75	North	100%	0%		
6	4, 7	50,000		100,000	1542.75	North	100%	0%		
7	1 – 3, 4	50,000	8,000	74,000	1542	North	100%	0%		
8	1 – 3, 5	50,000	8,000	74,000	1542	North	100%	0%		
9	1 – 5	50,000	8,000	124,000	1542.75	North	100%	0%		
10	1 – 6	50,000	8,000	174,000	1543.5	North	100%	0%		
11	1 – 7	50,000	8,000	224,000	1544.25	North	100%	0%	43%	57%
11A	1 – 7	50,000	8,000	224,000	1544.25	West	100%	0%	52%	48%
12	1 – 7	50,000	8,000	224,000	1545	25% North / 75% West	23%	77%	57%	43%
13	1 – 7	50,000	8,000	224,000	1545	50% North / 50% West	51%	49%	47%	53%
14	1 – 7	50,000	8,000	224,000	1545	75% North / 25% West	77%	23%	38%	62%

Table 6: Velocity and Water Surface Elevation in Inlets (top) and Culverts (bottom)

							North Inlet								West Inlet							
Scenario	Pumps Operating	Flowrate per Vertical pump (gpm)	Flowrate per Submersible pump (gpm)	Total Station Flowrate (gpm)	Target Wet Well WSEL (ft)	Influent Water Source – Box Culvert Branch	Avg Vel (ft/s)	St. Dev Vel (ft/s)	Min. Vel (ft/s)	Max Vel (ft/s)	Avg. WSEL (ft/s)	St. Dev WSEL (ft/s)	Min. WSEL (ft/s)	Max WSEL (ft/s)	Avg Vel (ft/s)	St. Dev Vel (ft/s)	Min. Vel (ft/s)	Max Vel (ft/s)	Avg. WSEL (ft/s)	St. Dev WSEL (ft/s)	Min. WSEL (ft/s)	Max WSEL (ft/s)
1	1 – 3		7,000	21,000	1536	North					1539.0	0.0	1538.9	1539.1					1538.4	0.5	1535.0	1538.5
2	4	40,000		40,000	1542	North	2.2	0.2	1.5	2.7	1542.0	0.0	1542.0	1542.1	0.0	0.1	-0.8	0.5	1542.0	0.0	1542.0	1542.1
2A	4	50,000		50,000	1542	North	2.6	0.2	1.9	3.2	1542.0	0.0	1541.9	1542.1	0.0	0.0	-0.1	0.1	1542.0	0.0	1541.9	1542.0
3	5	50,000		50,000	1542	North	2.6	0.2	1.8	3.2	1541.9	0.0	1541.9	1542.0	0.0	0.1	-0.4	0.4	1541.9	0.0	1541.9	1542.0
4	4, 5	50,000		100,000	1542.75	North					1539.0	0.0	1538.9	1539.1					1538.4	0.5	1535.0	1538.5
5	4, 6	50,000		100,000	1542.75	North					1542.6	0.1	1542.5	1542.7					1542.6	0.0	1542.5	1542.7
6	4, 7	50,000		100,000	1542.75	North					1542.6	0.0	1542.5	1542.7					1542.6	0.0	1542.5	1542.6
7	1 – 3, 4	50,000	8,000	74,000	1542	North					1541.9	0.0	1541.9	1542.0					1542.0	0.0	1541.9	1542.0
8	1 – 3, 5	50,000	8,000	74,000	1542	North					1541.9	0.0	1541.8	1542.0					1541.9	0.0	1541.9	1542.0
9	1 – 5	50,000	8,000	124,000	1542.75	North					1542.5	0.1	1542.3	1542.8					1542.4	0.1	1542.1	1542.7
10	1 – 6	50,000	8,000	174,000	1543.5	North					1543.3	0.1	1543.1	1543.5					1543.1	0.3	1542.5	1543.5
11	1 – 7	50,000	8,000	224,000	1544.25	North	4.3	1.6	-0.9	8.2	1543.9	0.1	1543.7	1544.2	0.2	0.4	-1.1	1.4	1543.5	0.3	1541.8	1544.1
11A	1 – 7	50,000	8,000	224,000	1544.25	West	0.0	0.3	-0.9	0.7	1544.4	0.1	1544.3	1544.6	7.6	0.4	5.6	8.9	1544.3	0.2	1543.7	1544.7
12	1 – 7	50,000	8,000	224,000	1545	25% North / 75% West	1.8	0.2	1.3	2.3	1545.2	0.0	1545.1	1545.3	5.2	0.3	4.2	6.2	1545.1	0.1	1544.9	1545.3
13	1 – 7	50,000	8,000	224,000	1545	50% North / 50% West	3.9	0.2	2.5	4.6	1545.2	0.1	1544.3	1545.4	3.2	0.3	2.4	3.9	1545.0	0.0	1544.9	1545.1
14	1 – 7	50,000	8,000	224,000	1545	75% North / 25% West	5.9	0.3	5.0	6.6	1545.1	0.1	1544.8	1545.4	1.5	0.1	1.2	1.9	1544.9	0.0	1544.9	1545.0

							West Culvert								East Culvert							
Scenario	Pumps Operating	Flowrate per Vertical pump (gpm)	Flowrate per Submersible pump (gpm)	Total Station Flowrate (gpm)	Target Wet Well WSEL (ft)	Influent Water Source – Box Culvert Branch	Avg Vel (ft/s)	St. Dev Vel (ft/s)	Min. Vel (ft/s)	Max Vel (ft/s)	Avg. WSEL (ft/s)	St. Dev WSEL (ft/s)	Min. WSEL (ft/s)	Max WSEL (ft/s)	Avg Vel (ft/s)	St. Dev Vel (ft/s)	Min. Vel (ft/s)	Max Vel (ft/s)	Avg. WSEL (ft/s)	St. Dev WSEL (ft/s)	Min. WSEL (ft/s)	Max WSEL (ft/s)
1	1 – 3		7,000	21,000	1536	North					1538.7	0.0	1538.6	1538.8					1538.7	0.0	1538.6	1538.8
2	4	40,000		40,000	1542	North	1.1	0.1	0.6	1.5	1542.1	0.0	1542.1	1542.1	1.5	0.2	1.0	1.9	1542.1	0.0	1542.0	1542.1
2A	4	50,000		50,000	1542	North	1.3	0.1	0.8	1.8	1542.0	0.0	1542.0	1542.0	1.7	0.2	1.1	2.3	1542.0	0.0	1541.9	1542.1
3	5	50,000		50,000	1542	North	1.3	0.2	0.7	1.8	1542.0	0.0	1542.0	1542.1	1.7	0.2	1.1	2.5	1542.0	0.0	1542.0	1542.0
4	4, 5	50,000		100,000	1542.75	North					1538.7	0.0	1538.6	1538.8					1538.7	0.0	1538.6	1538.8
5	4, 6	50,000		100,000	1542.75	North					1542.7	0.0	1542.6	1542.8					1542.7	0.1	1542.6	1542.8
6	4, 7	50,000		100,000	1542.75	North					1542.7	0.0	1542.6	1542.8					1542.7	0.1	1542.6	1542.8
7	1 – 3, 4	50,000	8,000	74,000	1542	North					1542.0	0.0	1541.9	1542.1					1542.0	0.0	1541.9	1542.1
8	1 – 3, 5	50,000	8,000	74,000	1542	North					1542.0	0.0	1541.9	1542.1					1542.0	0.0	1541.9	1542.1
9	1 – 5	50,000	8,000	124,000	1542.75	North					1542.6	0.3	1540.6	1542.9					1542.6	0.1	1542.3	1542.9
10	1 – 6	50,000	8,000	174,000	1543.5	North					1543.4	0.1	1543.3	1543.7					1543.4	0.2	1543.1	1543.8
11	1 – 7	50,000	8,000	224,000	1544.25	North	3.8	0.6	2.0	5.4	1544.1	0.2	1543.2	1544.5	5.2	1.0	2.5	7.4	1544.1	0.2	1543.6	1544.5
11A	1 – 7	50,000	8,000	224,000	1544.25	West	4.4	0.8	2.2	6.8	1543.9	0.1	1543.6	1544.3	4.0	0.4	2.8	5.5	1544.1	0.1	1543.0	1544.4
12	1 – 7	50,000	8,000	224,000	1545	25% North / 75% West	4.5	0.5	2.8	6.0	1544.9	0.1	1543.9	1545.1	3.4	0.4	2.2	4.5	1544.9	0.1	1544.1	1545.1
13	1 – 7	50,000	8,000	224,000	1545	50% North / 50% West	3.4	0.3	2.6	4.2	1545.0	0.0	1544.9	1545.1	3.9	0.4	2.9	5.0	1544.9	0.1	1544.2	1545.1
14	1 – 7	50,000	8,000	224,000	1545	75% North / 25% West	2.5	0.5	1.4	3.6	1545.0	0.0	1544.8	1545.1	4.2	0.4	3.0	5.6	1544.9	0.1	1544.2	1545.1

6.1 Pump Velocity

Velocities were measured in two pumping bays using the pitot tube apparatus. To determine which pumps to test, two case scenarios with adverse surface swirl and swirl angle inside of the pumps were selected. This resulted in choosing pump 4 in scenario 7 for surface swirl and pump 6 in scenario 11a for high swirl angle. A North to South and East to West profile was measured in the bellmouth at the approximate location of the impeller (Figure 13). Each of the 10 positions was sampled for three minutes.

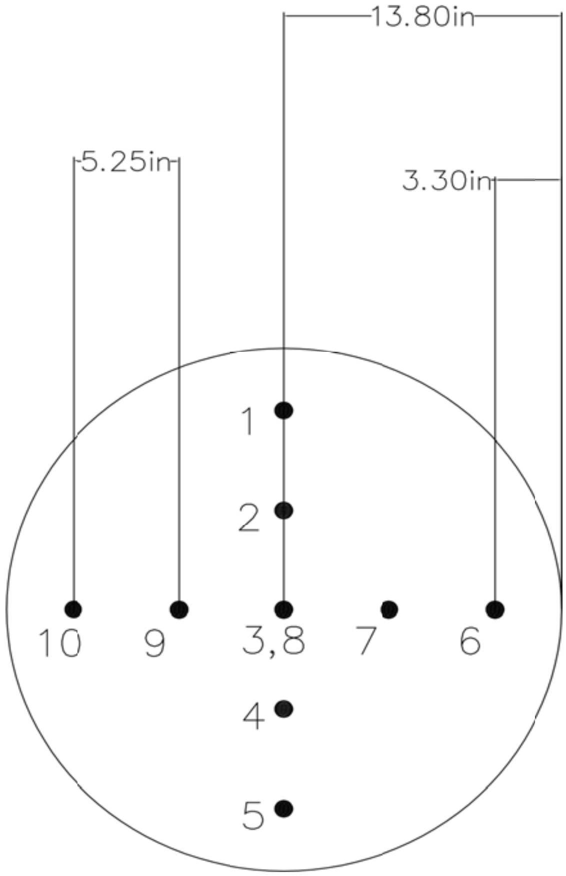


Figure 13: Numbered pitot tube positions 1-10 and the spacing measured in inches.

All of the measured velocities in Table 7 and Table 8 portray an even flow through the bell mouth and into the section where the impeller is located. The tables show that the results of the testing fall within the criteria by ANSI standards mentioned in the acceptance portion of the report (Section 5.4.3). Velocities closer to the edge of the pipe are anticipated to be slightly less than 100% of the bulk velocity.

Table 7: Pump 4 pitot tube results and calculations.

Pump 4, Scenario 7 Velocity Profiles (ft/s)					
	Position	**V bulk Avg**	**V pitot Avg**	**% of Bulk**	**St Dev / Avg**
North/South	1	26.57	27.74	104%	0.5%
	2		28.02	105%	0.8%
	3		27.29	103%	0.5%
	4		27.38	103%	0.2%
	5		27.58	104%	0.2%
East/West	6		27.78	105%	0.2%
	7		27.62	104%	0.6%
	8		27.87	105%	0.4%
	9		27.57	104%	0.6%
	10		27.12	102%	0.7%

Table 8: Pump 6 pitot tube results and calculations.

Pump 6, Scenario 11A Velocity Profiles (ft/s)					
	Position	**V bulk Avg**	**V pitot Avg**	**% of Bulk**	**St Dev / Avg**
North/South	1	26.16	27.57	105%	0.8%
	2		27.78	106%	1.0%
	3		28.01	107%	0.8%
	4		27.30	104%	0.5%
	5		27.43	105%	0.3%
East/West	6		27.34	105%	0.6%
	7		27.39	105%	0.4%
	8		27.82	106%	0.7%
	9		28.06	107%	4.2%
	10		27.76	106%	0.9%

6.2 Flow Swirl

Table 9 summarizes the vertical turbine pump 10 minute swirl data for all scenarios. The average swirl for any condition never exceeded 5°. The worst swirl condition occurs in vertical turbine pump 6 for scenarios 12 and 13. This may be explained by the general flow pattern in the pump station causing cross flow in front of bay 6. Observations show that there is upwelling in the center bay. This indicates too much flow entering that bay and the asymmetry of the submersible pumps cause more flow to exit the center bay in front of bay 6. This crossflow is exacerbated when vertical pump 7 is operating.

Overall, the flow swirl is acceptable to ANSI standard with the exception of vertical turbine pump 6. For scenario 12, a maximum 10 second sample of swirl reaches 12.7° and for scenario 13, 13% of the 10 minute averages exceed 5°. These conditions only slightly exceed acceptance criteria and are acceptable if these operational conditions are infrequent.

Table 9: Intake Swirl Measurements

							Intake 4					Intake 5				
Scenario	Pumps Operating	Flowrate per Vertical pump (gpm)	Flowrate per Submersible pump (gpm)	Total Station Flowrate (gpm)	Target Wet Well WSEL (ft)	Influent Water Source – Box Culvert Branch	Avg Θ	St. Dev Θ	Max Θ	% Time Θ > 5	Direction	Avg Θ	St. Dev Θ	Max Θ	% Time Θ > 5	Direction
1	1 – 3		7,000	21,000	1536	North										
2	4	40,000		40,000	1542	North	0.3	0.4	1.5	0%	CW					
2A	4	50,000		50,000	1542	North	0.3	0.4	1.2	0%	CW					
3	5	50,000		50,000	1542	North						0.6	0.7	2.5	0%	CCW
4	4, 5	50,000		100,000	1542.75	North	0.5	0.4	1.3	0%	Both	0.2	0.4	1.9	0%	CCW
5	4, 6	50,000		100,000	1542.75	North	0.6	0.7	3.1	0%	Both					
6	4, 7	50,000		100,000	1542.75	North	0.5	0.5	1.8	0%	Both					
7	1 – 3, 4	50,000	8,000	74,000	1542	North	0.3	0.4	1.3	0%	CCW					
8	1 – 3, 5	50,000	8,000	74,000	1542	North						1.0	0.7	2.5	0%	CCW
9	1 – 5	50,000	8,000	124,000	1542.75	North	0.7	0.6	2.4	0%	Both	0.4	0.4	1.2	0%	CCW
10	1 – 6	50,000	8,000	174,000	1543.5	North	0.6	0.5	1.9	0%	Both	0.3	0.4	1.2	0%	Both
11	1 – 7	50,000	8,000	224,000	1544.25	North	1.0	0.6	3.0	0%	CCW	0.6	0.6	3.6	0%	Both
11A	1 – 7	50,000	8,000	224,000	1544.25	West	0.9	0.7	2.4	0%	CCW	0.4	0.4	1.2	0%	Both
12	1 – 7	50,000	8,000	224,000	1545	25% North / 75% West	0.7	0.6	1.9	0%	Both	0.3	0.4	1.2	0%	CW
13	1 – 7	50,000	8,000	224,000	1545	50% North / 50% West	0.8	0.7	2.5	0%	CCW	0.3	0.4	1.2	0%	CCW
14	1 – 7	50,000	8,000	224,000	1545	75% North / 25% West	1.4	1.0	4.3	0%	CCW	0.5	0.5	2.5	0%	CW
7A	1 – 3, 4	69,000	8,000	93,000	1542	North	0.5	0.4	1.3	0%	CW					
7B	1-3, 7	64,000	8,000	88,000	1542	North										
8A	1-3, 5	67,000	8,000	91,000	1542	North						0.4	0.4	1.8	0%	CCW
8B	1-3, 6	64,000	8,000	88,000	1542	North										

							Intake 6					Intake 7				
Scenario	Pumps Operating	Flowrate per Vertical pump (gpm)	Flowrate per Submersible pump (gpm)	Total Station Flowrate (gpm)	Target Wet Well WSEL (ft)	Influent Water Source – Box Culvert Branch	Avg Θ	St. Dev Θ	Max Θ	% Time Θ > 5	Direction	Avg Θ	St. Dev Θ	Max Θ	% Time Θ > 5	Direction
1	1 – 3		7,000	21,000	1536	North										
2	4	40,000		40,000	1542	North										
2A	4	50,000		50,000	1542	North										
3	5	50,000		50,000	1542	North										
4	4, 5	50,000		100,000	1542.75	North										
5	4, 6	50,000		100,000	1542.75	North	1.1	0.8	2.5	0%	Both					
6	4, 7	50,000		100,000	1542.75	North						1.0	0.7	3.0	0%	CCW
7	1 – 3, 4	50,000	8,000	74,000	1542	North										
8	1 – 3, 5	50,000	8,000	74,000	1542	North										
9	1 – 5	50,000	8,000	124,000	1542.75	North										
10	1 – 6	50,000	8,000	174,000	1543.5	North	1.8	1.3	6.2	2%	CCW					
11	1 – 7	50,000	8,000	224,000	1544.25	North	2.6	1.1	5.6	2%	CCW	1.5	1.0	4.2	0%	CCW
11A	1 – 7	50,000	8,000	224,000	1544.25	West	2.8	1.3	5.7	8%	CCW	1.3	0.7	2.9	0%	CCW
12	1 – 7	50,000	8,000	224,000	1545	25% North / 75% West	2.2	1.8	12.7	2%	CCW	0.4	0.5	1.9	0%	CCW
13	1 – 7	50,000	8,000	224,000	1545	50% North / 50% West	3.0	1.5	6.3	13%	CCW	1.2	0.9	4.4	0%	CCW
14	1 – 7	50,000	8,000	224,000	1545	75% North / 25% West	1.8	0.9	5.0	2%	CCW	1.9	1.0	4.6	0%	CCW
7A	1 – 3, 4	69,000	8,000	93,000	1542	North										
7B	1-3, 7	64,000	8,000	88,000	1542	North						0.4	0.4	1.4	0%	CCW
8A	1-3, 5	67,000	8,000	91,000	1542	North										
8B	1-3, 6	64,000	8,000	88,000	1542	North	0.9	0.7	2.8	0%	CCW					

6.3 Video and Observations

Video taken during the experiment was used to document the surface flow throughout the model. The model was segmented into several different sections to take consistent video. The video taken was used along with general observations during experiments to track flow and determine any undesirable flow or consistencies between scenarios.

6.3.1 Junction Chamber

Flow separation and large recirculation was observed along the eastern edge of the chamber in every scenario tested. Recirculation is also present on the western side of the junction chamber on the southwest chamfered corner (Figure 14). Both recirculation areas vary based on the flowrate. Higher flowrates have higher velocity, turbulence, and variability of reattachment point of the flow. A standing wave is always located on the upstream face of the splitter wall protruding into the junction chamber. The volume of flow into the pump station dictates how large the standing wave is. During all test scenarios with total station flowrates of 124,000 gpm and higher with the exception of scenario 12, a secondary wave or small hydraulic jump develops immediately downstream of the standing wave. The changes made in the junction chamber, e.g. reduction of wall length by five feet, have led to an acceptable flow pattern from the supply channels and through the junction chamber into the East and West culverts.

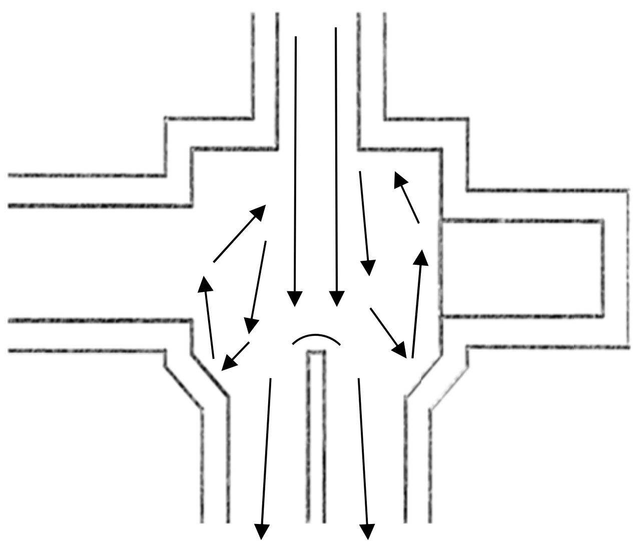


Figure 14: General flow lines in the junction chamber

6.3.2 Downstream of Culverts

The end of the splitter wall produces eddies varying in strength and duration. The widening of the channel creates flow separation and reverse flow on the outside walls of the channel (Figure 15). The east wall does not always experience this recirculation as strongly as the west wall. This indicates more flow generally enters the east half of the pumping bay approach area.

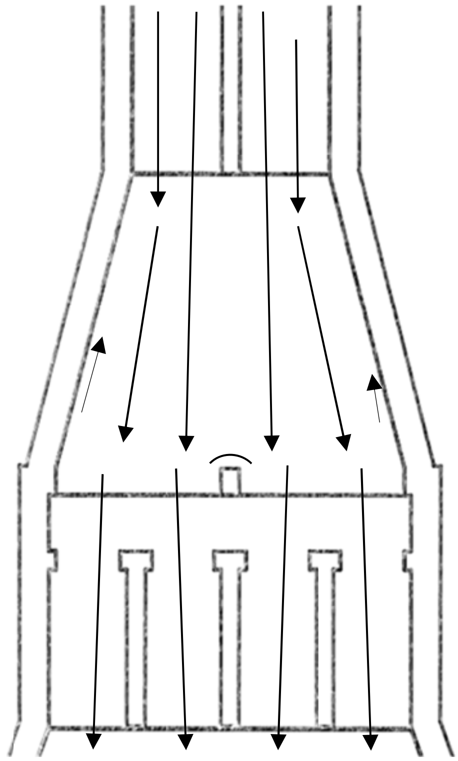


Figure 15: General flow lines downstream of the culverts

6.3.3 Pumping Bay Approach

The flow is highly variable in this section of the model and is dependent on which pumps are operating. The flow generally will come out of the trash rack channels straight with moderate turbulence having passed through the racks. After passing through the channel and the slope break, the water trends towards whatever pumps are operating as shown in observation note located in Appendix B.

6.3.4 Pumping Bays

Pumping bays 4 through 7 all show similar trends in accordance with their orientation relative to the center pumping bay (Figure 16). The flow enters the pumping bay on the outer wall of the chamber (east for bays 4 and 5 and west for bays 6 and 7). The flow travels to the back of the pumping bay and around the back side of the pump. After this point, the flow becomes turbulent once it reaches the inside back corner of the bay and is either pulled down to the intake or gets entrained in the recirculation and reverse flow characteristics of the inside wall for each of the pumping bays. The recirculation and reverse flow takes up about 1/3 of the width of the pumping bay and is highly evident during the overhead video footage of the pumping bays. Pumping bay 6 has the strongest entrance/recirculation speeds based on the surface movement.

Another phenomenon observed was surface swirl up to ANSI Type 3 vortex, which forms a coherent dye core from the surface to the intake. Each of the four pumping bays with vertical pumps experienced this problem in the rear inside corners. However, as shown in Table 10, type 3 vortices occur for less than 10% of the observed time with the exception of vertical turbine pump 6 for scenario 5. These vortices form because of cross flow at the bay entrances and uneven approach flow.

These dye cores were more prevalent when only one or two intakes were operating. At the higher flows and more pumps in operation, the additional turbulence and waves in the pump station did not allow dye cores to form.

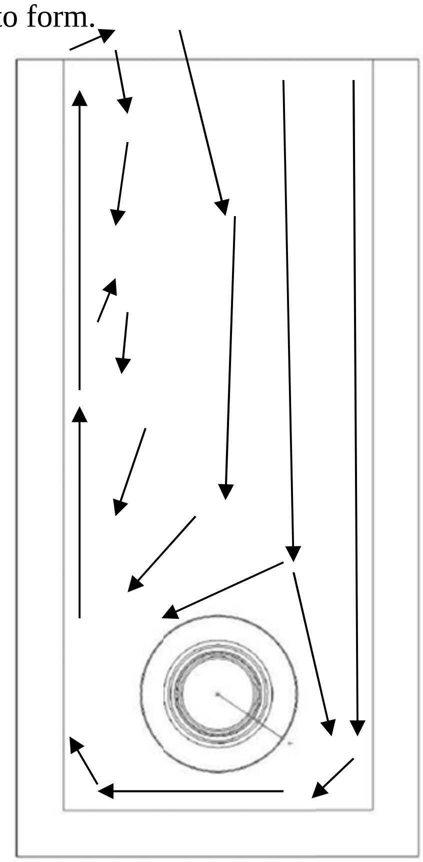


Figure 16: General flow lines of pumping bay 4 and 5

Table 10: Percentage Time of Type 3 Vortices Observed

Scenario	Pumps Operating	Flowrate per Vertical pump (gpm)	Flowrate per Submersible pump (gpm)	Total Station Flowrate (gpm)	Target Wet Well WSEL (ft)	Influent Water Source – Box Culvert Branch	Intake 4 % Time Surface Type 3 Present	Intake 5 % Time Surface Type 3 Present	Intake 6 % Time Surface Type 3 Present	Intake 7 % Time Surface Type 3 Present
1	1 – 3		7,000	21,000	1536	North				
2	4	40,000		40,000	1542	North	0.9%			
2A	4	50,000		50,000	1542	North	7.6%			
3	5	50,000		50,000	1542	North		7.1%		
4	4, 5	50,000		100,000	1542.75	North	0.0%	6.6%		
5	4, 6	50,000		100,000	1542.75	North	4.5%		14.5%	
6	4, 7	50,000		100,000	1542.75	North	2.8%			0.0%
7	1 – 3, 4	50,000	8,000	74,000	1542	North	8.8%			
8	1 – 3, 5	50,000	8,000	74,000	1542	North		5.5%		
9	1 – 5	50,000	8,000	124,000	1542.75	North	0.0%	0.2%		
10	1 – 6	50,000	8,000	174,000	1543.5	North	4.4%	0.0%	0.0%	
11	1 – 7	50,000	8,000	224,000	1544.25	North	0.0%	0.0%	0.0%	0.0%
11A	1 – 7	50,000	8,000	224,000	1544.25	West	0.0%	0.0%	0.0%	0.0%
12	1 – 7	50,000	8,000	224,000	1545	25% North / 75% West	0.0%	0.0%	4.2%	0.0%
13	1 – 7	50,000	8,000	224,000	1545	50% North / 50% West	0.0%	0.0%	0.0%	0.0%
14	1 – 7	50,000	8,000	224,000	1545	75% North / 25% West	0.0%	0.0%	0.0%	0.0%
7A	1-3, 4	75,000	8,000	111,000	1542	North	2.9%			
7B	1-3, 7	75,000	8,000	111,000	1542	North				1.4%
8A	1-3, 5	75,000	8,000	111,000	1542	North		0.6%		
8B	1-3, 6	75,000	8,000	111,000	1542	North			1.0%	

7 Conclusions

The results from the majority of scenarios tested suggest acceptable operation of the pump station. There were a few cases of marginal performance under extreme events summarized below.

7.1 Center Bay Pumps 1, 2 & 3

Reverse flow out of the center bay is present for some scenarios. This is caused by the center bay location and lower bulk velocity entering the center bay compared to the vertical pump bays. This causes the flow to upwell at the back wall and surface flow out of the center pumping bay and into the neighboring bays to the east and west (Pumps 5 and 6). This flow effect increases separation of flow in the vertical turbine pump bays at the shared walls.

7.2 Vertical Turbine Pump 6

Vertical turbine pump 6 had excessive swirl angle in the pump; however, this flow scenario is thought to be hydrologically infrequent. The tests where pump 6 maximum recorded swirl exceeded 5° were total station flowrates of 174,000 gpm and greater. Also, all testing with pump 6 active was completed with the 50,000 gpm vertical turbine pump flowrate. Lower pump 6 flowrates may lower this swirl angle. It was also observed that the velocity of the recirculation was greater than other pumping bays during high flow tests where all seven pumps were operating. This could potentially be caused by the asymmetry of the locations of the submersible pumps in the center bay or uneven inflow from the culverts. As the water is drawn to the center bay it trends towards the west and could be entrained in the suction and recirculation at the opening of bay 6.

7.3 Culvert Velocity Differences

The east and west culverts are for the most part nearly equal in their velocities approaching the pump station. However, when the velocities differ in the culverts, the asymmetry can increase velocity on one side of the model and cause cross flow in front of the bay inlets causing rotational flow, swirl and vortices in the bay and vertical pumps.

8 Recommendations

The physical modeling team recommends the following for the Broadway Pump Station.

1. Maintain isolation of the maintenance channel during operation to reduce surging into the pump station and the west supply channel.
2. Construct back splitter wall connected perpendicularly to the center of the rear bay wall extending 14” (prototype) to the edge of the bellmouth intake and nine feet tall extending from the floor of the bay.
3. Place the start of center box culvert wall 21 feet from north entrance of the junction box.
4. Operate vertical turbine pump 6 last in the pumping sequence. Discussion with MWH indicates there are no foreseeable issues with operating pump 6 last in the pumping

sequence. This will maximize water depth and flow turbulence mitigating vortices and swirl discussed in testing results.

5. Be aware of potential marginal vertical turbine operation for pump 6 when flow is entering from both the west and north inlets. This event type is hydrologically infrequent, so anticipated marginal operation may be acceptable.
6. If marginal operation of pump 6 is unacceptable, review potential mitigation as described in Appendix A of ANSI/HI 9.8-2012. Use of these mitigation methods may cause other adverse flow condition at suction intake. These include, but are not limited to, the following items.
    a. Curtain walls or horizontal grating in bay upstream of pumps
    b. Floor splitter below pumps

9 References

Hydraulic Institute (2012), *American National Standard for Rotodynamic Pumps for Pump Intake Design*. ANSI/HI 9.8-2012.

Shawn P. Clark , Jonathan M. Tsikata & Melissa Haresign (2010), *Experimental study of energy loss through submerged trashracks*, Journal of Hydraulic Research, 48:1, 113-118.

10 Appendix B – Video Descriptions

- Scenario 1: Pumps 1-3
- Scenario 2: Pump 4
- Scenario 2A: Pump 4
- Scenario 3: Pump 5
- Scenario 4: Pumps 4 & 5
- Scenario 5: Pumps 4 & 6
- Scenario 6: Pumps 4 & 7
- Scenario 7: Pumps 1-3 & 4
- Scenario 8: Pumps 1-3 & 5
- Scenario 9: Pumps 1-5
- Scenario 10: Pumps 1-6
- Scenario 11: Pumps 1-7 (North Inlet)
- Scenario 11A: Pumps 1-7 (West Inlet)
- Scenario 12: Pumps 1-7 (25% North / 75% West)
- Scenario 13: Pumps 1-7 (50% North / 50% West)
- Scenario 14: Pumps 1-7 (75% North / 25% West)
- Scenario 7A: Pumps 1-3 & 4 (1.5 Froude scaled flow)
- Scenario 7B: Pumps 1-3 & 7 (1.5 Froude scaled flow)
- Scenario 8A: Pumps 1-3 & 5 (1.5 Froude scaled flow)
- Scenario 8B: Pumps 1-3 & 6 (1.5 Froude scaled flow)

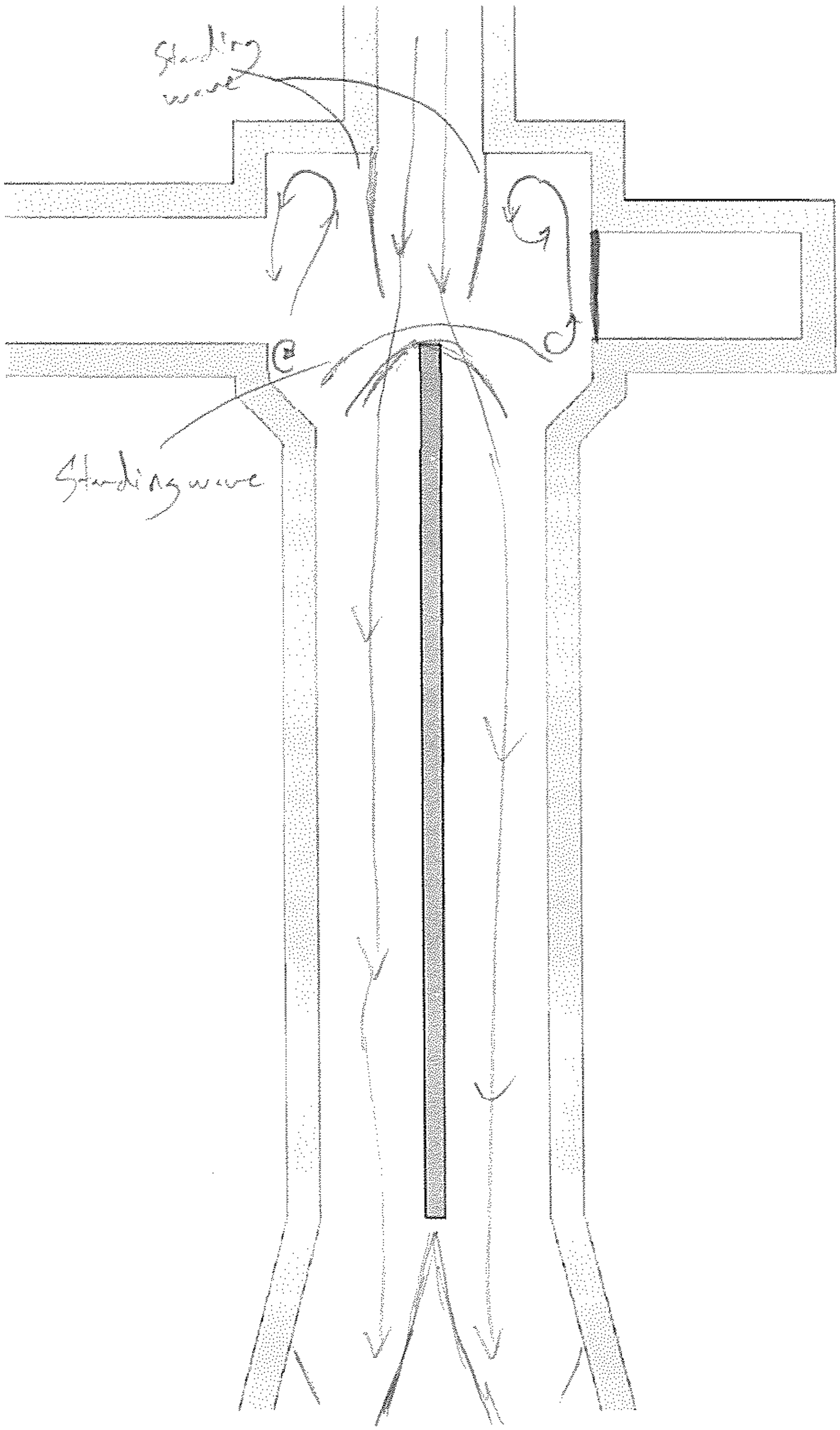
11 Appendix A – Flow Observations

SAFL Run no.	Scenario	Pumps Operating	Flowrate per Vertical pump (gpm)	Flowrate per Submersible pump (gpm)	Total Station Flowrate (gpm)	Wet Well WSEL (ft)	Influent Water Source – Box Culvert Branch	Vertical Pump Pressure (inches H20)	Submersible Pump Pressure (inches H20)	Supply Pressure (inches H20)
1	1	1 – 3		7,000	21,000	1536	North	0.0	48.1	1.1
2	2	4	40,000		40,000	1542	North	68.5	0.0	4.1
3	2A	4	50,000		50,000	1542	North	107.0	0.0	6.5
4	3	5	50,000		50,000	1542	North	107.0	0.0	6.5
5	4	4, 5	50,000		100,000	1542.75	North	107.0	0.0	25.9
6	5	4, 6	50,000		100,000	1542.75	North	107.0	0.0	25.9
7	6	4, 7	50,000		100,000	1542.75	North	107.0	0.0	25.9
8	7	1 – 3, 4	50,000	8,000	74,000	1542	North	107.0	62.9	14.2
9	8	1 – 3, 5	50,000	8,000	74,000	1542	North	107.0	62.9	14.2
10	9	1 – 5	50,000	8,000	124,000	1542.75	North	107.0	62.9	39.8
11	10	1 – 6	50,000	8,000	174,000	1543.5	North	107.0	62.9	78.3
12	11	1 – 7	50,000	8,000	224,000	1544.25	North	107.0	62.9	129.7
13	11A	1 – 7	50,000	8,000	224,000	1544.25	West	107.0	62.9	129.7
14	12	1 – 7	50,000	8,000	224,000	1545	25% North / 75% West	107.0	62.9	129.7
15	13	1 – 7	50,000	8,000	224,000	1545	50% North / 50% West	107.0	62.9	129.7
16	14	1 – 7	50,000	8,000	224,000	1545	75% North / 25% West	107.0	62.9	129.7

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description: 1 Pumps 1-3

Run # 1 Notes by: RUBG Date / Time: 6/28/16

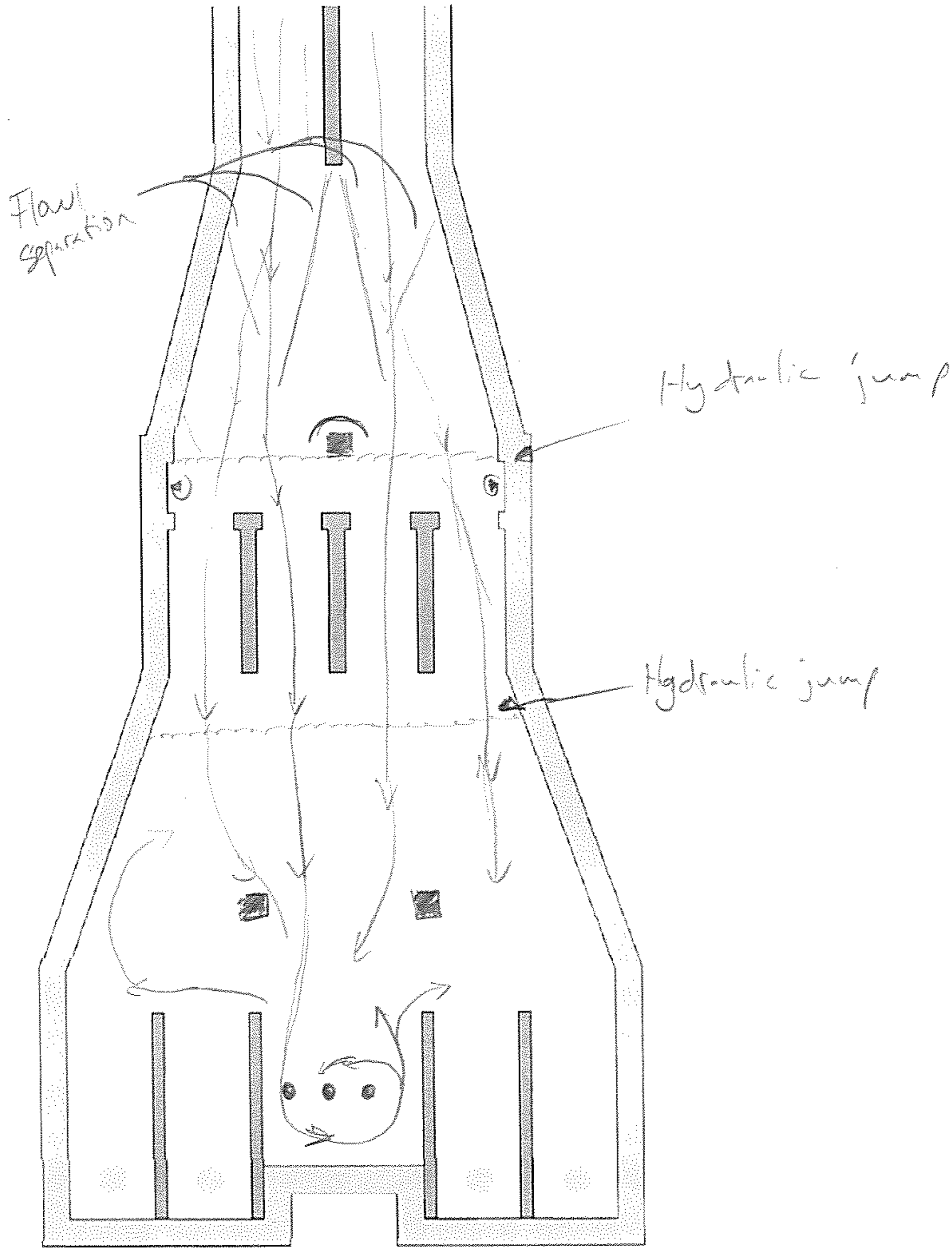


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 1 pumps 1-3

Run # 1 Notes by: RSG Date / Time: 6/28/16

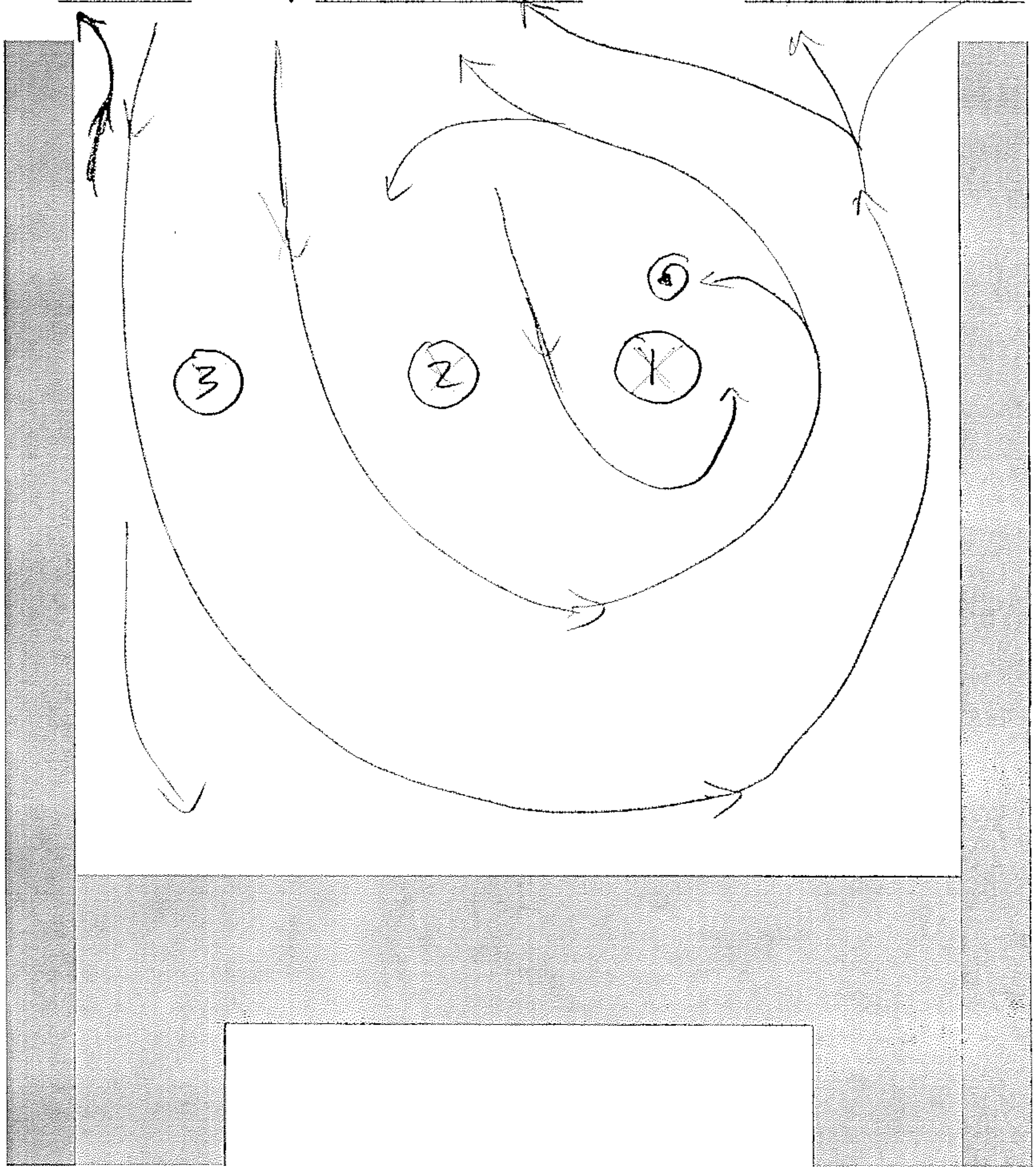


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description 1 Pumps 1-3

Run # 1 Notes by: RobG Date / Time: 6/28/16



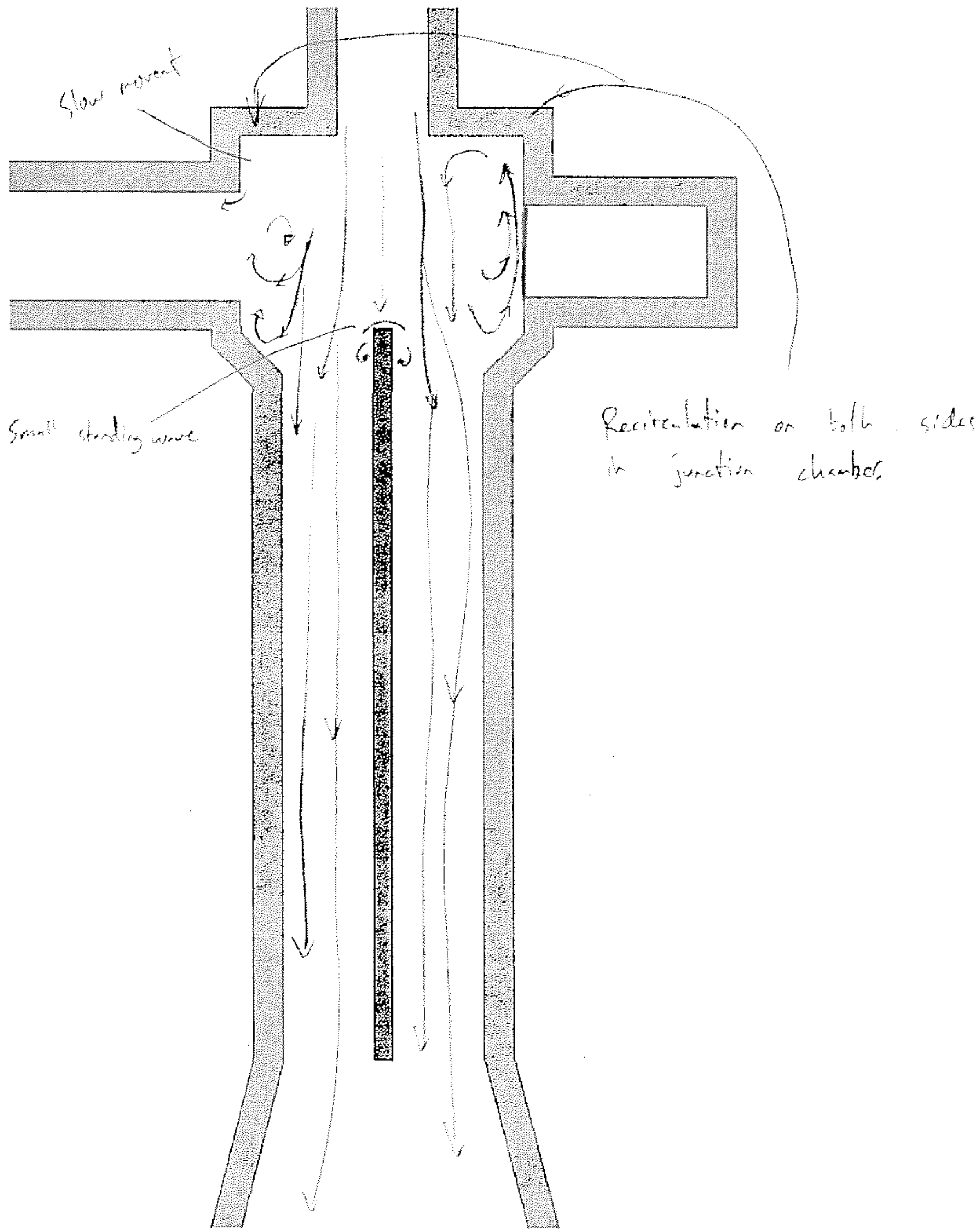
Swirl u.s. of pump #1 developing into an air core to the opening when at its worst.

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 2 pump 4 (40,000 gpm)

Run # 1 Notes by: ROB G Date / Time: ____________

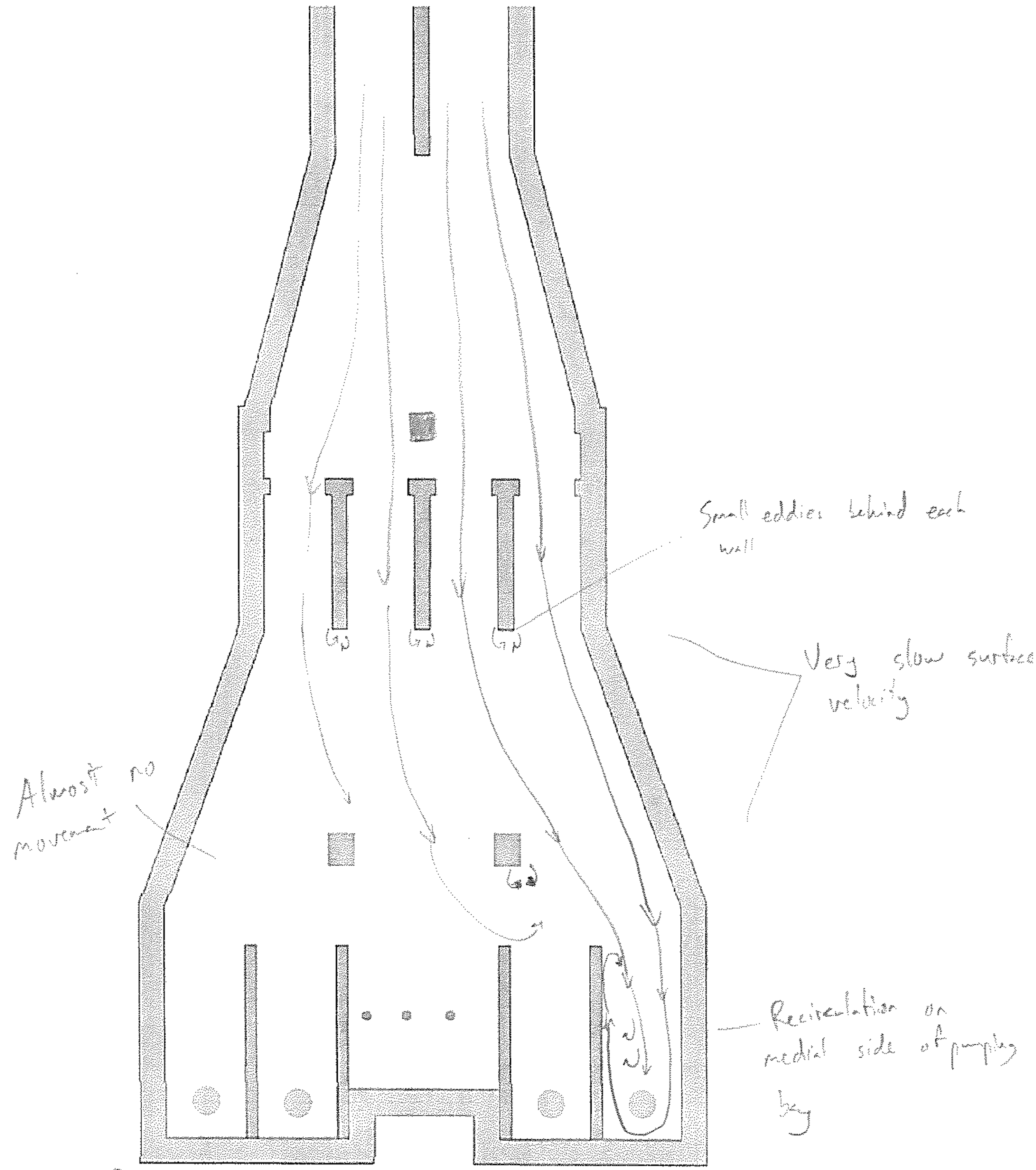


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 2 pump 4 (40,000 gpm)

Run # 1 Notes by: RobCa Date / Time:



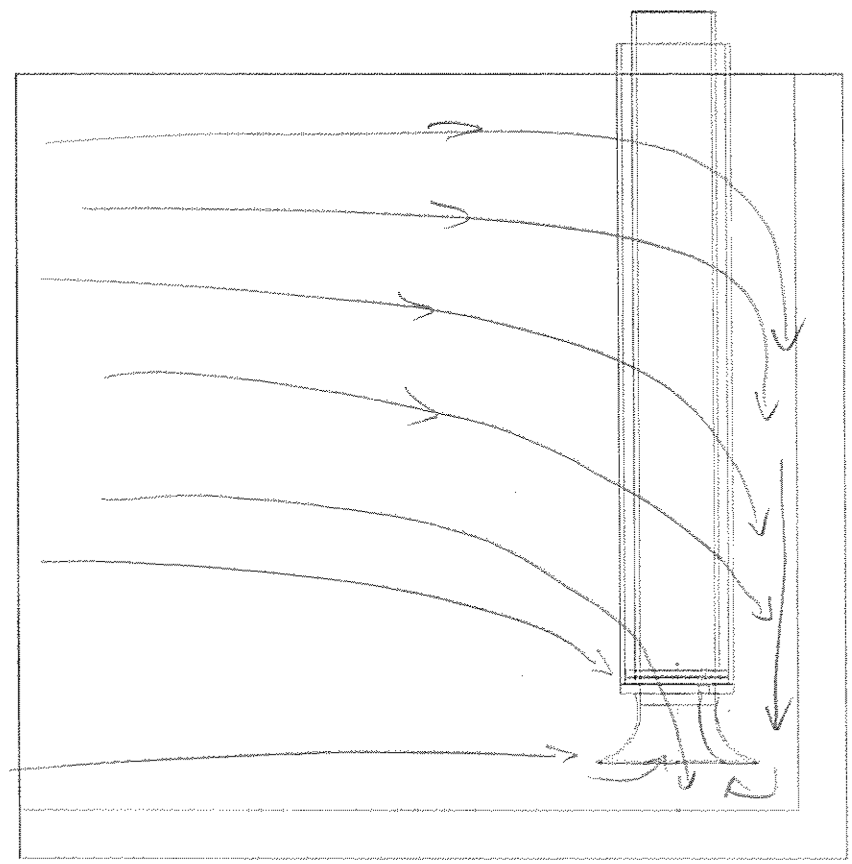
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 2 40K gpm Bay 4

Run # 1 Notes by: RoBG Date / Time:

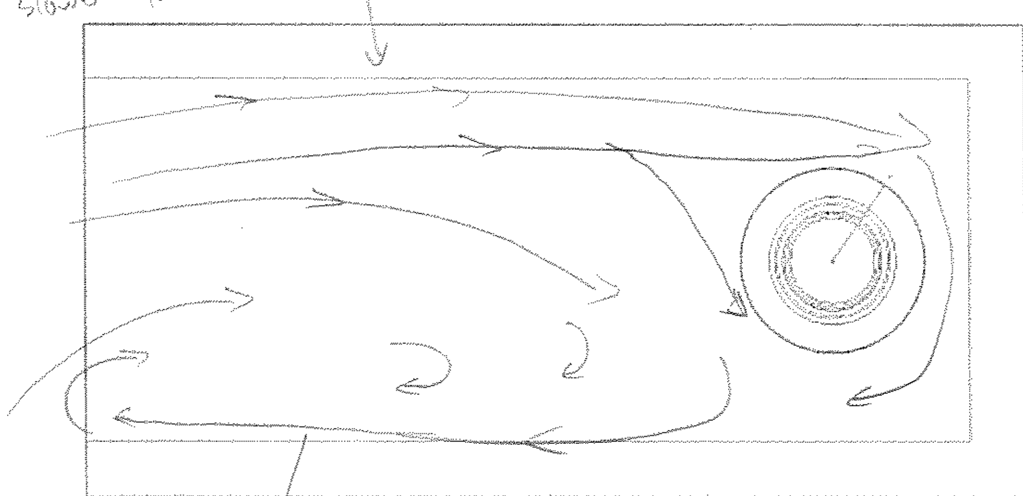
TOP



Flow goes to the back then down to the bell mouth.

Flow on outside edge much slower than inside wall edge

SIDE



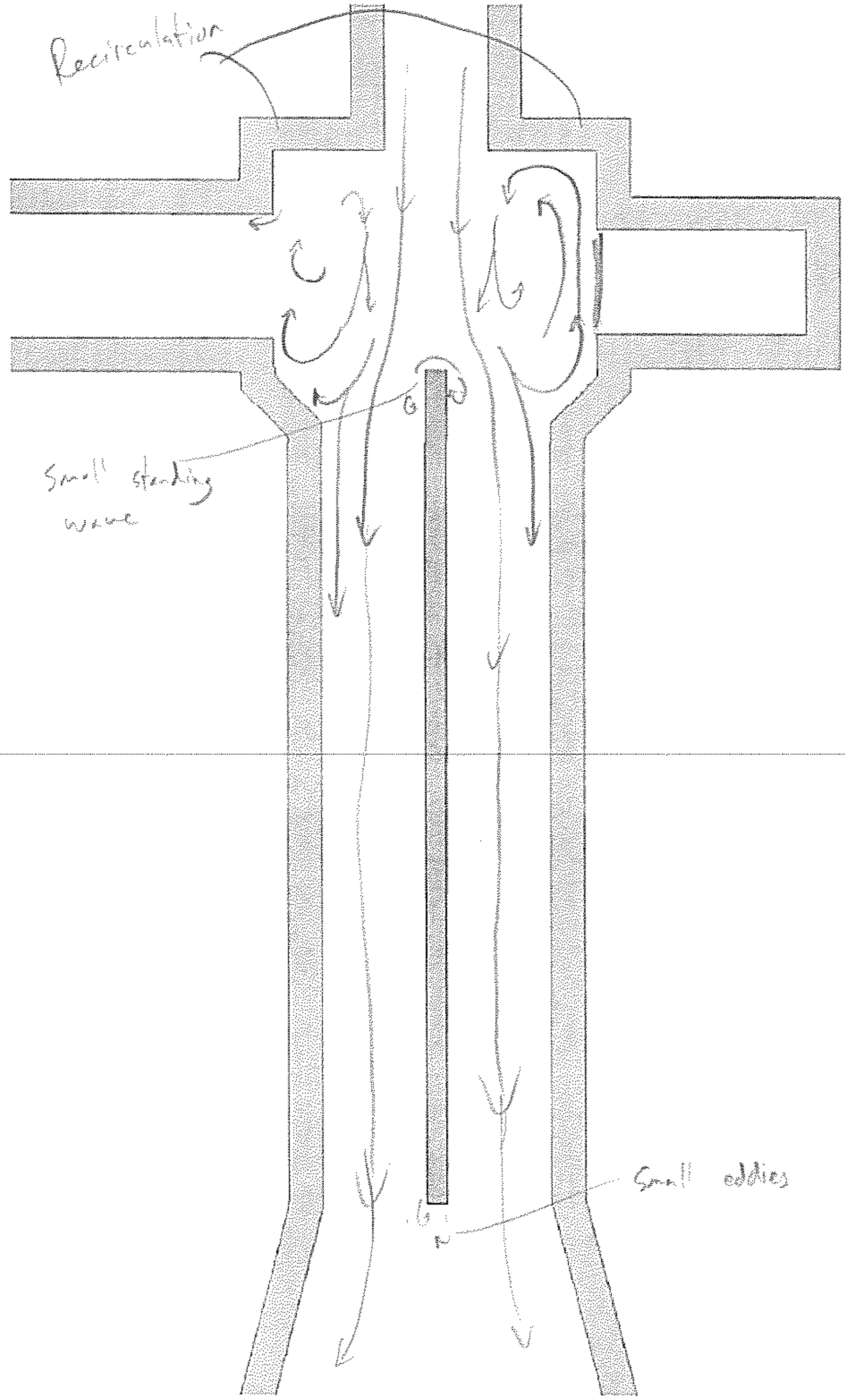
Strong recirculation on medial edge wall.

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 2A pump 4 (50,000 gpm)

Run # 1 Notes by: RoBG Date / Time:

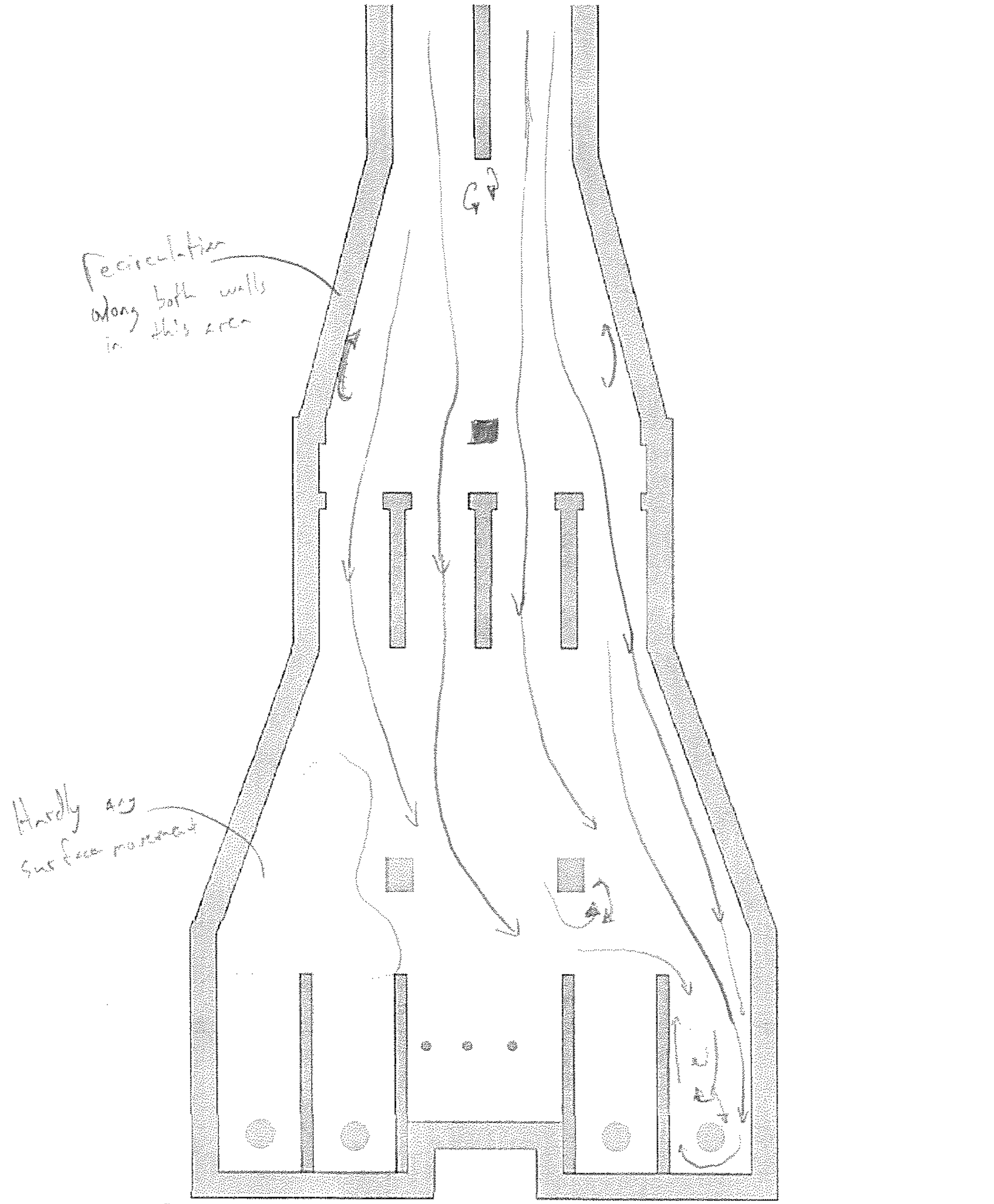


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 2A pump 4 (50,000 gpm)

Run # 1 Notes by: RobG Date / Time:



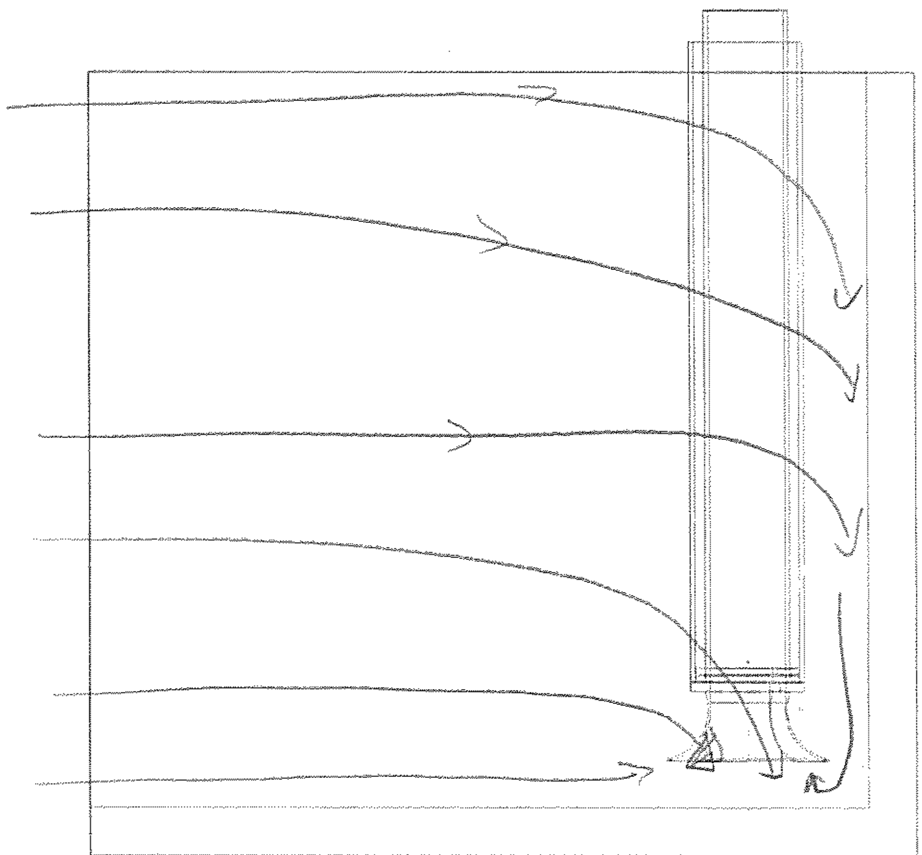
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 2A 50K gpm Bay 4

Run # 1 Notes by: Rob G Date / Time:

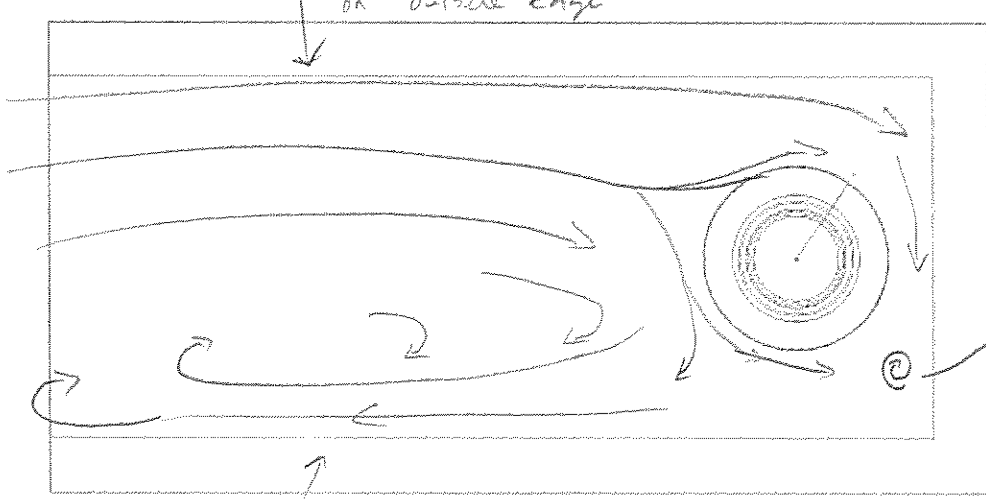
TOP



Water goes to backwall first then travels down to pump opening.

SIDE

slower movement on outside edge



Some type 3 surface swirl but limited in duration

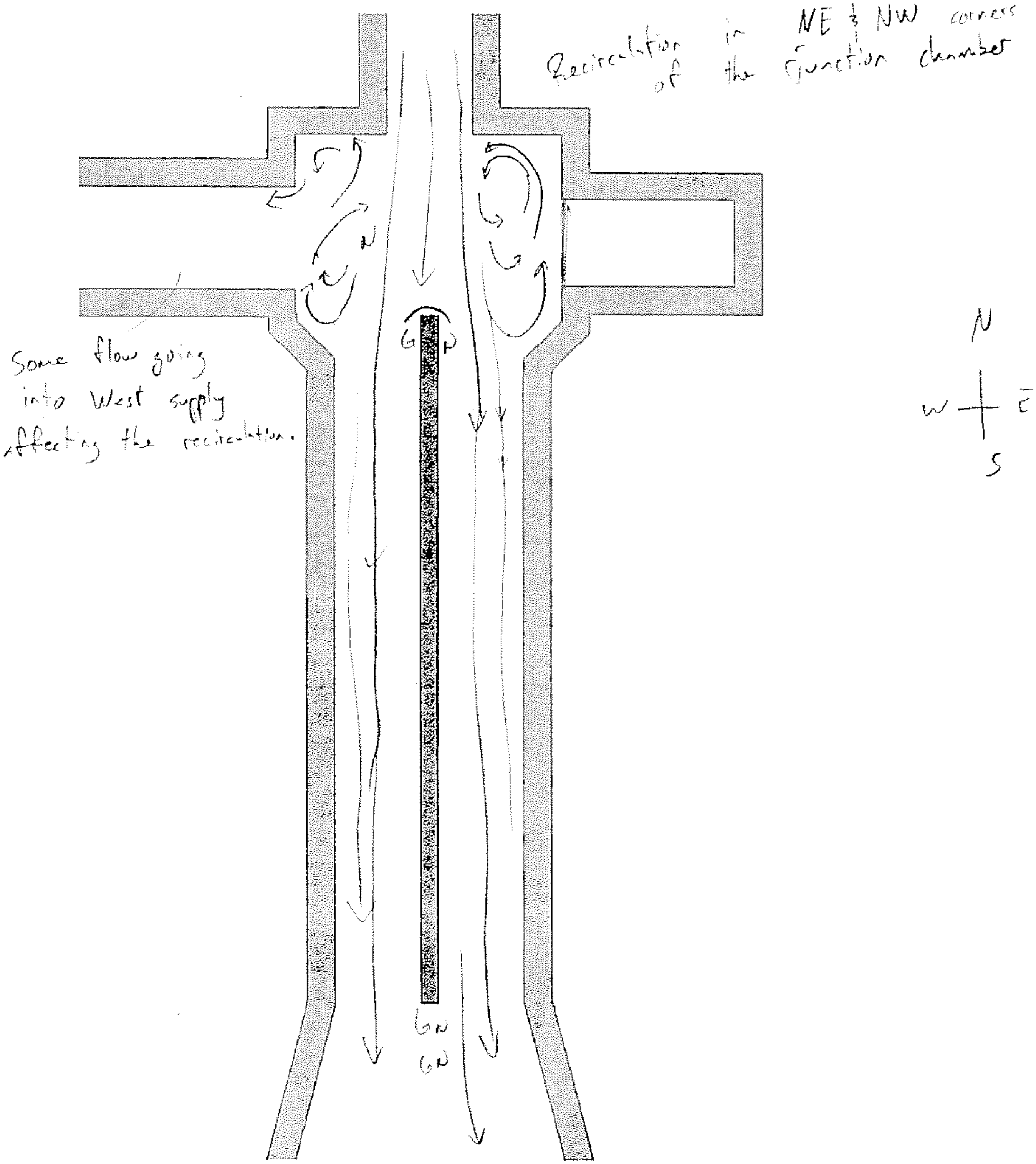
Fast and strong recirculation on inside edge.

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description: 3 Pump 5 50 000 gpm

Run #: 1 Notes by: Rob G Date / Time: ______

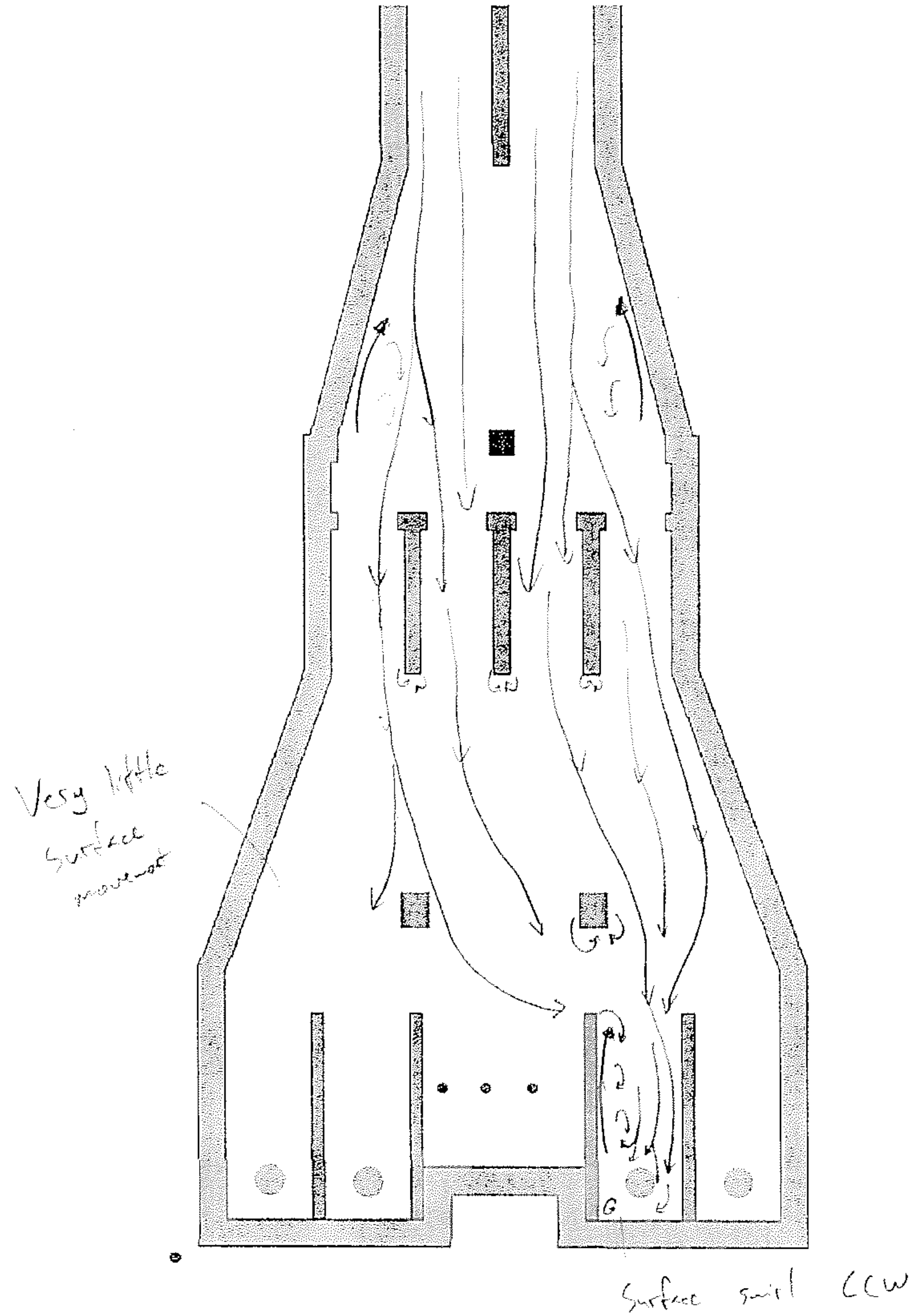


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 3 Pump 5 50,000 gpm

Run # 1 Notes by: Bob G Date / Time: ______



Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

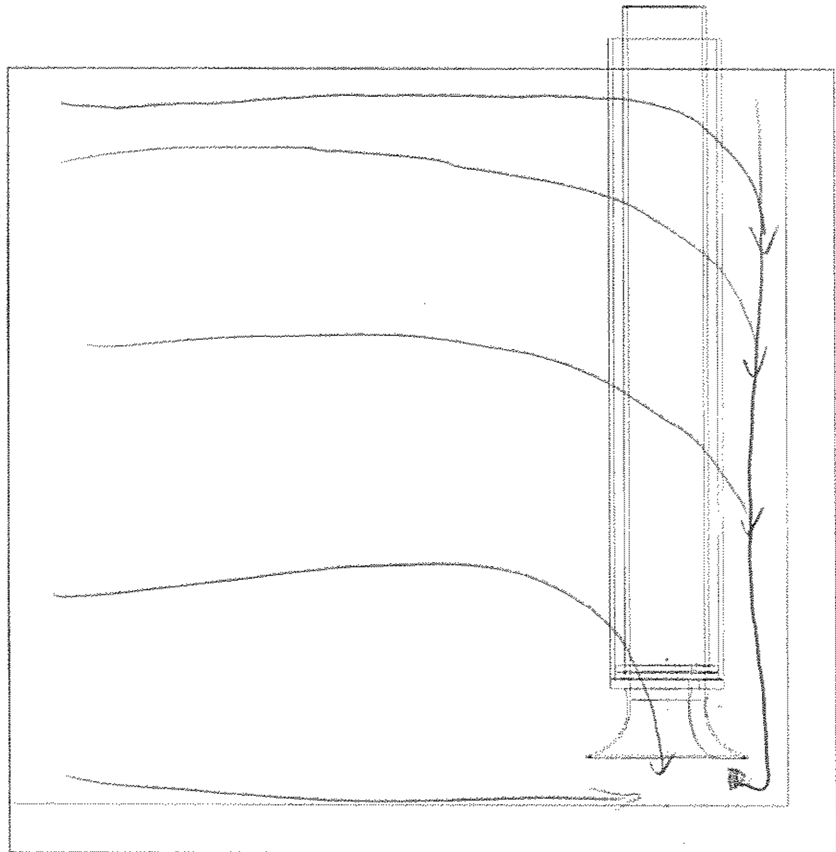
Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 3 pump 5 50K gpm Bay 5

Run # 1 Notes by: [illegible] Date / Time:

TOP

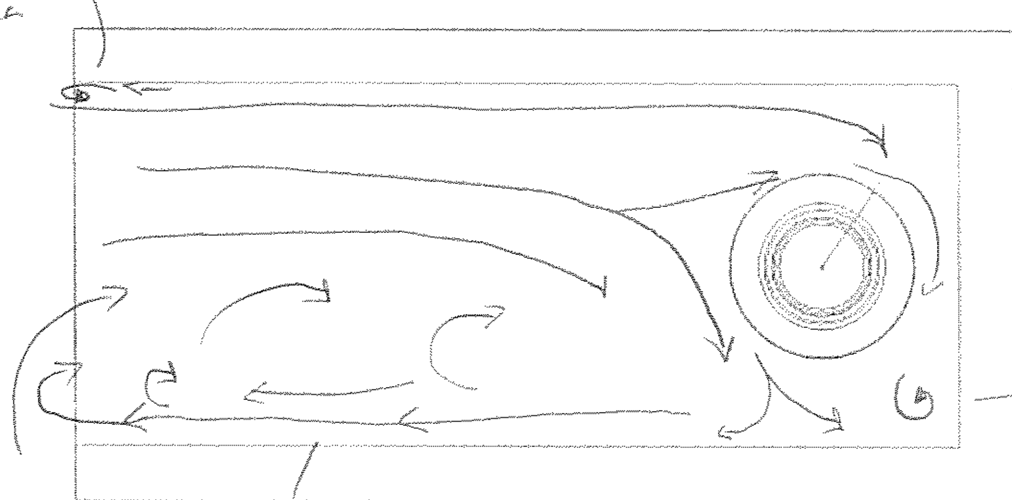
* Note: Not sure if pulling confetti constitutes as type 4 swirl since it occasionally is pulled down without surface swirl.



Water goes to back of pumping bay before going to floor and pump opening.

SIDE

Small recirculation area



CCW swirl pull down confetti intermittent type swirl

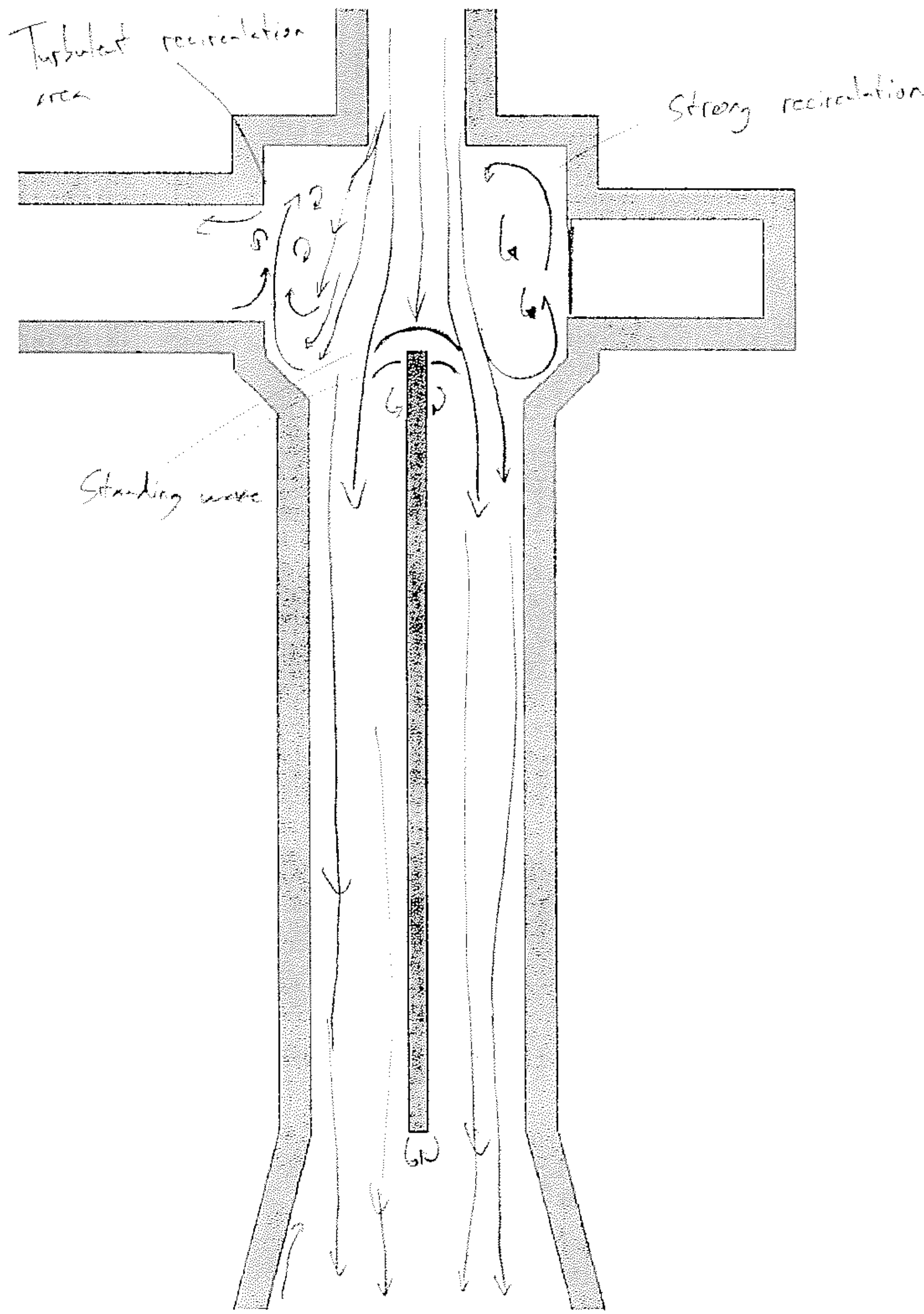
Strong recirculation on inside edge

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 4 Pumps 4 ; 5 100,000 gpm tot'l

Run # 1 Notes by: Rob G Date / Time: ____________

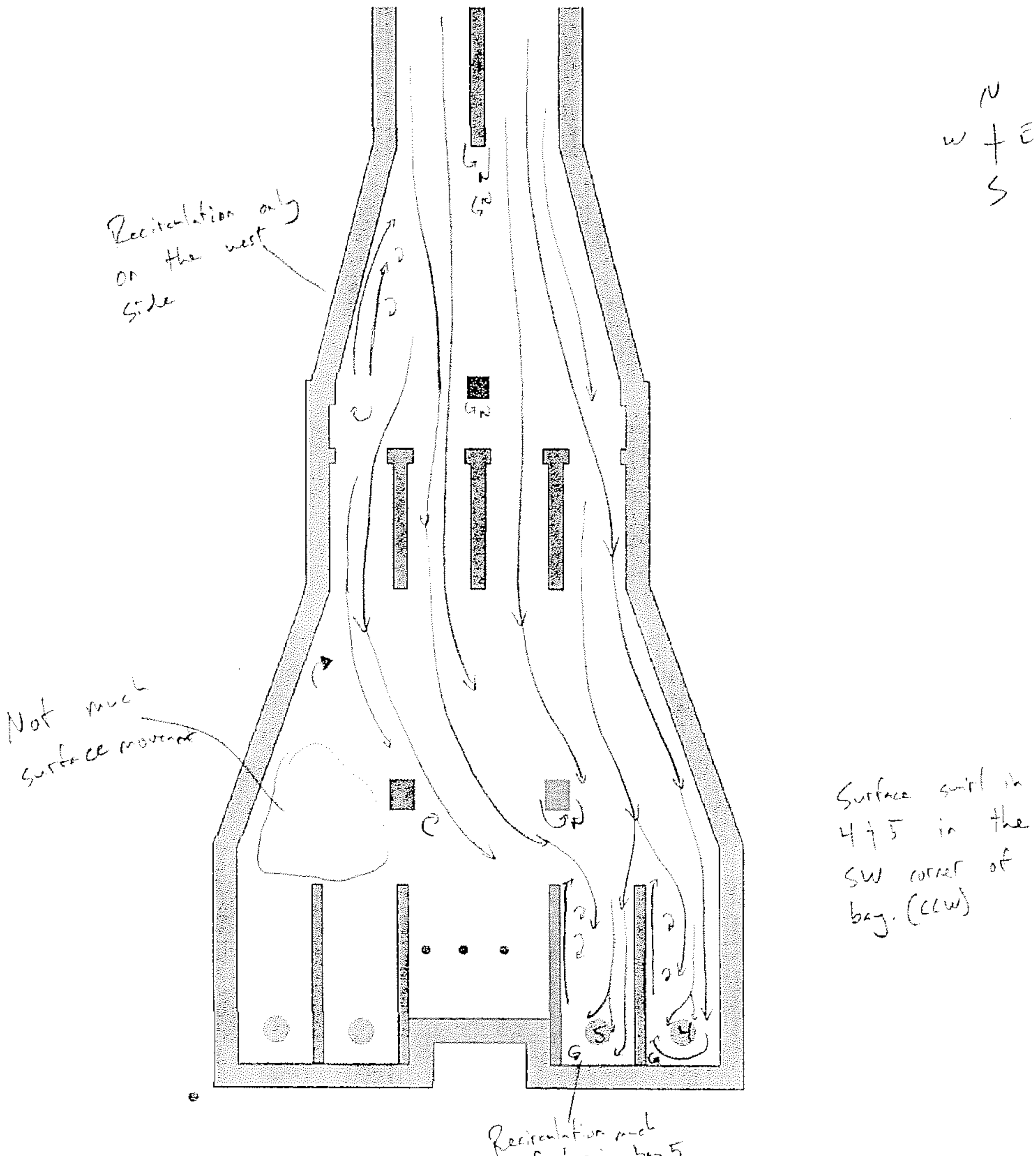


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 4 Pumps 4 & 5 100,000 gpm total

Run # 1 Notes by: RobG Date / Time: ______



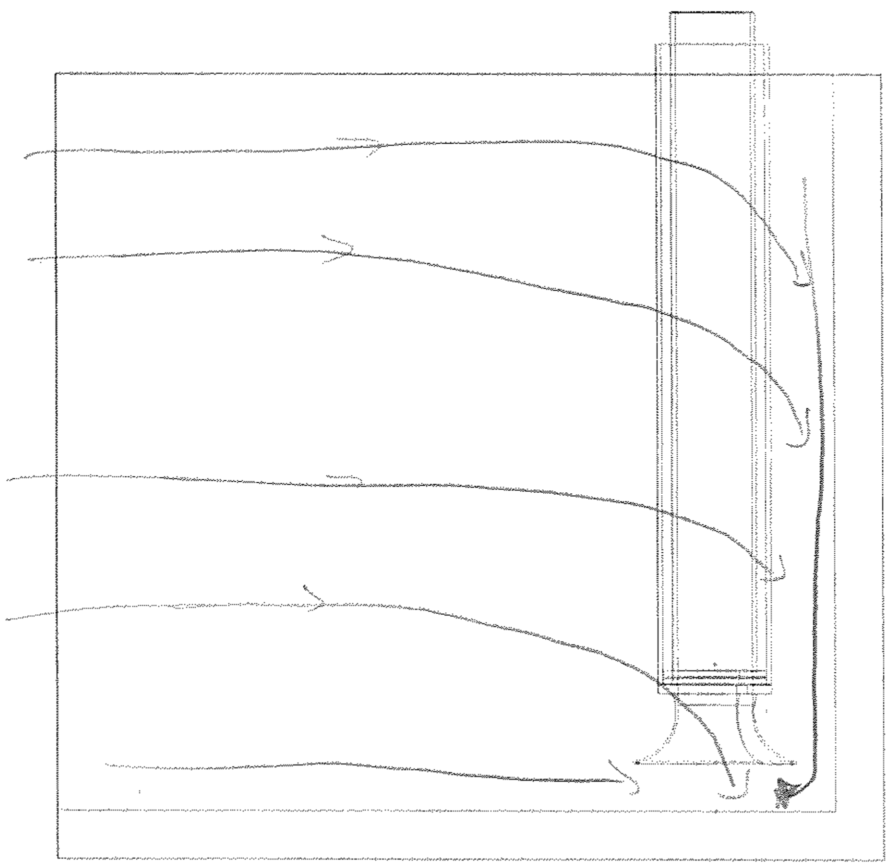
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

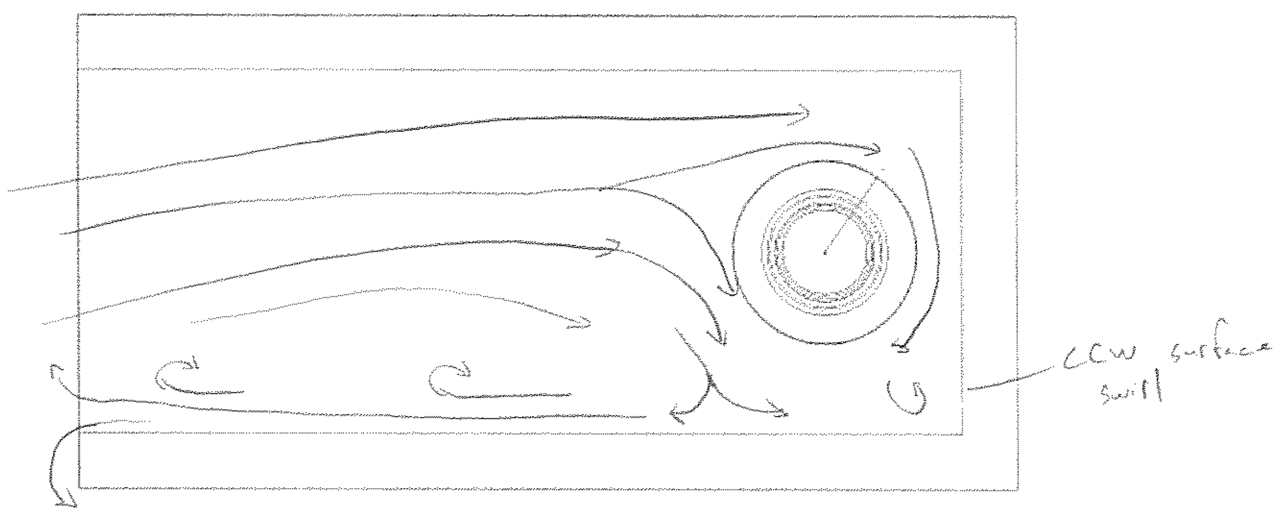
Scenario # and Description 4 Pumps 4 & 5 Bay 4

Run # 1 Notes by: RoBG Date / Time: ______

TOP



SIDE



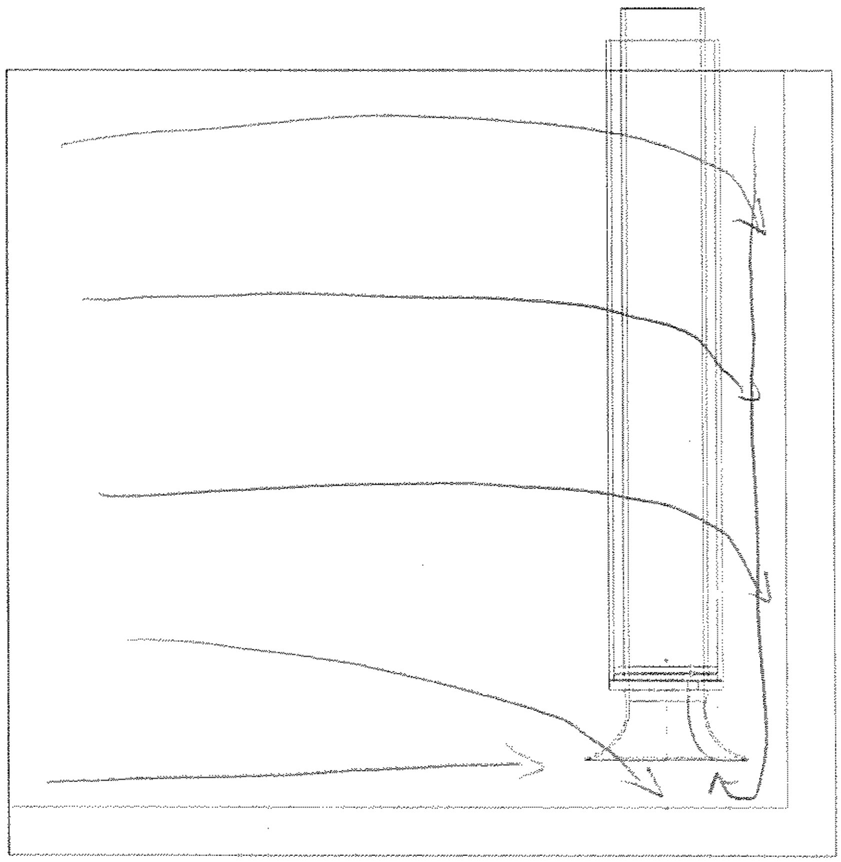
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

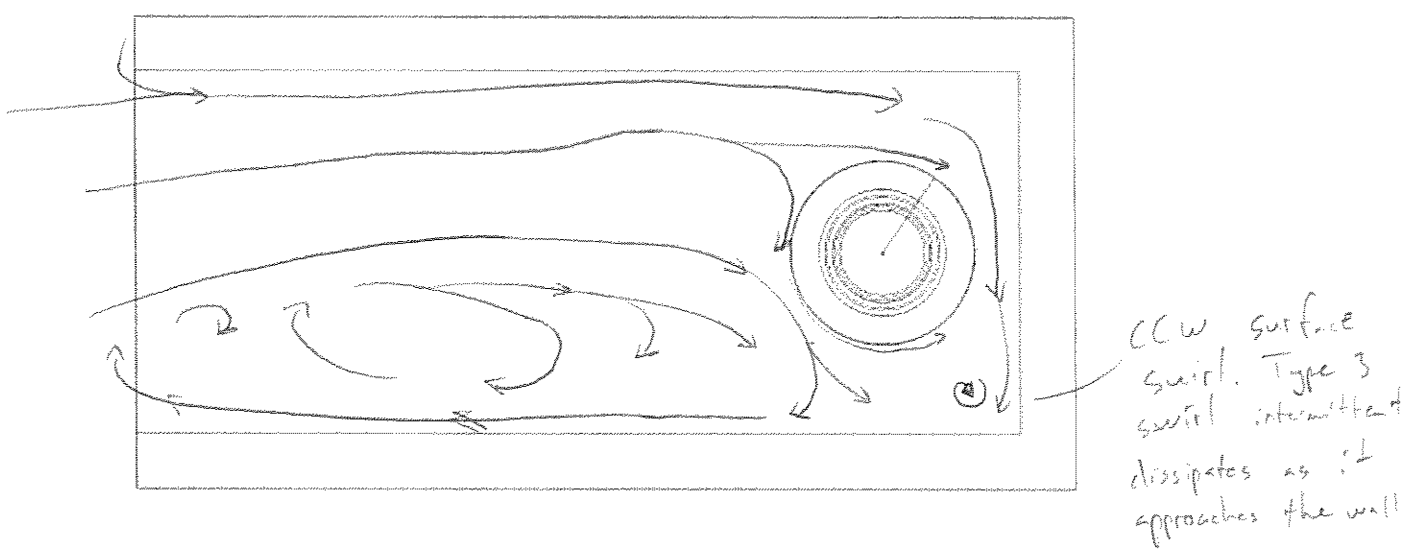
Scenario # and Description 4 Pumps 4 & 5 Bay 5

Run # 1 Notes by: Rob G Date / Time:

TOP



SIDE

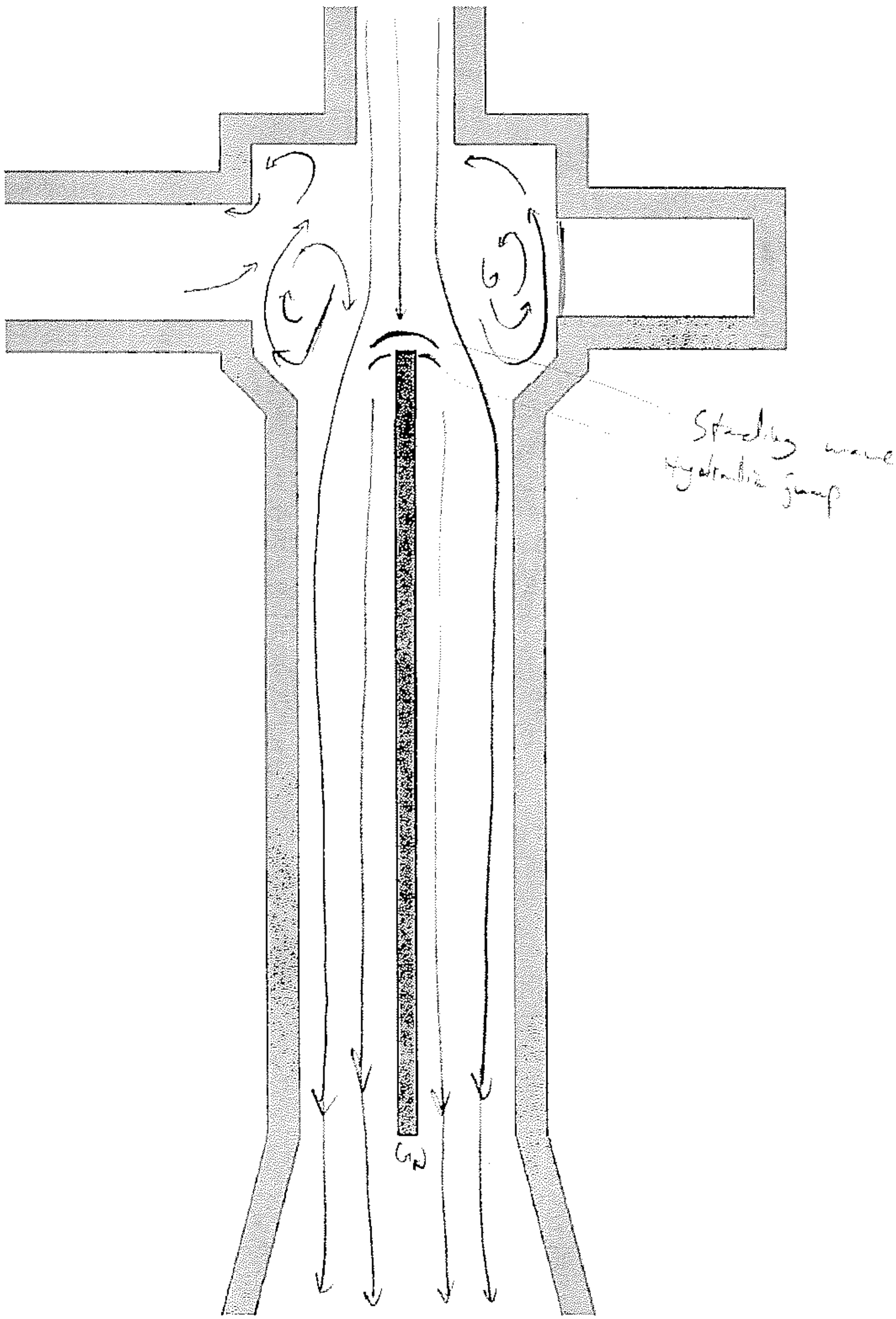


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 5 pumps 4 & 6 100,000 gpm total

Run # 1 Notes by: RobG Date / Time:

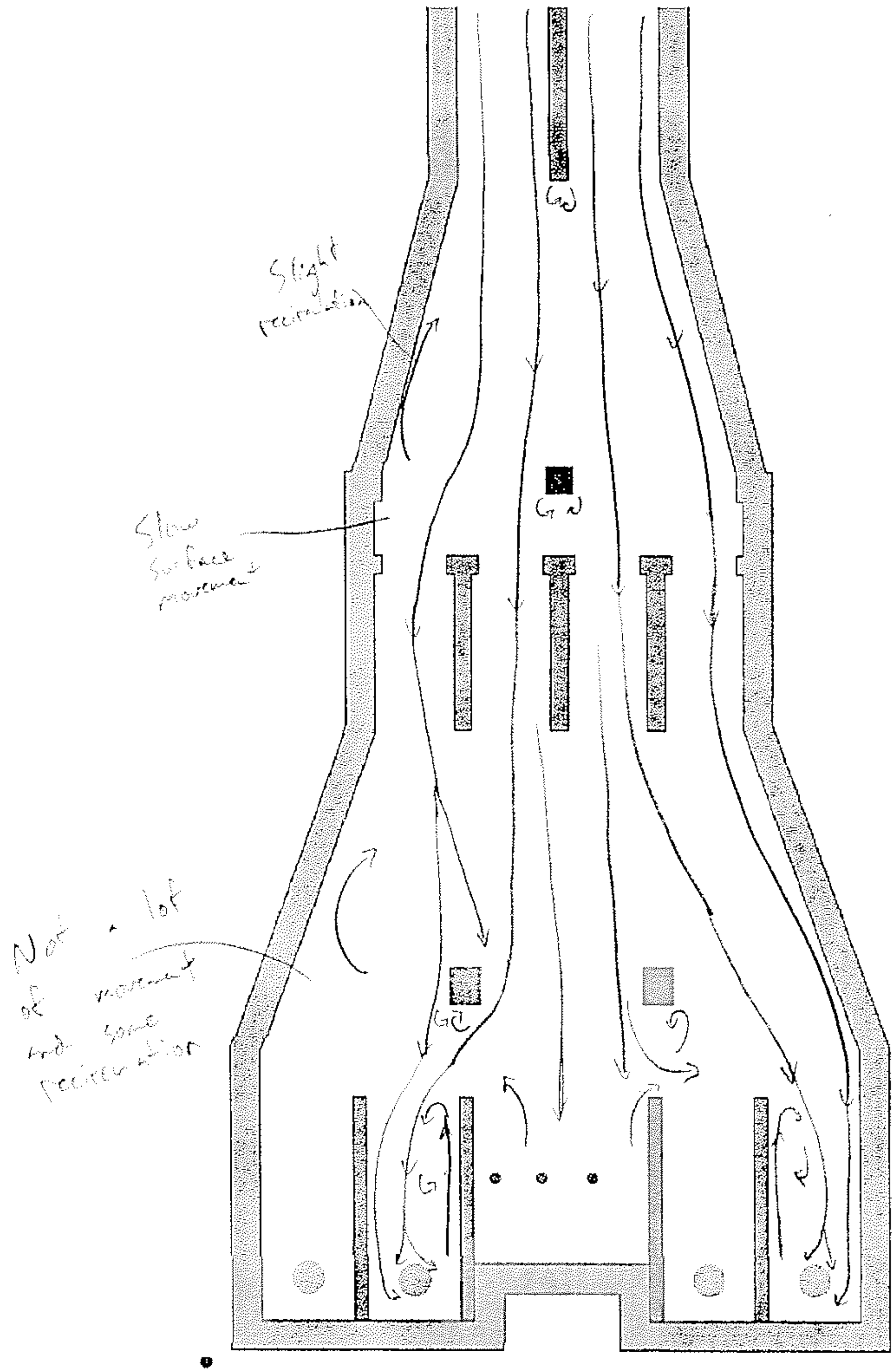


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 5 pumps 4 & 6 100 gpm bhl

Run # 1 Notes by: RoBG Date / Time: ______



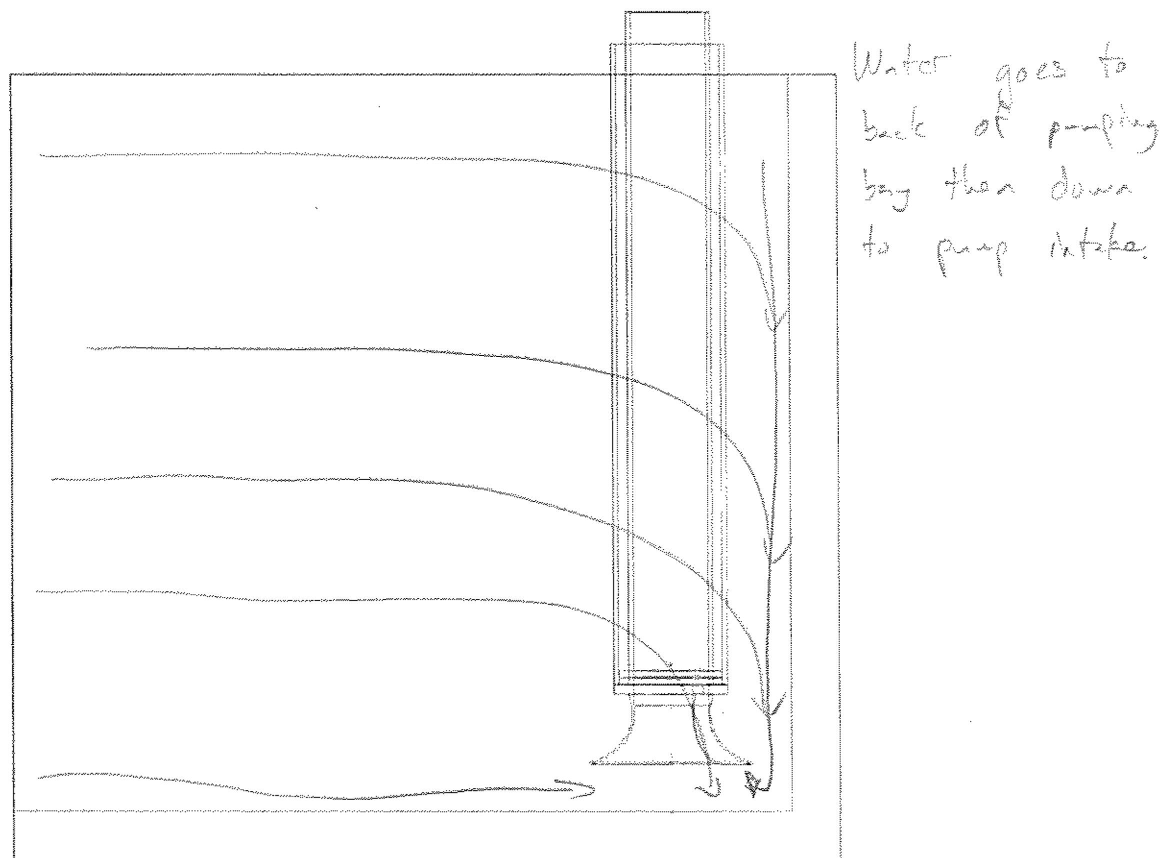
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

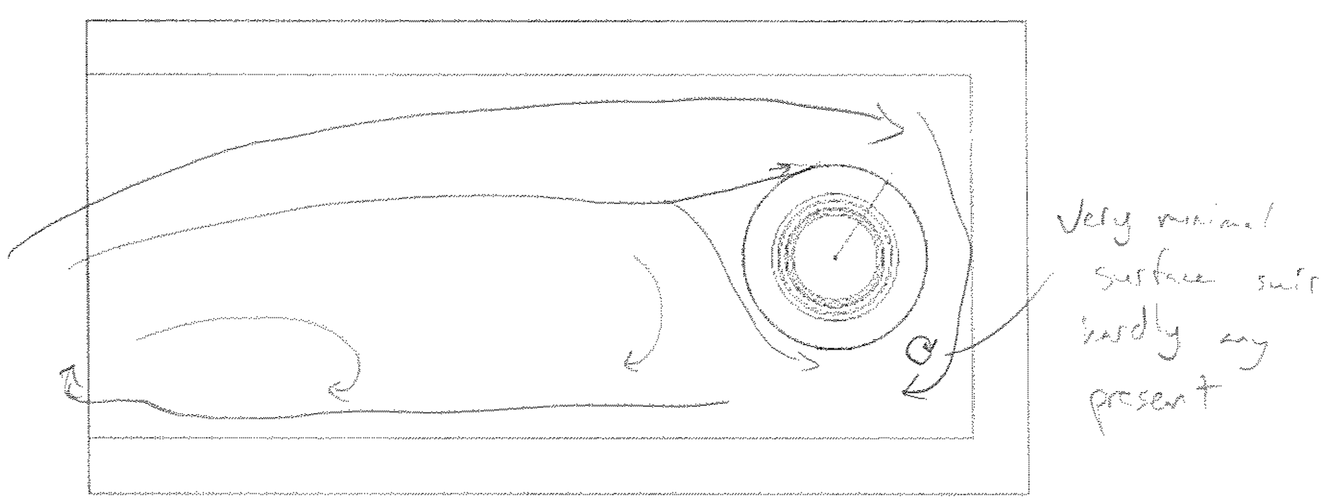
Scenario # and Description 5 Pumps 4 & 6 Bay 4

Run # ______ Notes by: RoBG Date / Time: ______

TOP



SIDE



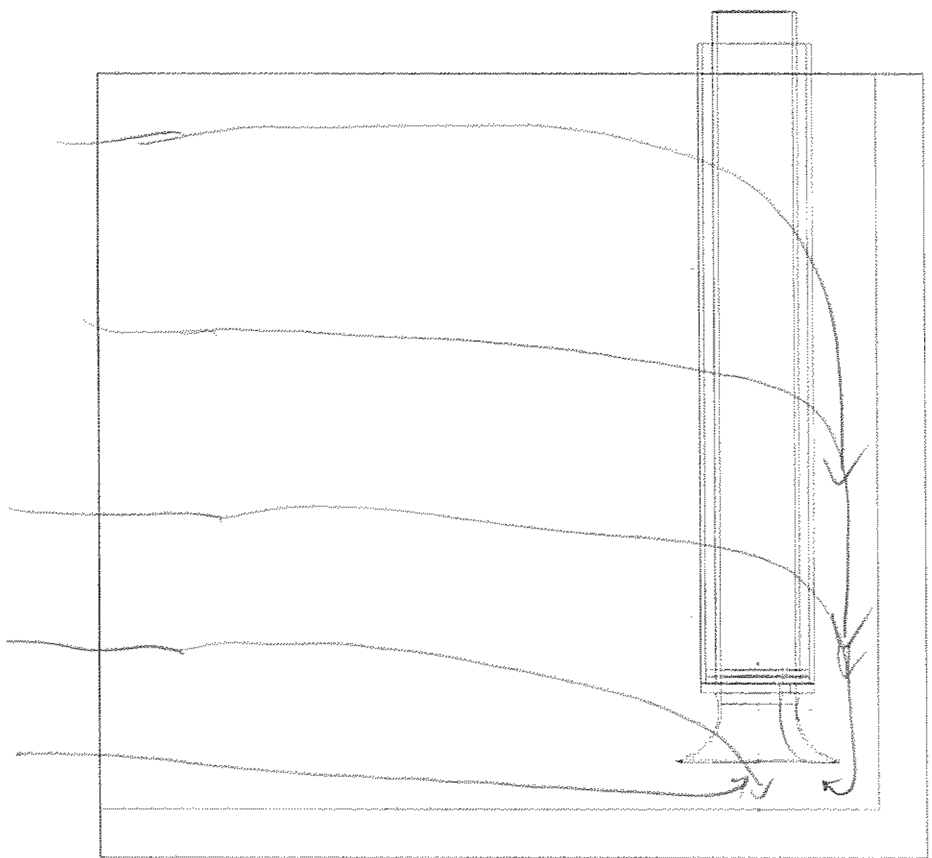
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 5 Pumps 4 & 6 Bay 6

Run # ______ Notes by: Rob G Date / Time: ______

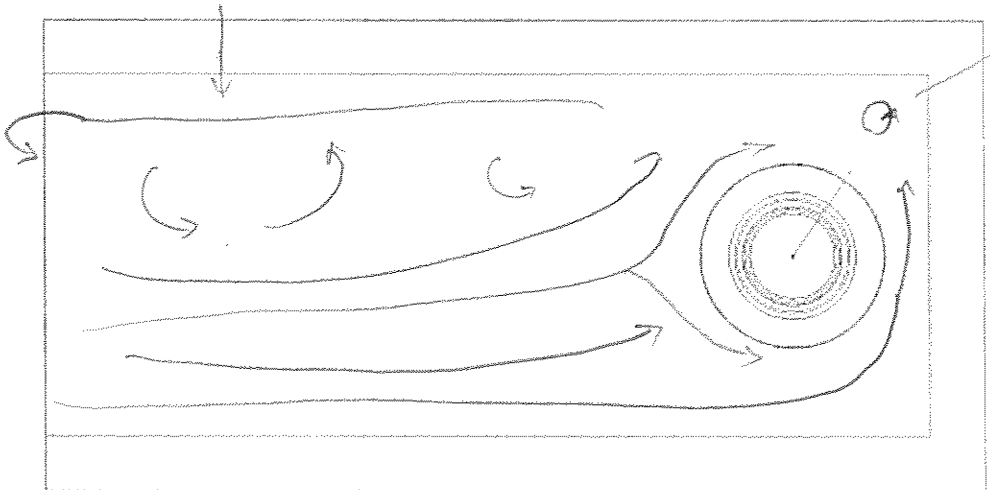
TOP



Water goes to the back of the bay and gets pulled down to intake

Strong recirculation

SIDE



up to type 3 surface swirl that seems relatively consistent

0:41 seconds of Dye core over 3:32 video time.

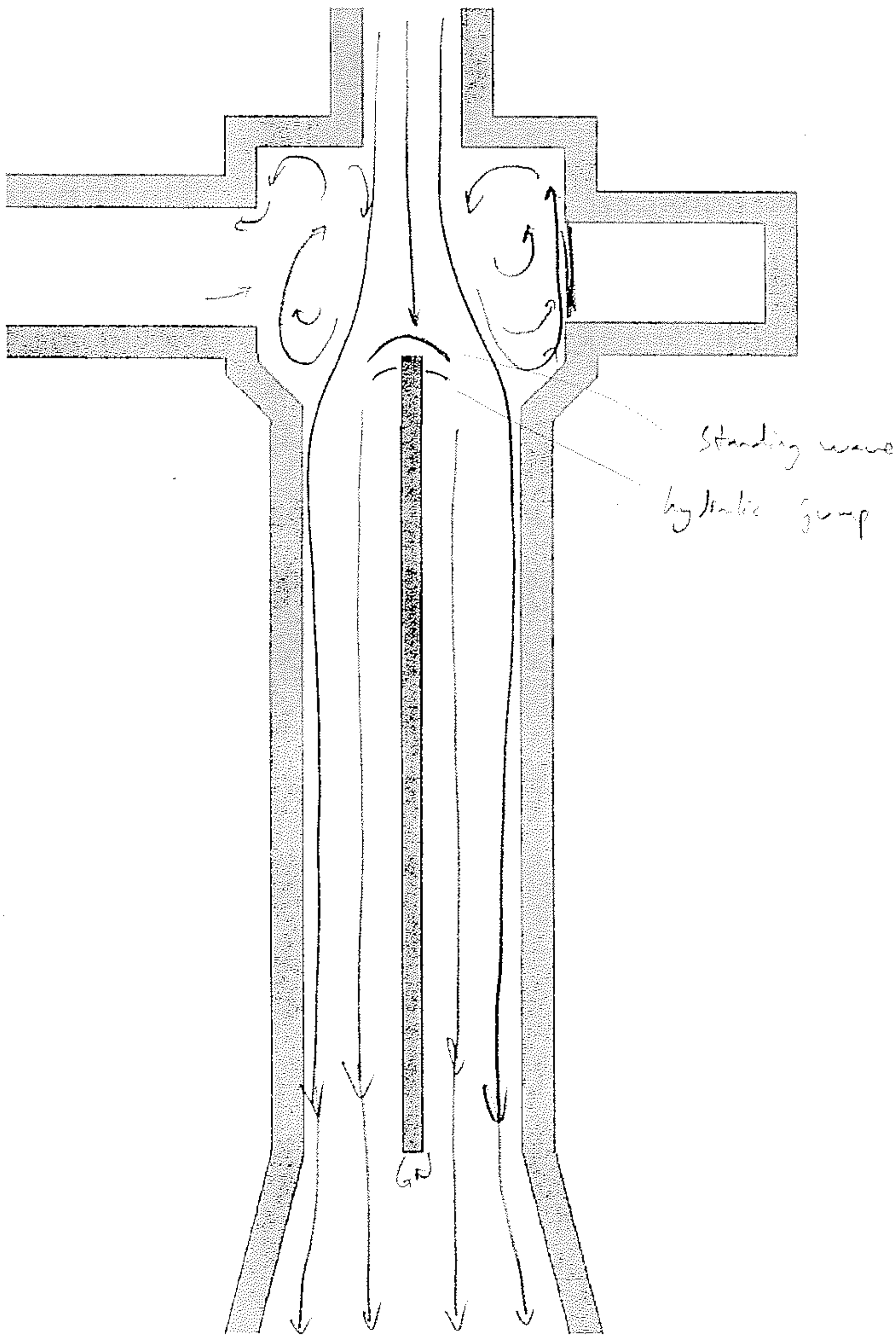
~20%

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 6 Pumps 4;7

Run # 1 Notes by: Rozg Date / Time:

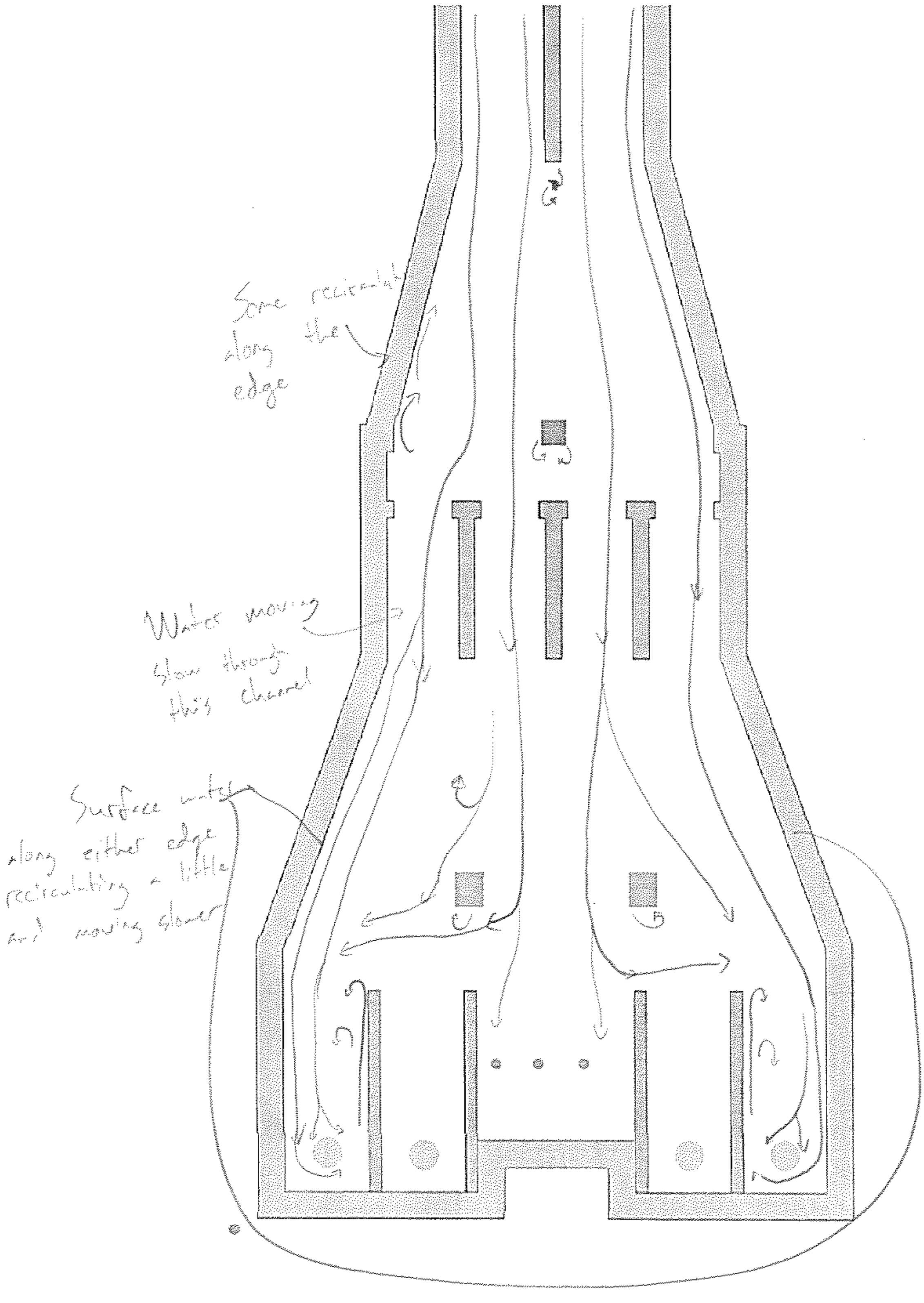


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 6 Pumps 4 & 7

Run # 1 Notes by: RobG Date / Time:



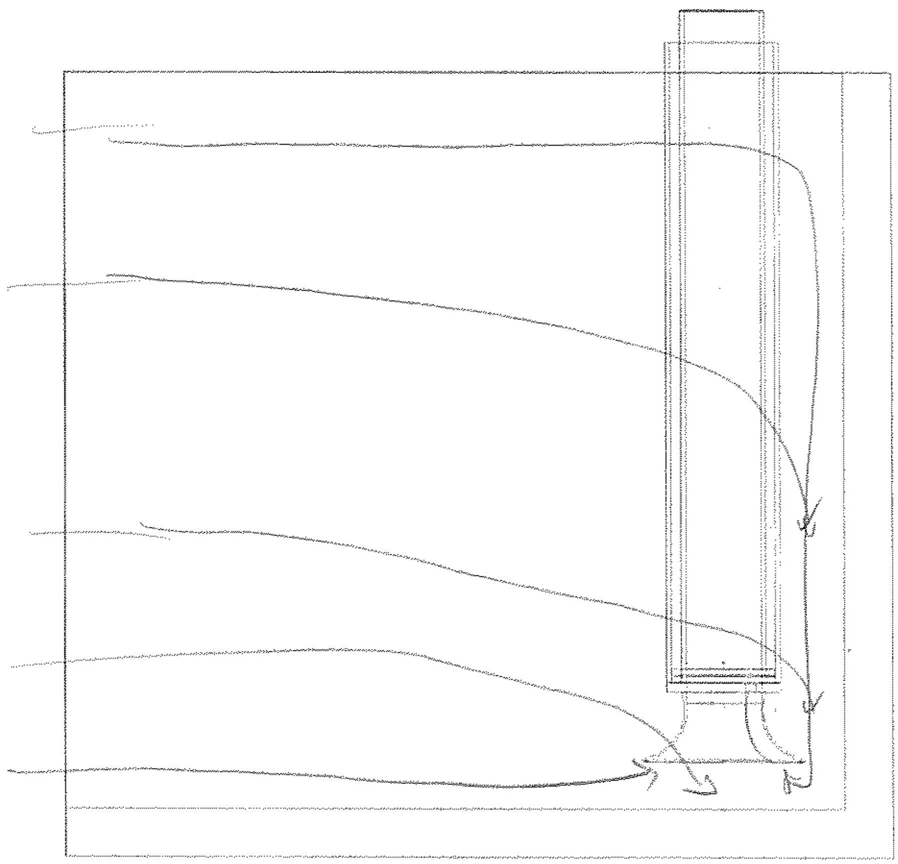
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

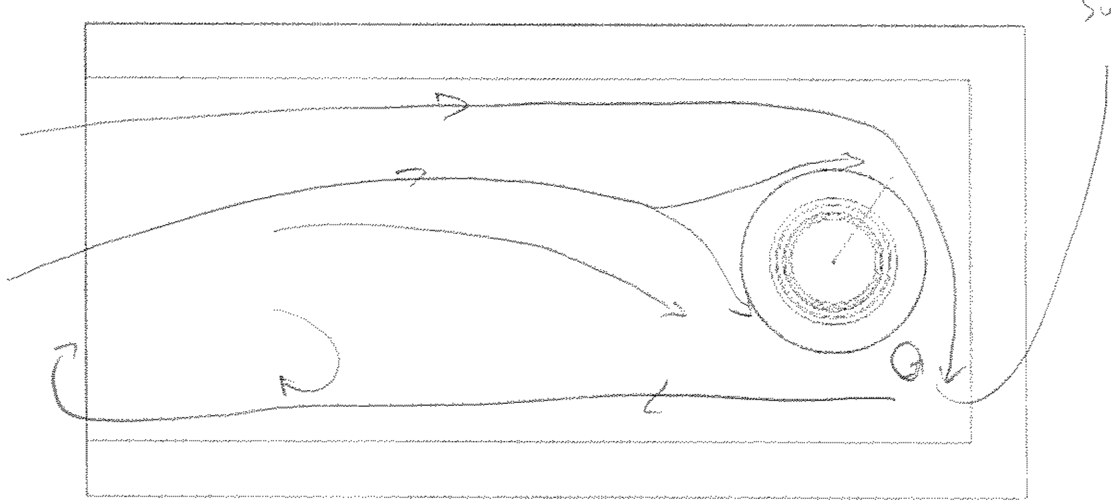
Scenario # and Description 6 Pump 4+7 Bay 4

Run # 1 Notes by: Bob G. Date / Time:

TOP



SIDE



Surface swirl developing into type 3 but for a short time

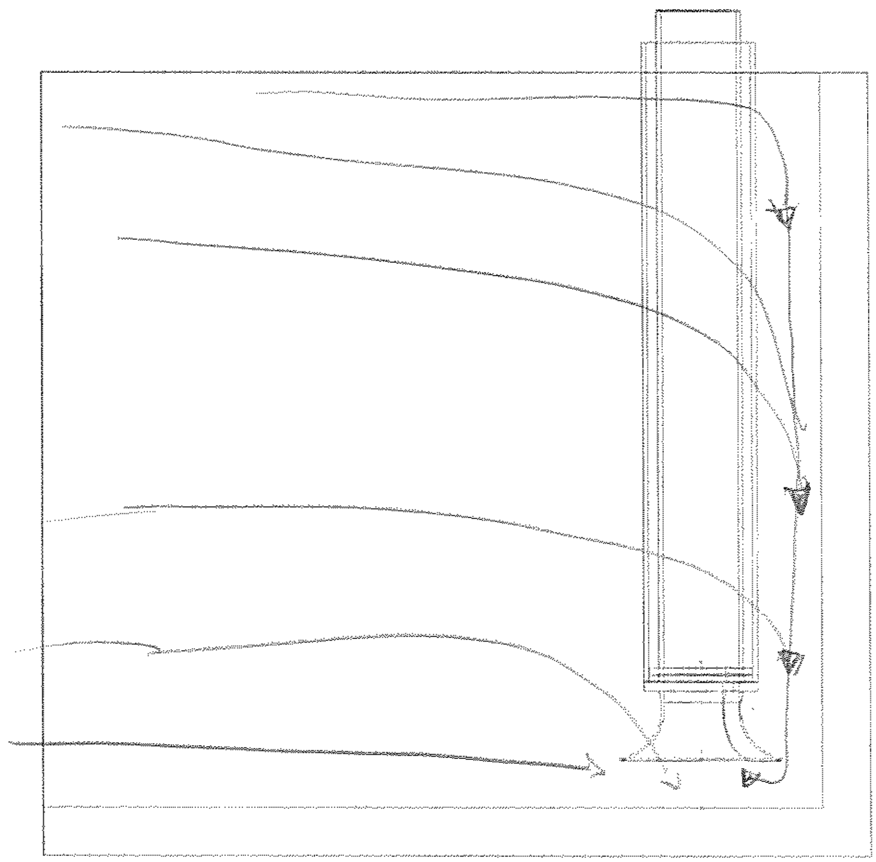
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

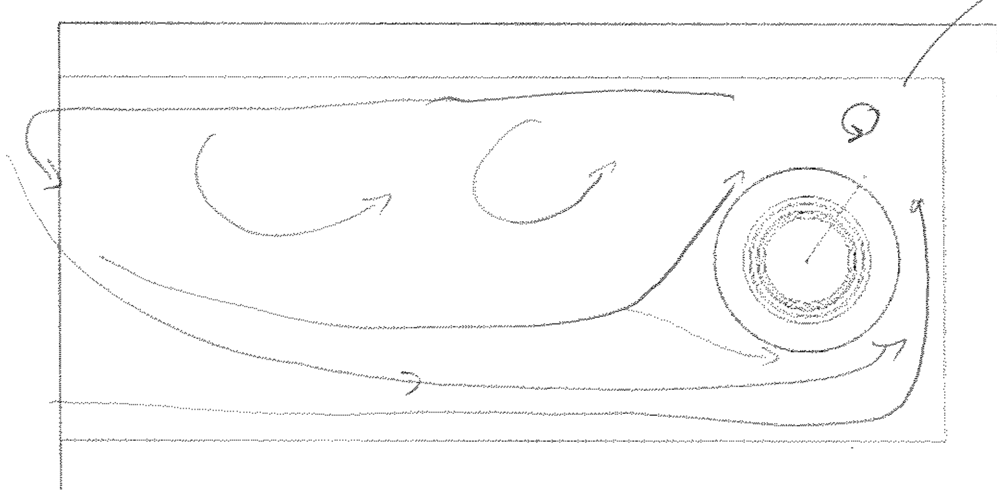
Scenario # and Description: 6 Pumps 4 & 7 Bay: 7

Run #: 1 Notes by: RSG Date / Time: ______

TOP



SIDE



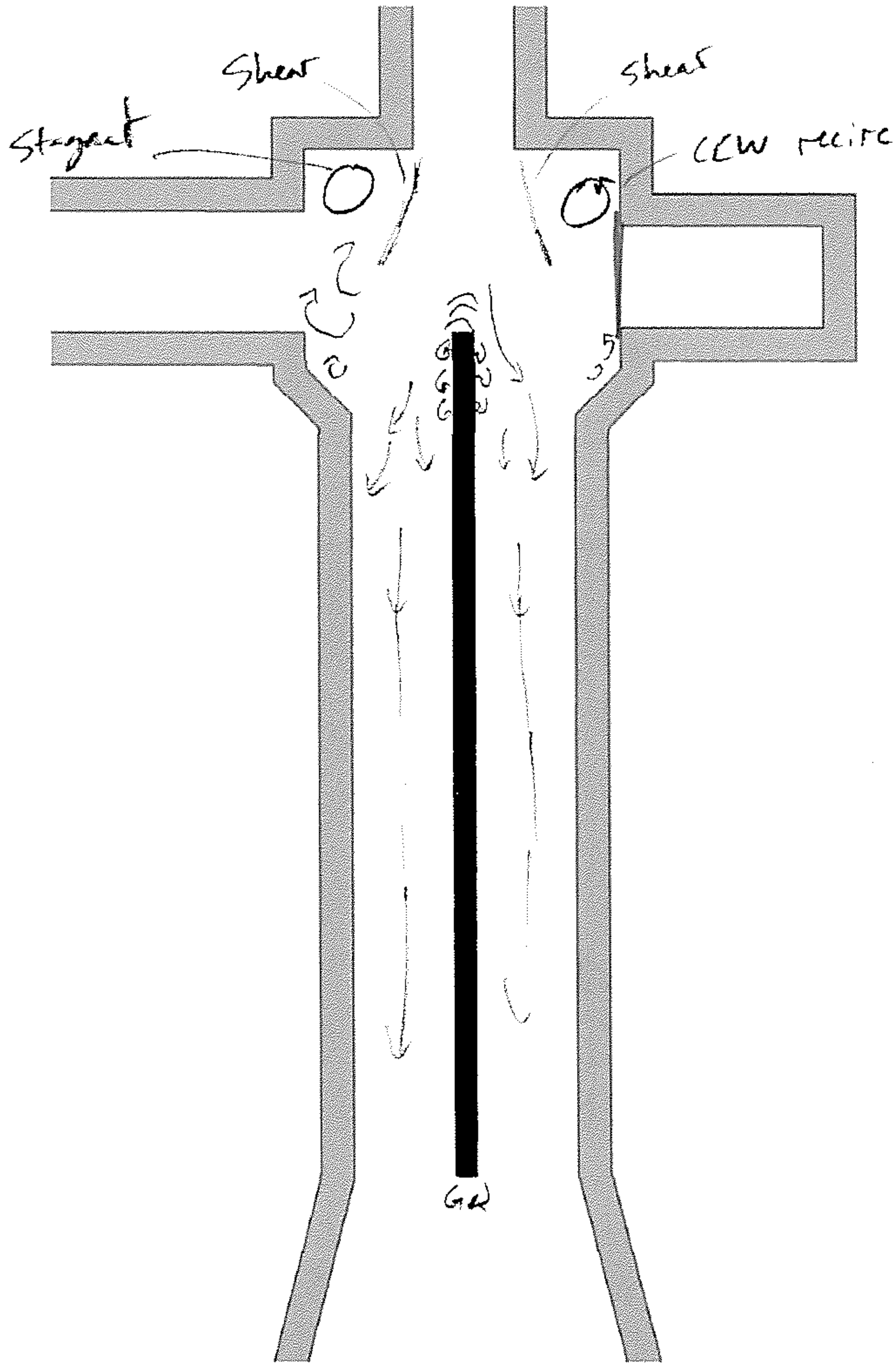
Some surface swirl but does not develop into a type 3.

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 7 pumps 1-4

Run # 1 Notes by: RSG Date / Time: 6/17/16

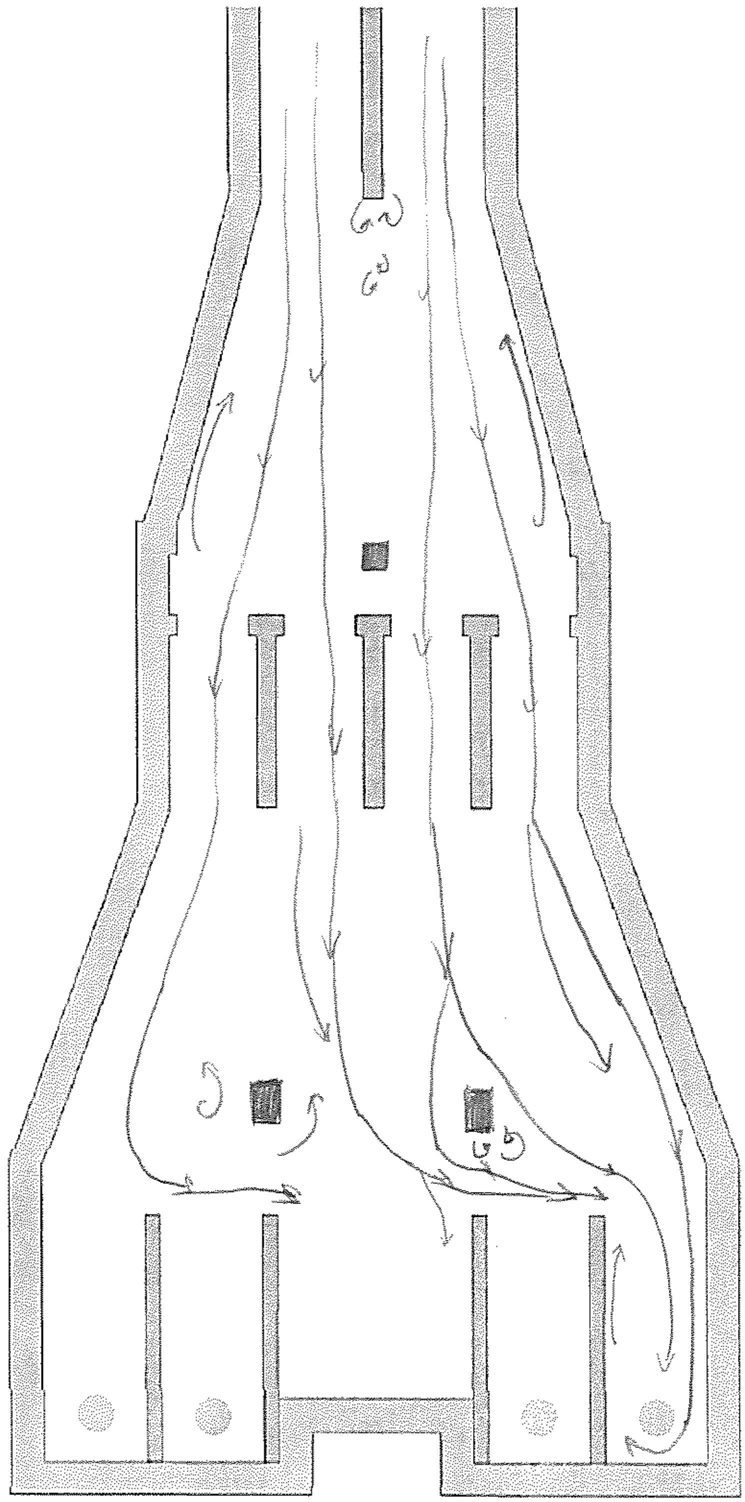


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 7 pumps 1-4

Run # 6 Notes by: BoRG Date / Time: 7/8/16

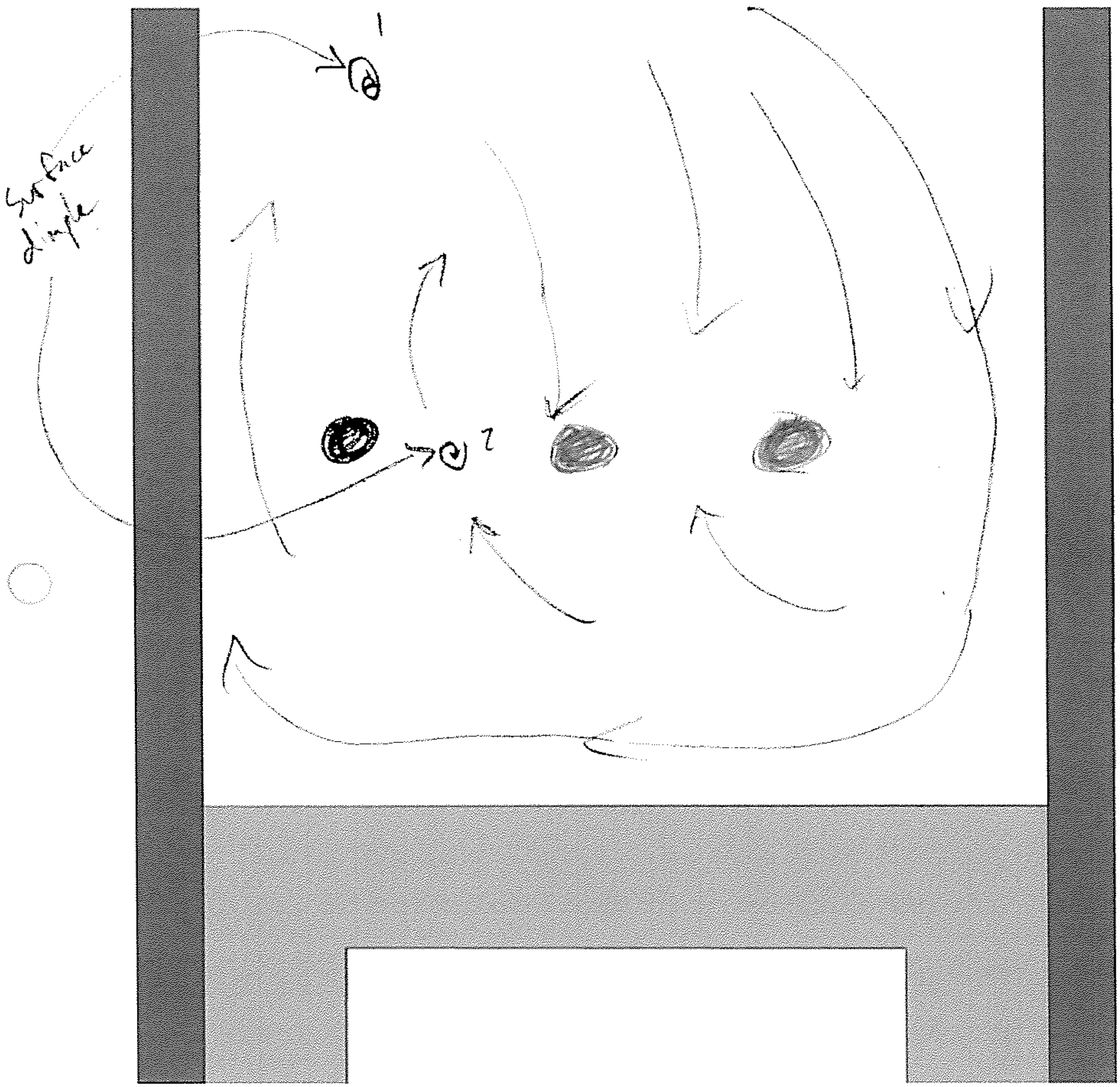


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description 7 Pumps 1-4

Run # 1 Notes by: RSG / MEL Date / Time: 6/17 10:44



Surface dimple #1 is intermittent but can be very strong at times pulling debris down.

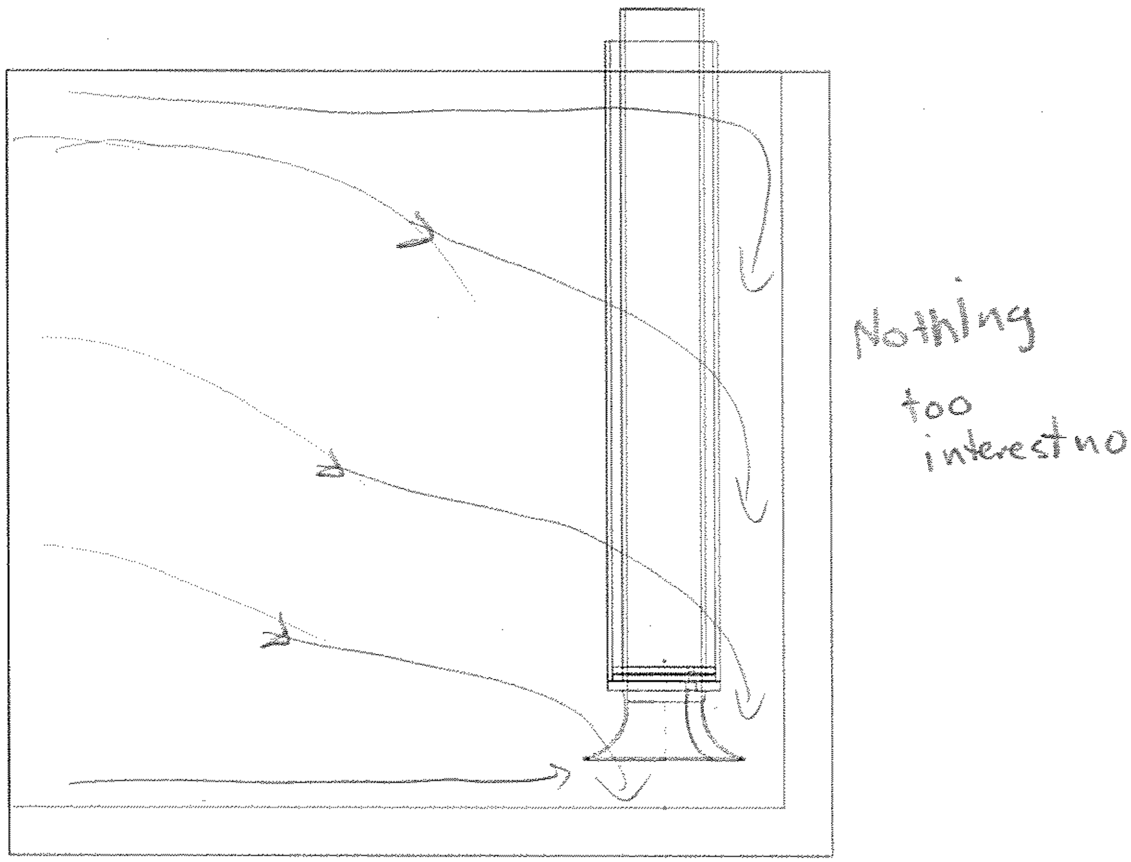
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

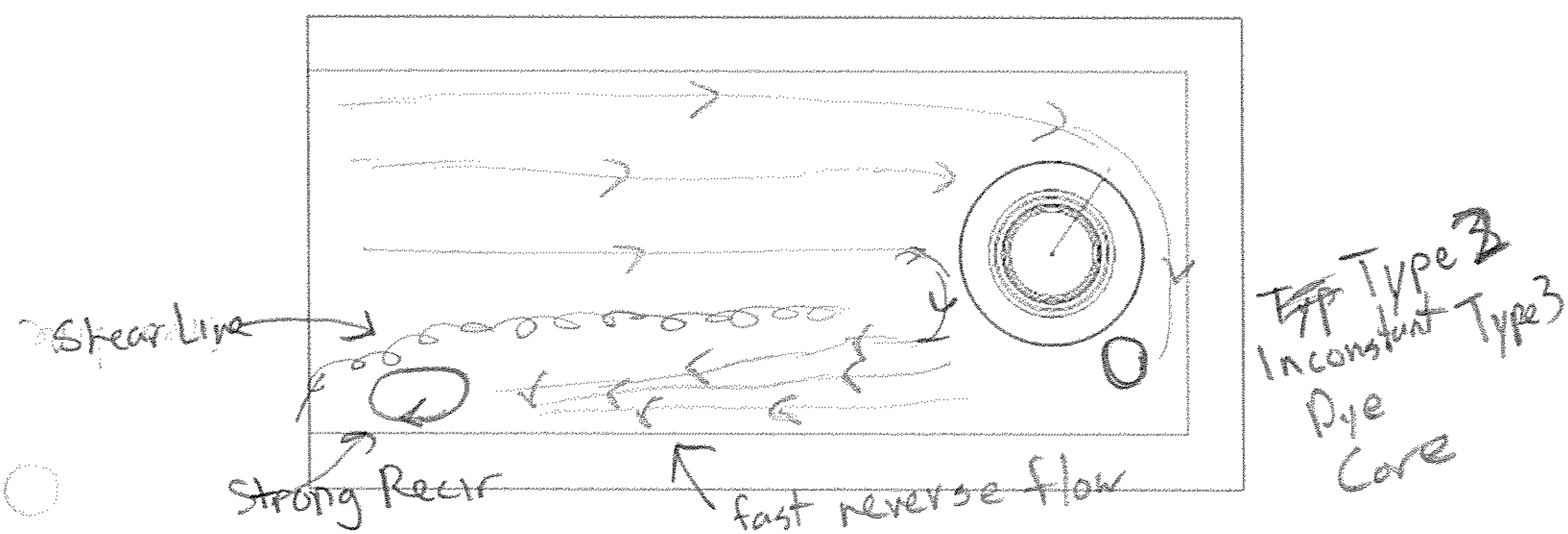
Scenario # and Description 7 Pump 1-4 Bay 4

Run # 18 Notes by: RG/MEL Date / Time: 6/17 10:3

TOP



SIDE

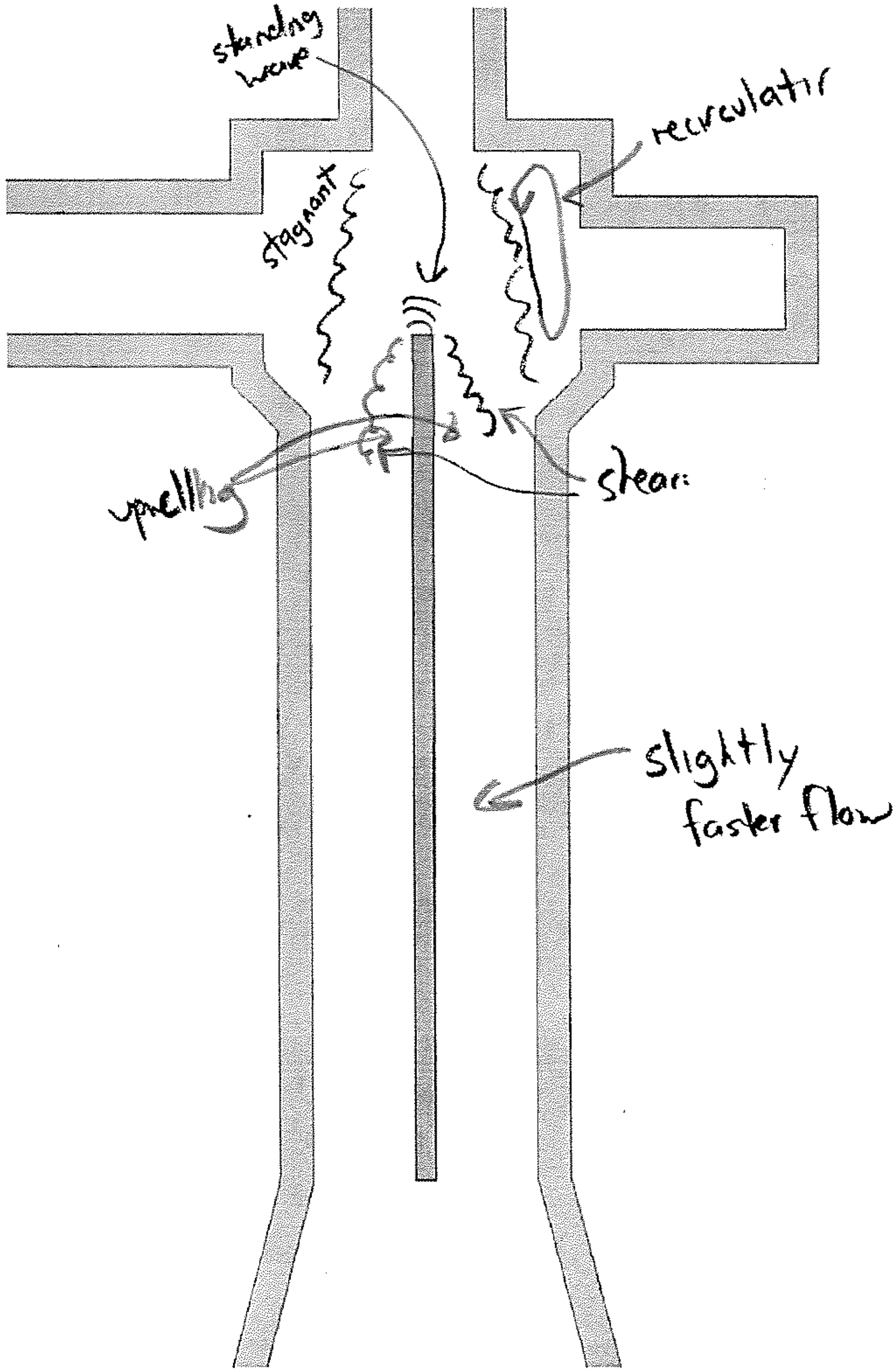


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 8 Pumps 1-3,5

Run # 1 Notes by: MEC Date / Time: 6/17 3:30

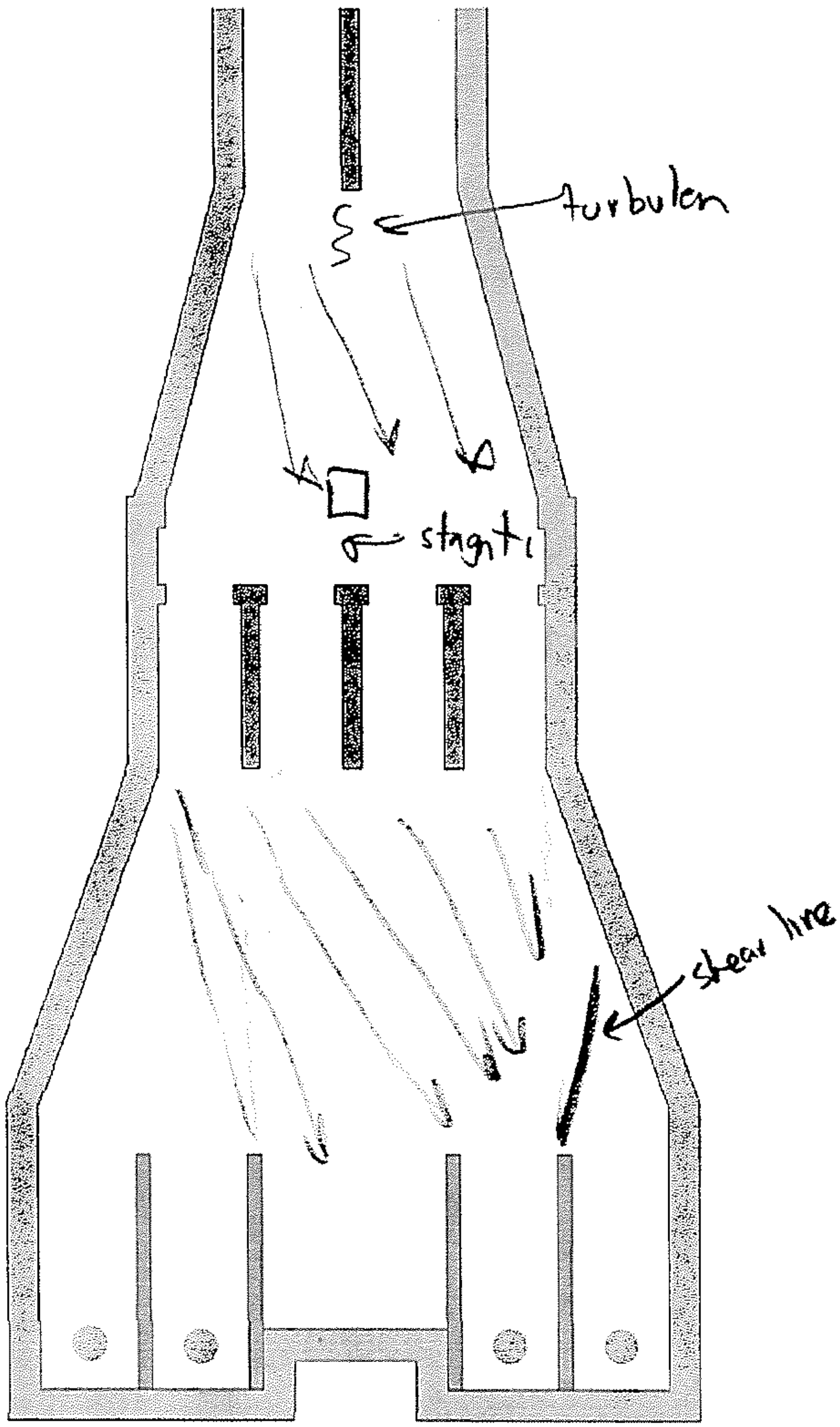


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 8 Pump 1-3, 4 5

Run # 1 Notes by: ME Date / Time: 6-17 3:50

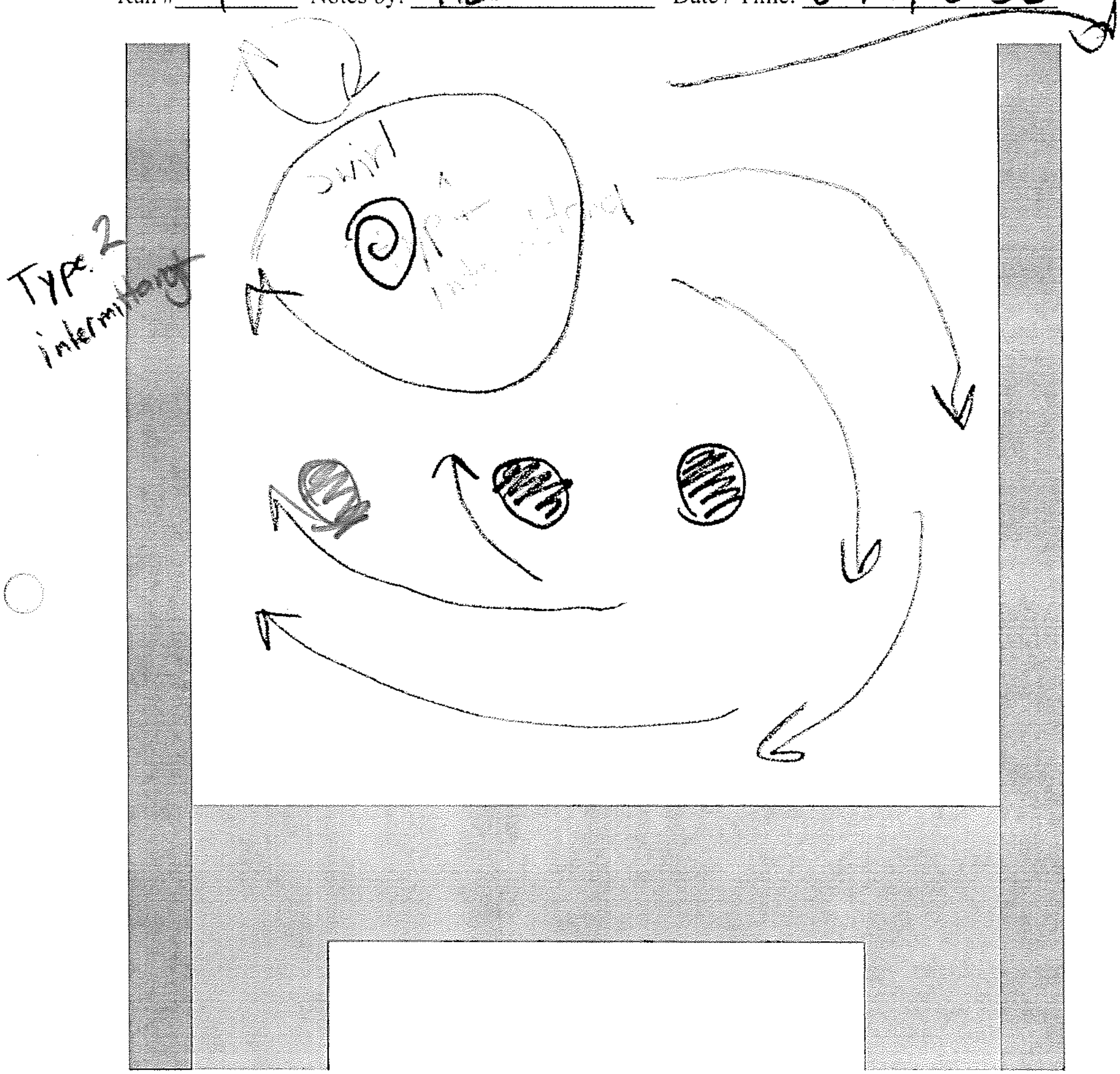


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description: 8, Pump 1-3, ~~4~~ 5

Run #: 1   Notes by: MEL   Date / Time: 6-17, 3:50



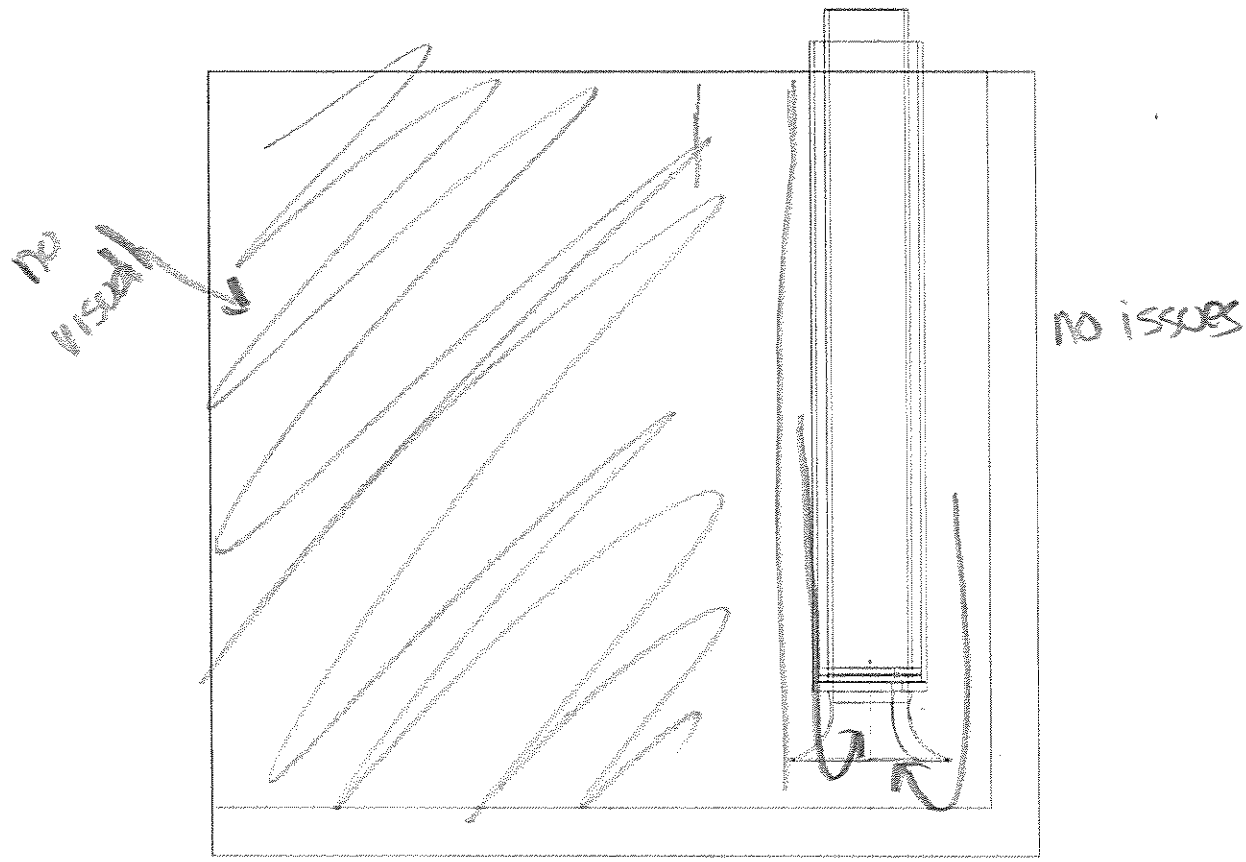
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

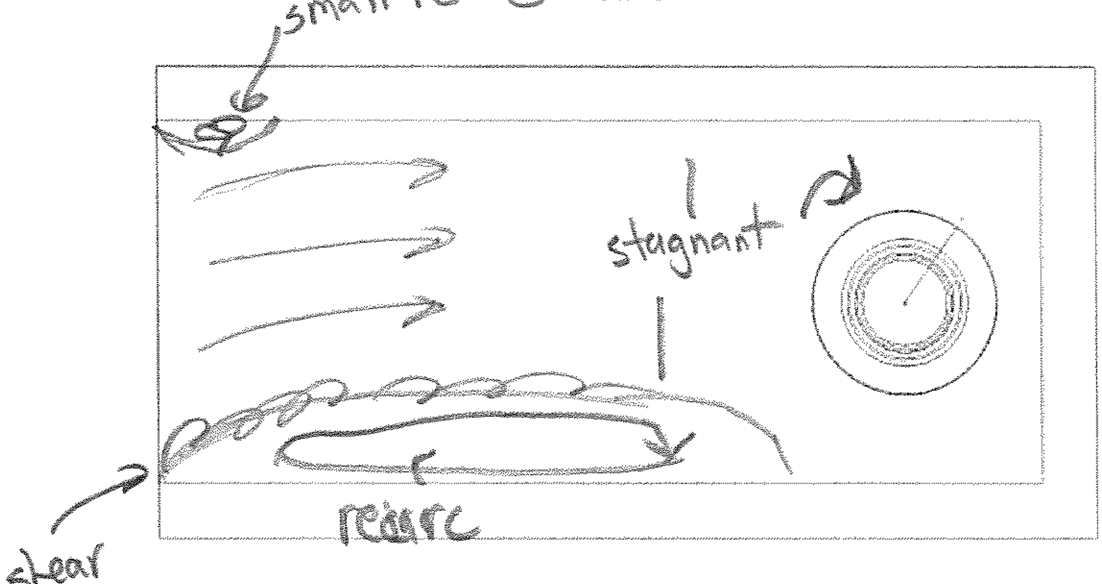
Scenario # and Description 8, Pumps 1-3, 5 Bay 5

Run # 1 Notes by: MEL Date / Time: 6/17 4:04

TOP



SIDE

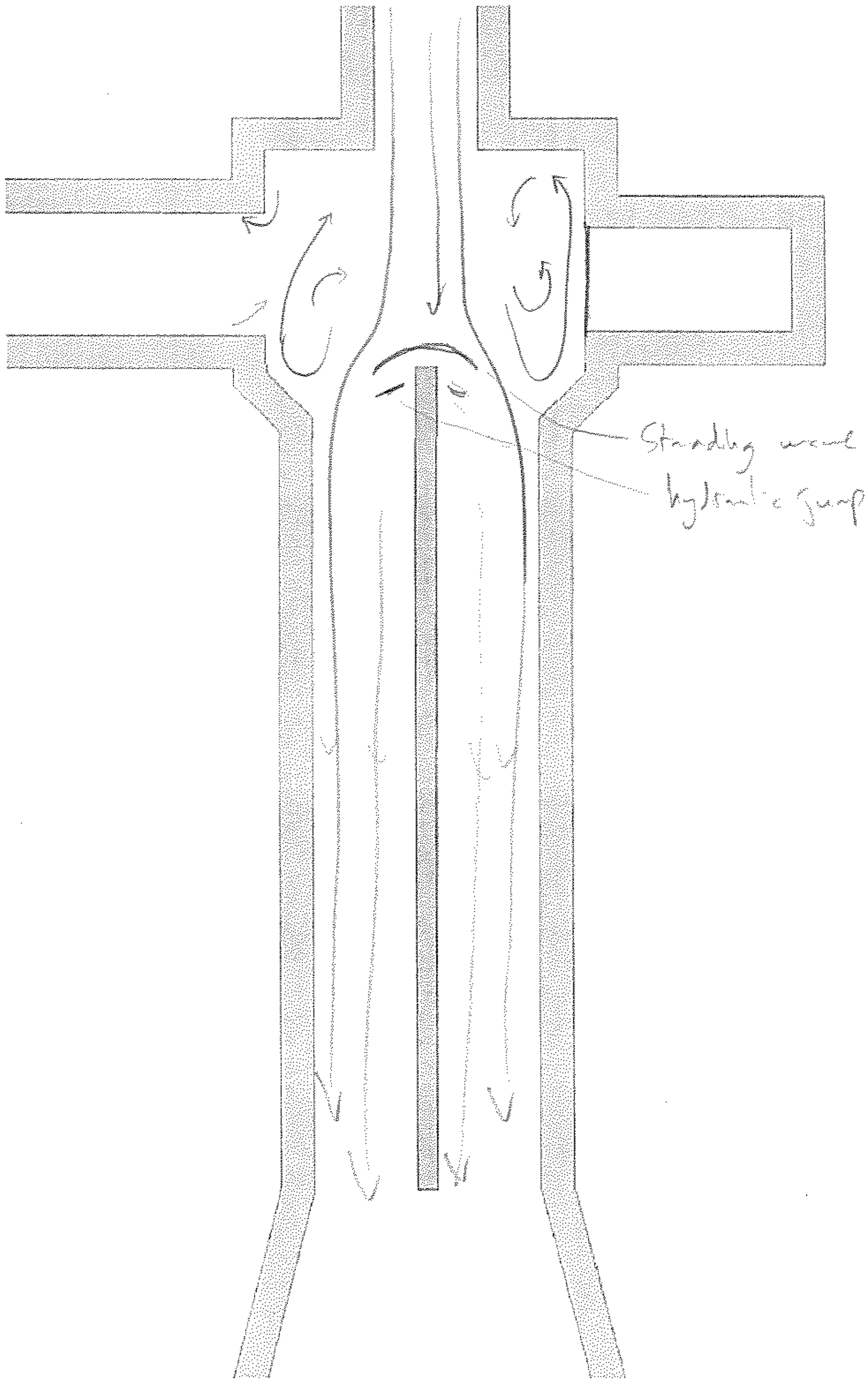


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 9 Pumps 1-5

Run #________ Notes by: RobG. Date / Time: ________

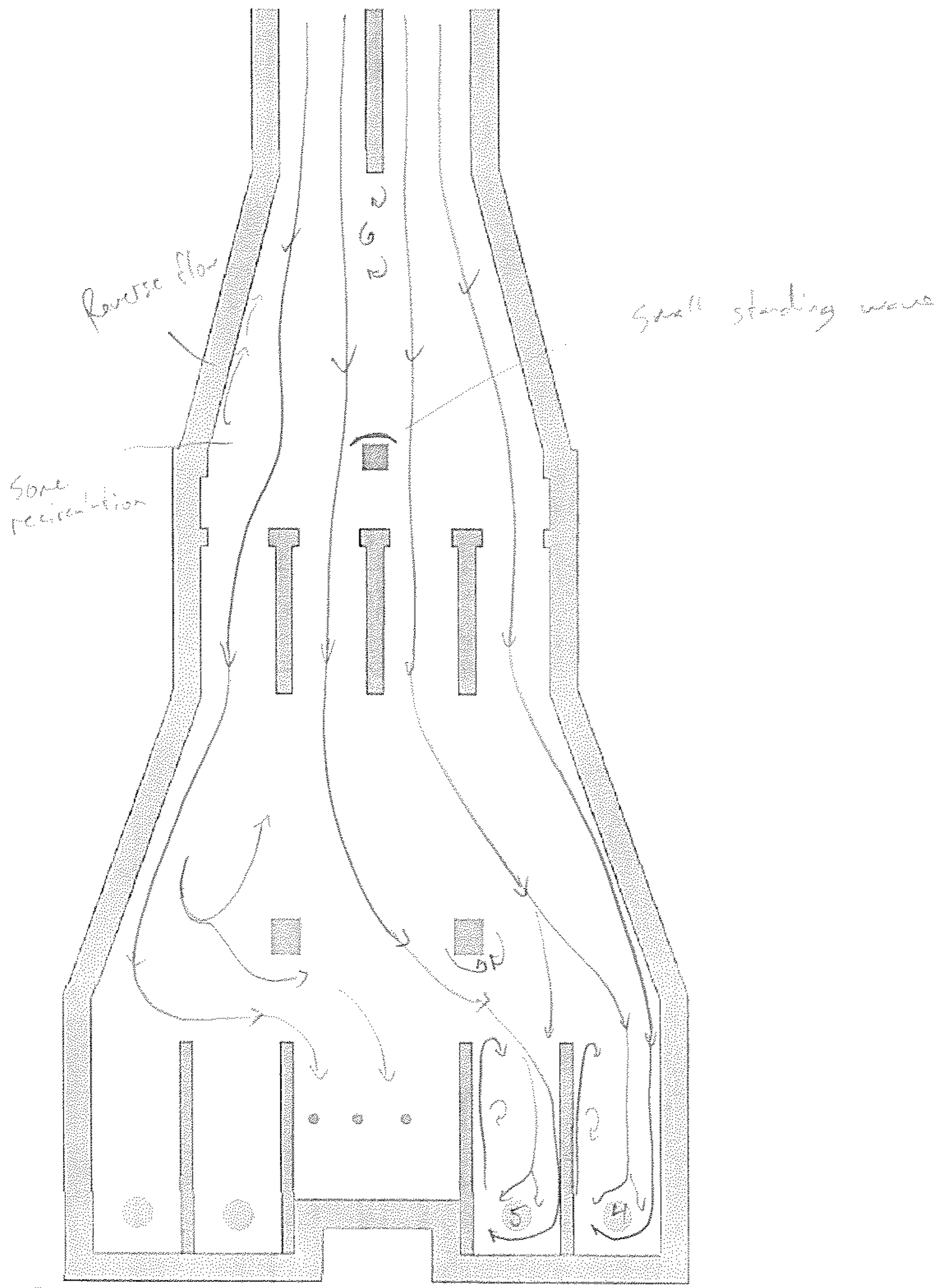


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 9 Pumps 1-5

Run # _________ Notes by: Rob G Date / Time: _________

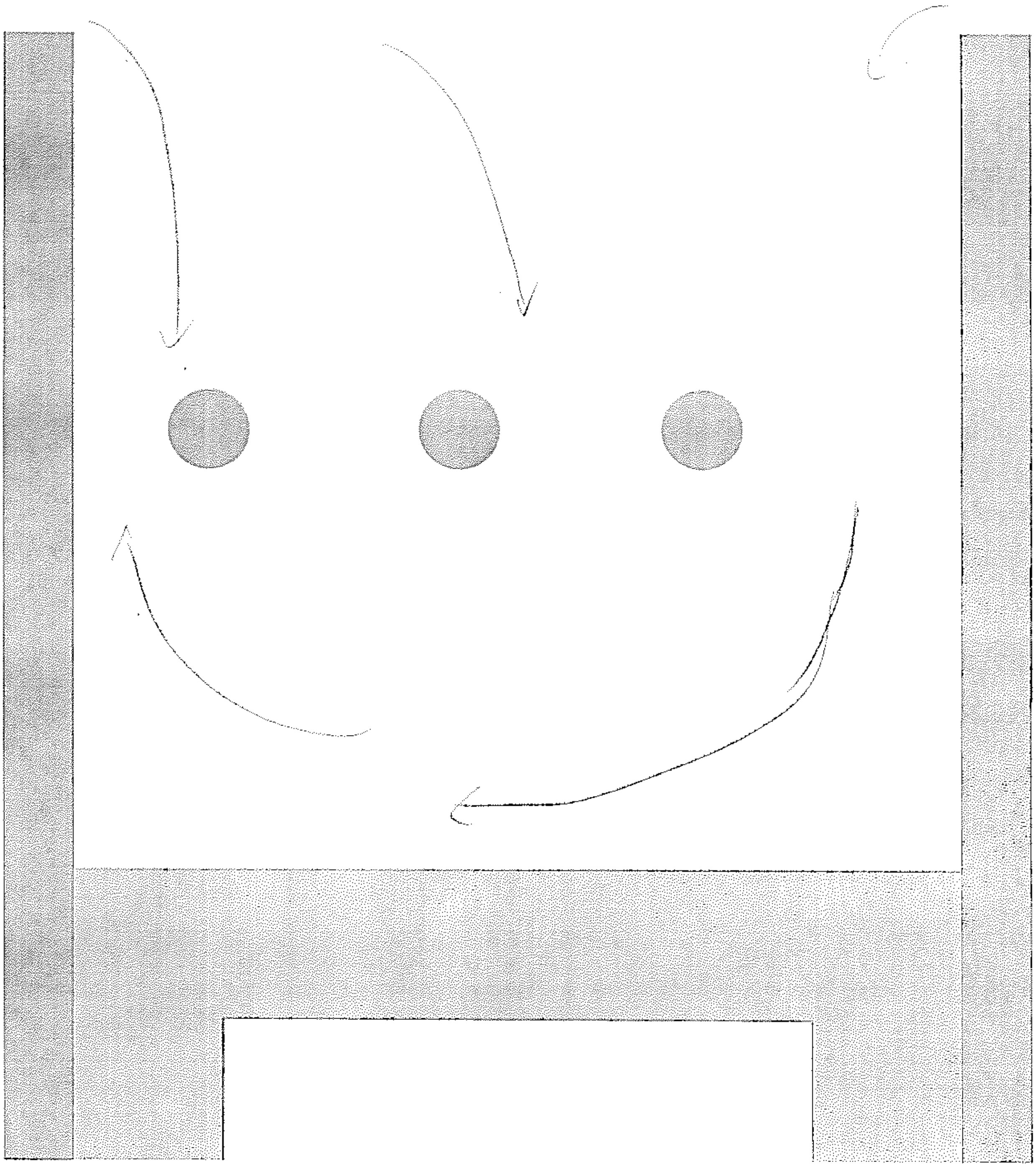


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description a Pumps 1-5

Run # ________ Notes by: ________________ Date / Time: ________________



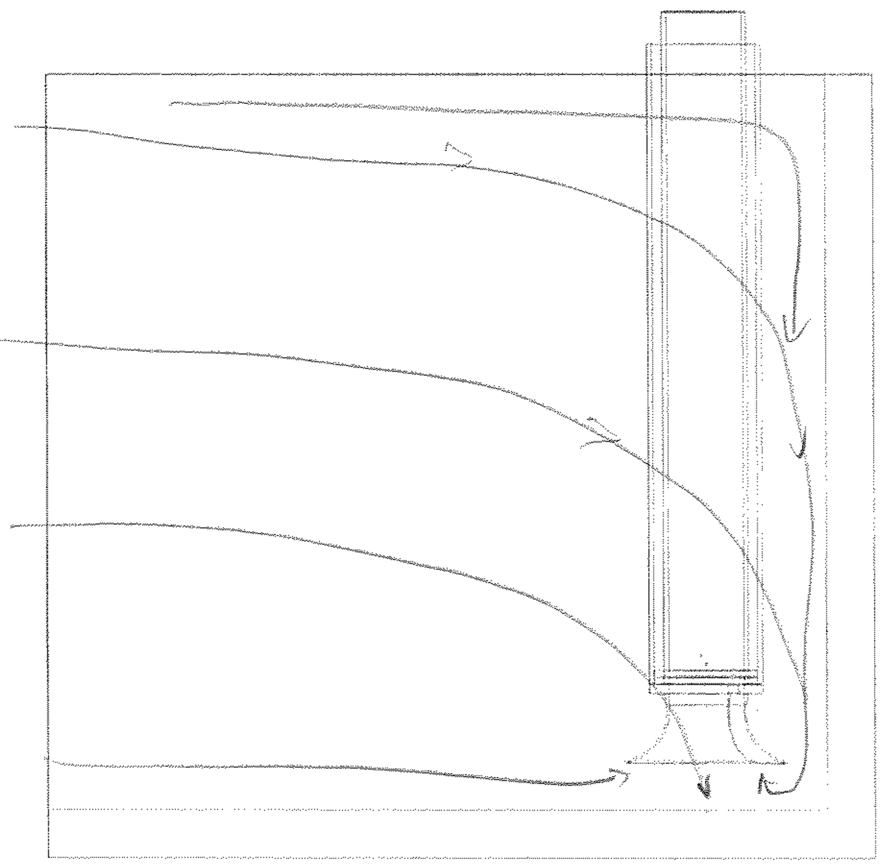
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

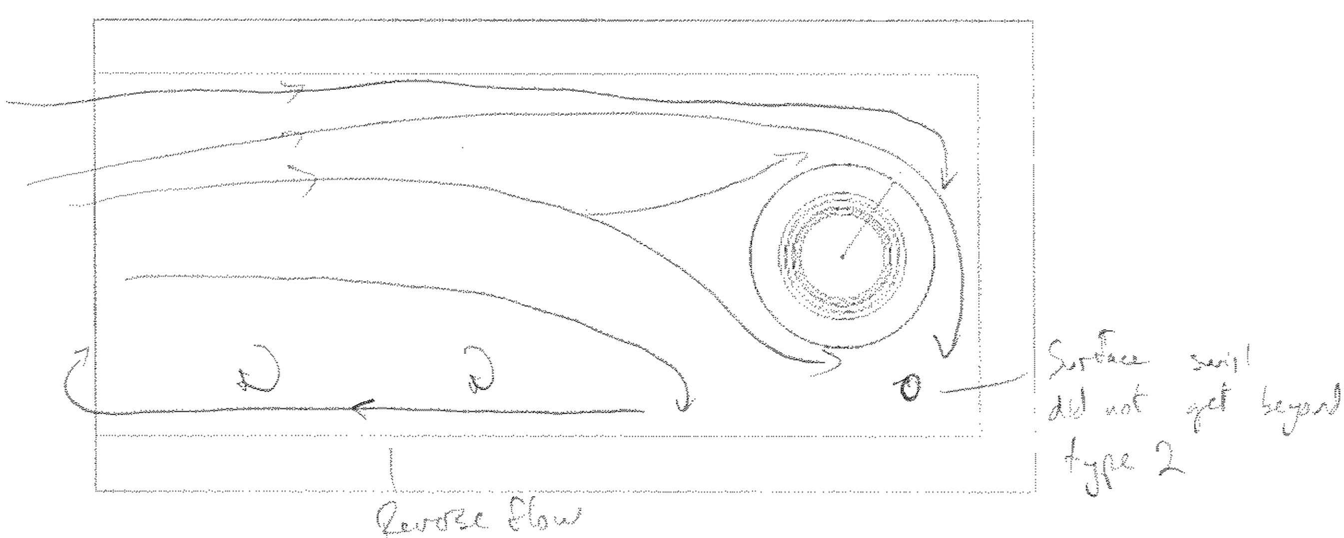
Scenario # and Description 9 Pump 1-5 Bay 4

Run #________ Notes by: ________________ Date / Time: ________________

TOP



SIDE



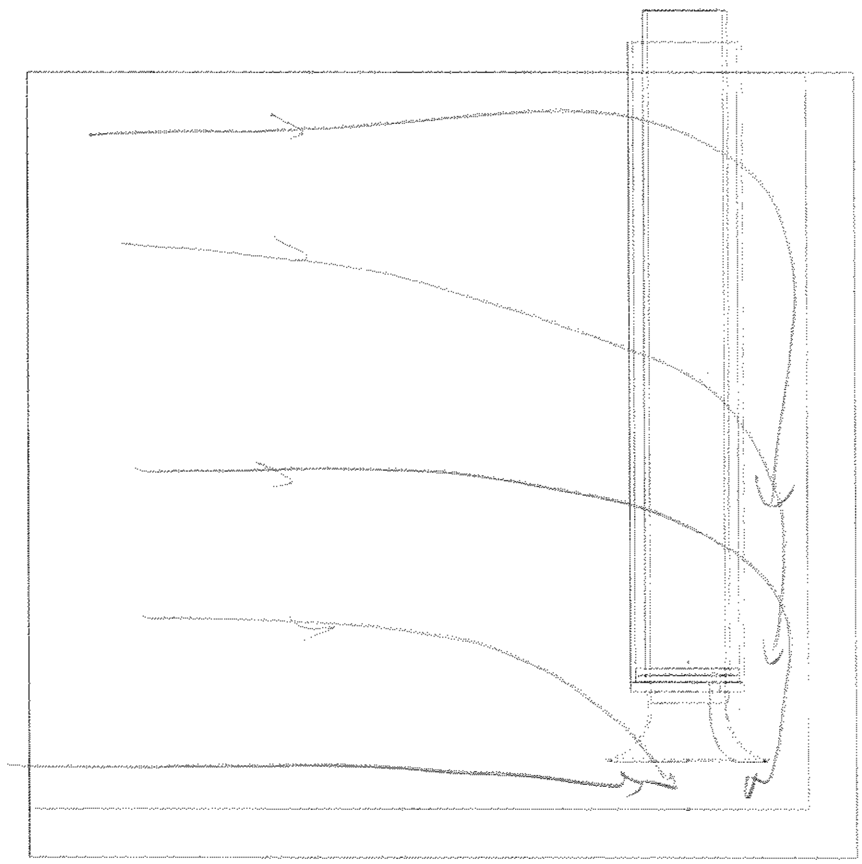
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

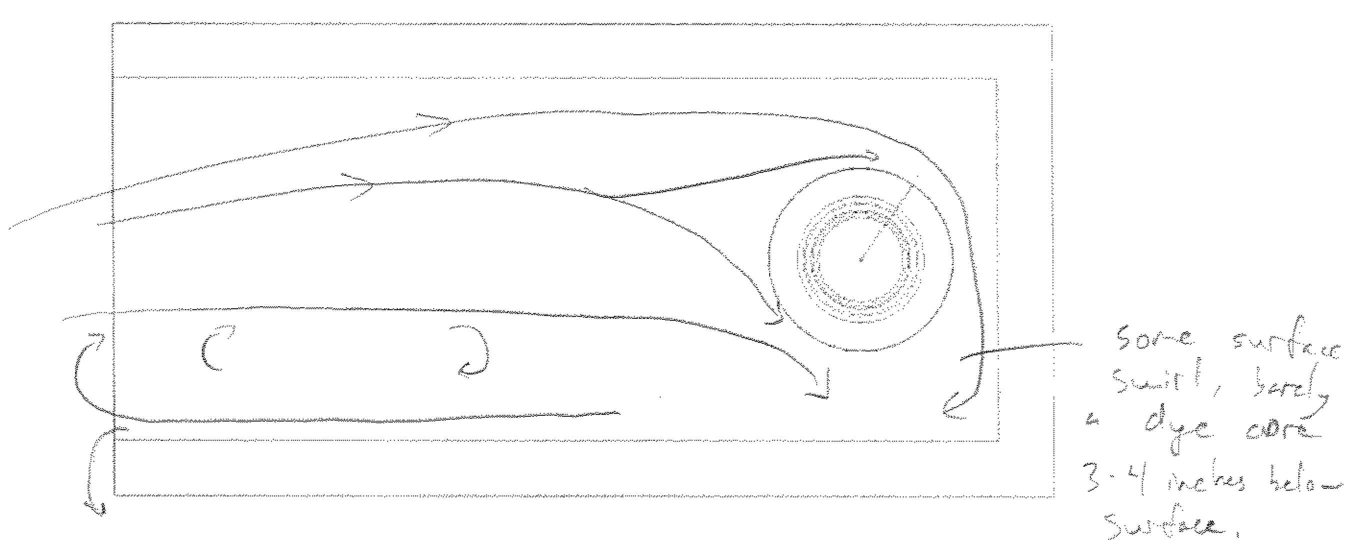
Scenario # and Description 9 Pumps 1-5 Bay 5

Run #______ Notes by: __________ Date / Time: __________

TOP



SIDE

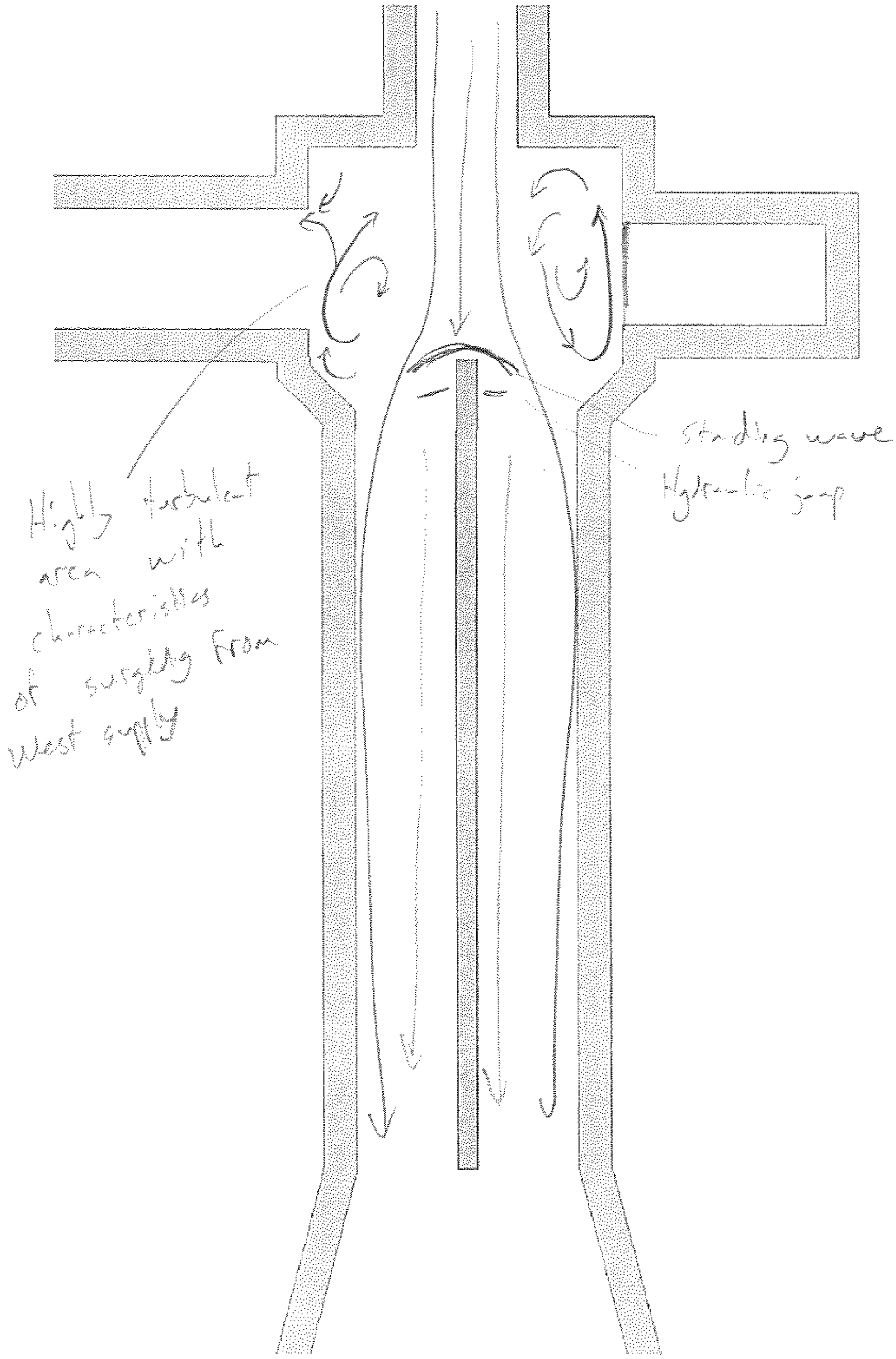


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 10 Pumps 1-6

Run #__________ Notes by: ROB C7 Date / Time: __________

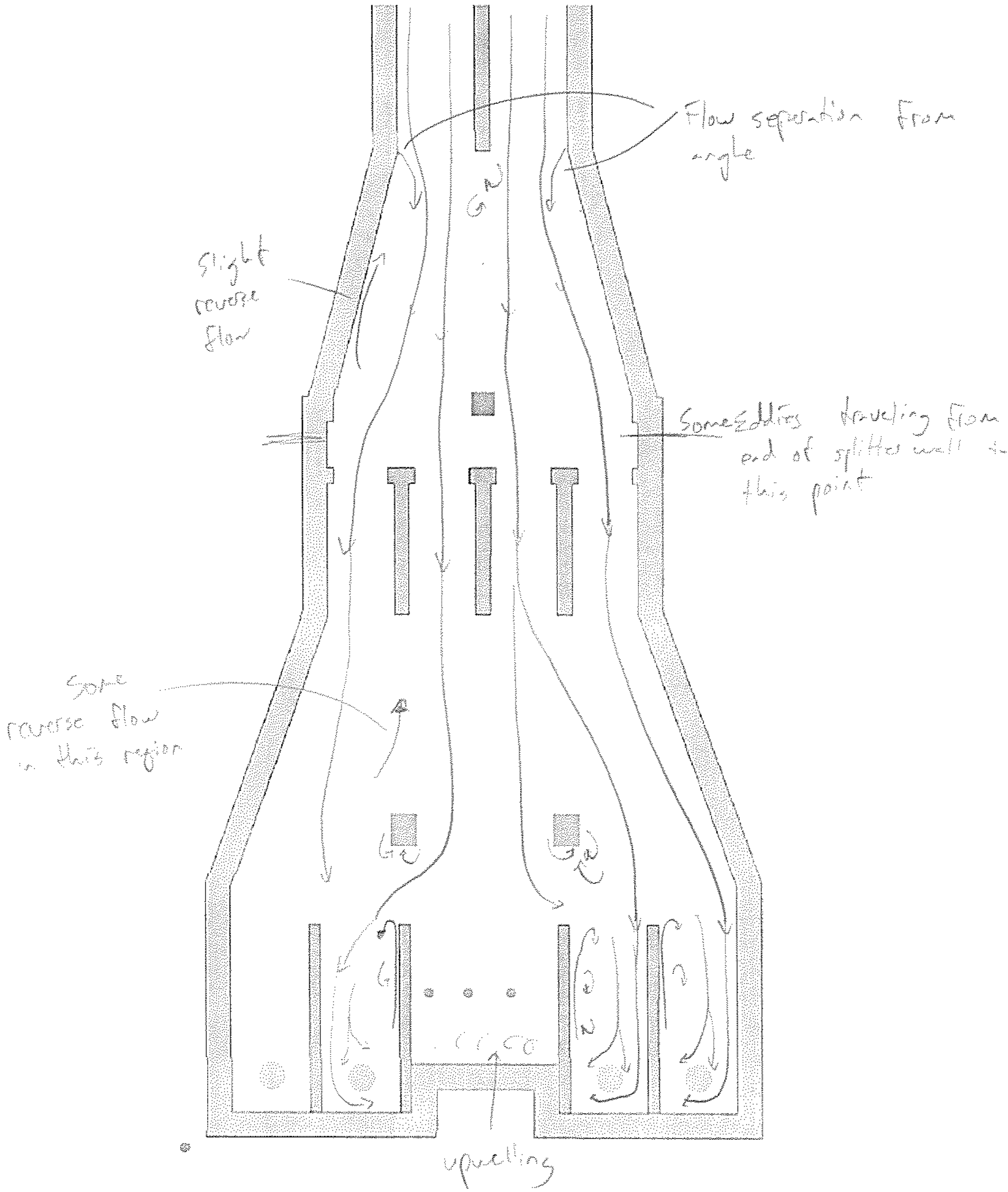


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 10 Pumps 1-6

Run #__________ Notes by: ROBG Date / Time: __________

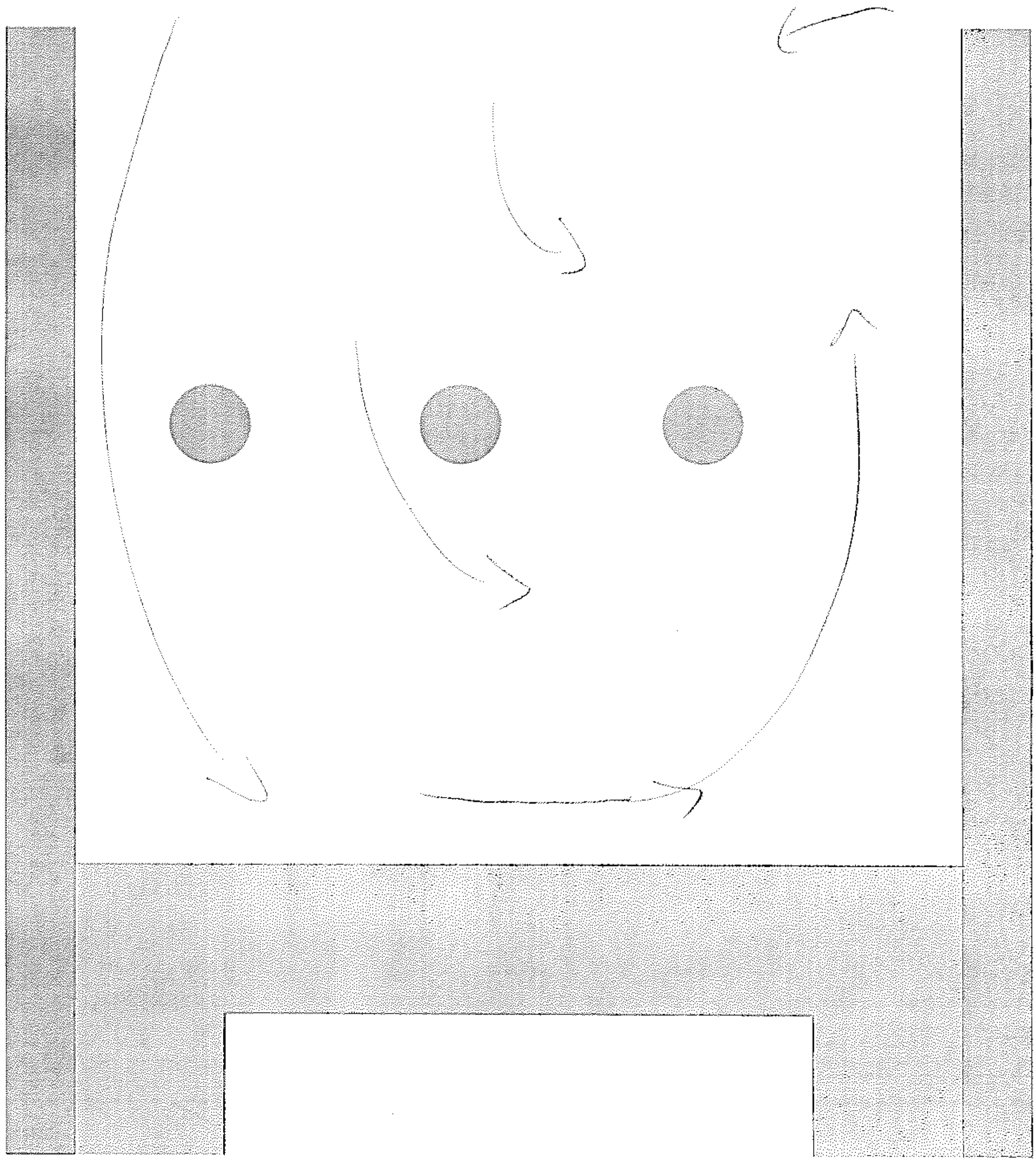


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description ______10______ pumps 1-6__________________

Run #__________ Notes by: ____________________ Date / Time: ____________________



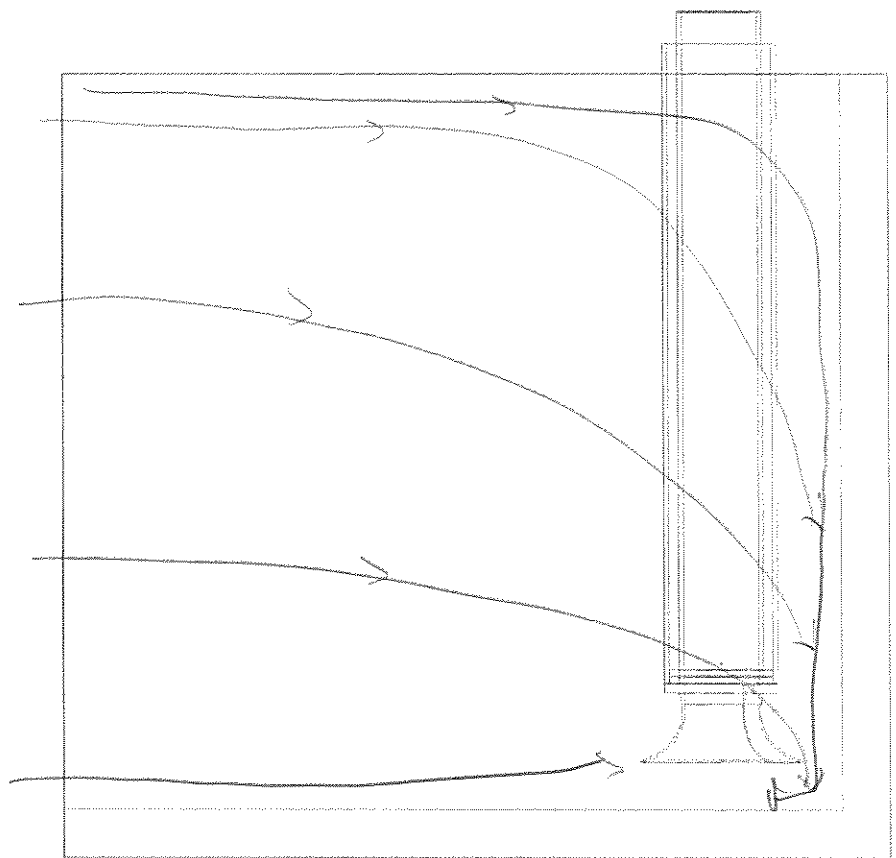
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

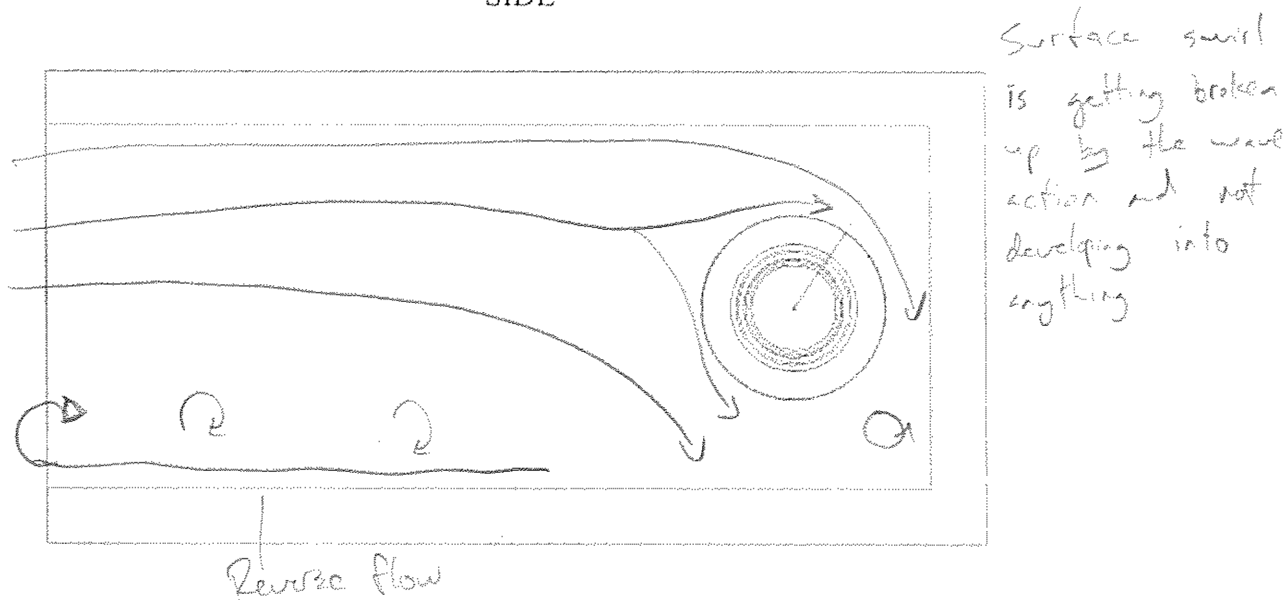
Scenario # and Description 10 Pumps 1-6 Bay 4

Run #__________ Notes by: Rob G Date / Time: __________

TOP



SIDE



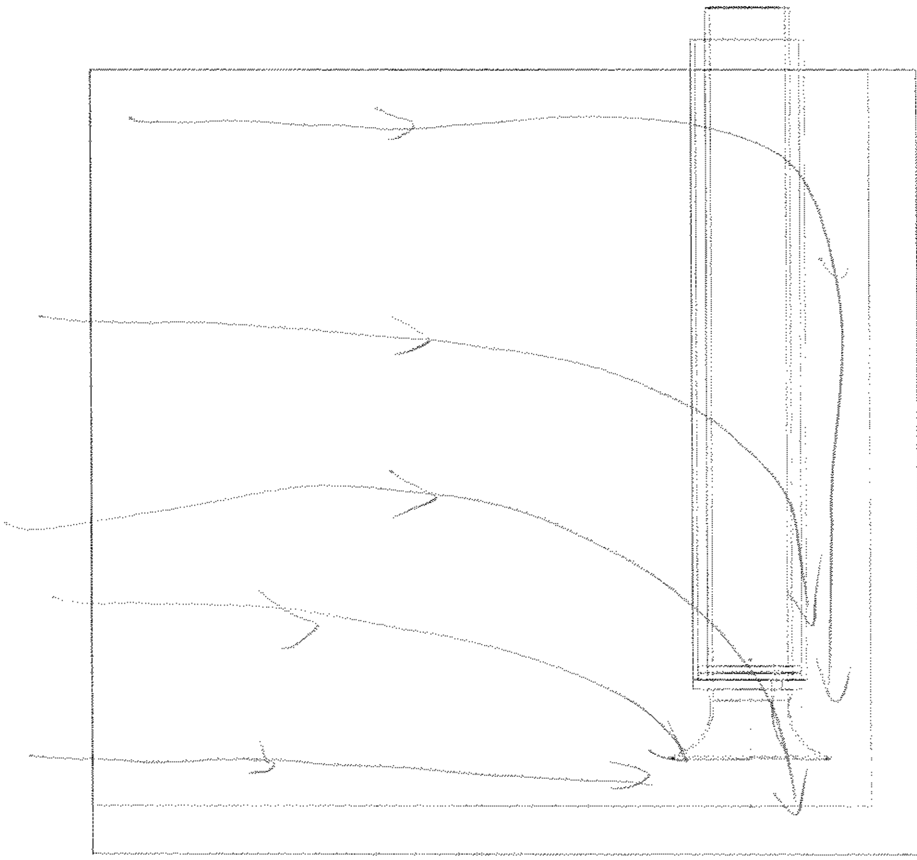
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

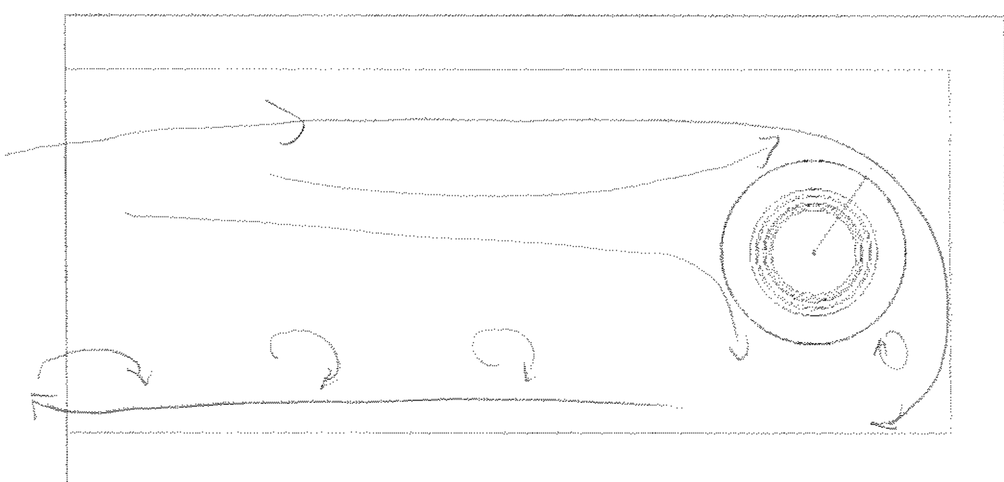
Scenario # and Description 10 Pumps 1-6 Bay 5

Run # ________ Notes by: ____________________ Date / Time: ____________________

TOP



SIDE



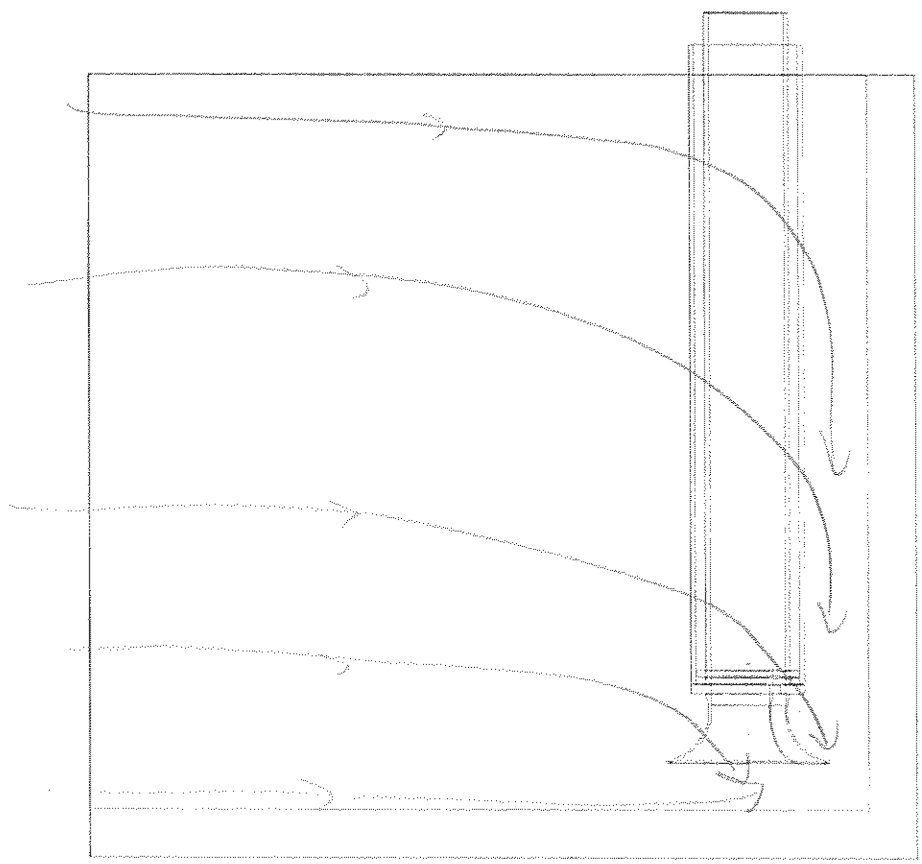
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

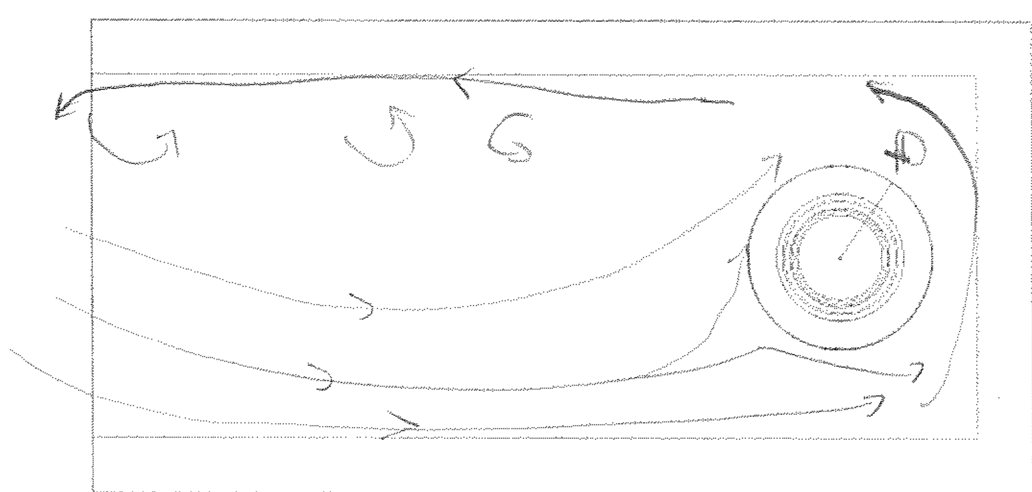
Scenario # and Description 10 Pumps 1-6 Bay 6

Run # ______ Notes by: ______ Date / Time: ______

TOP



SIDE

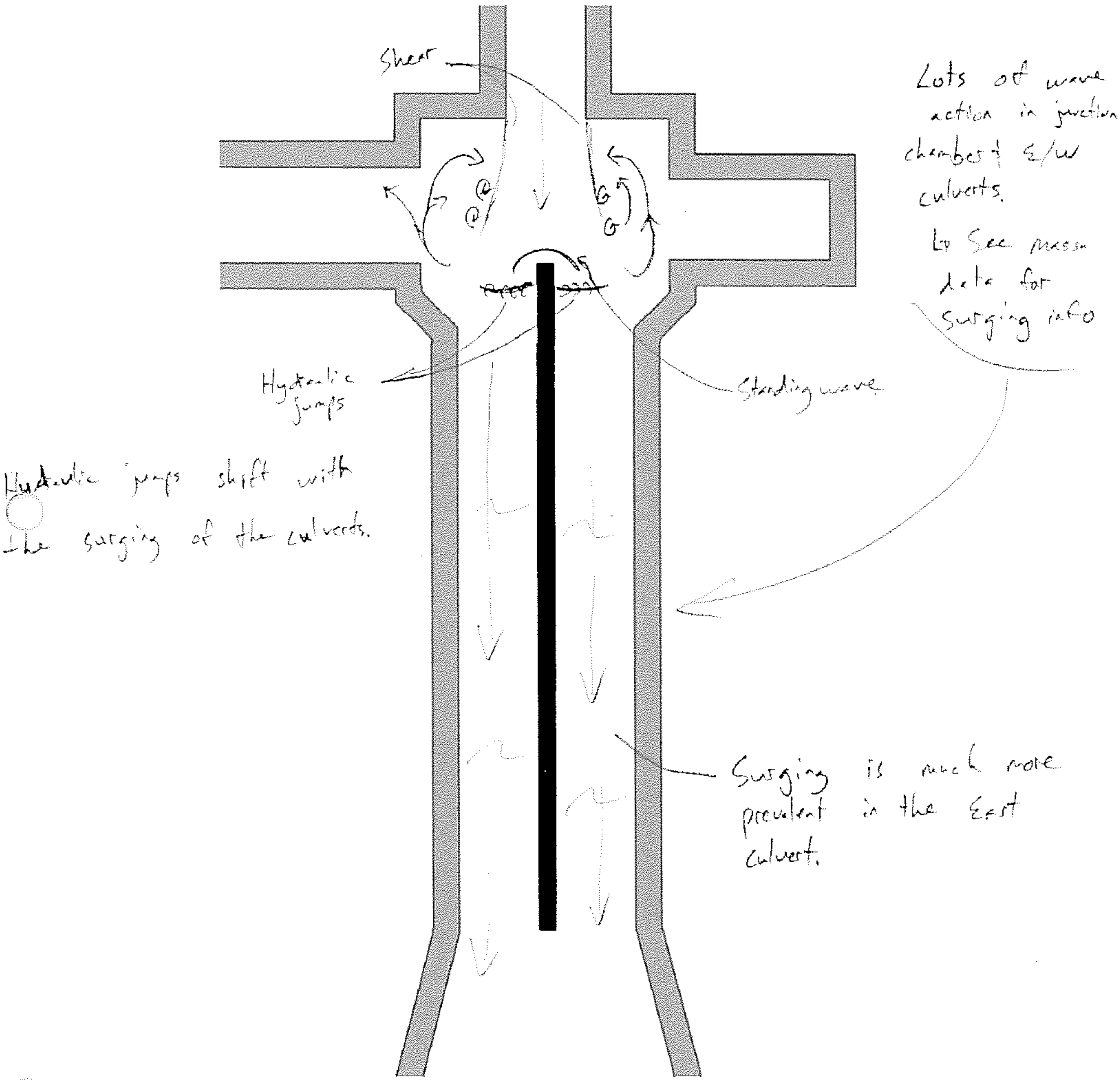


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 11 pumps 1-7

Run # Scf1 12 Notes by: RobG MEL Date / Time: 6/21 10:00

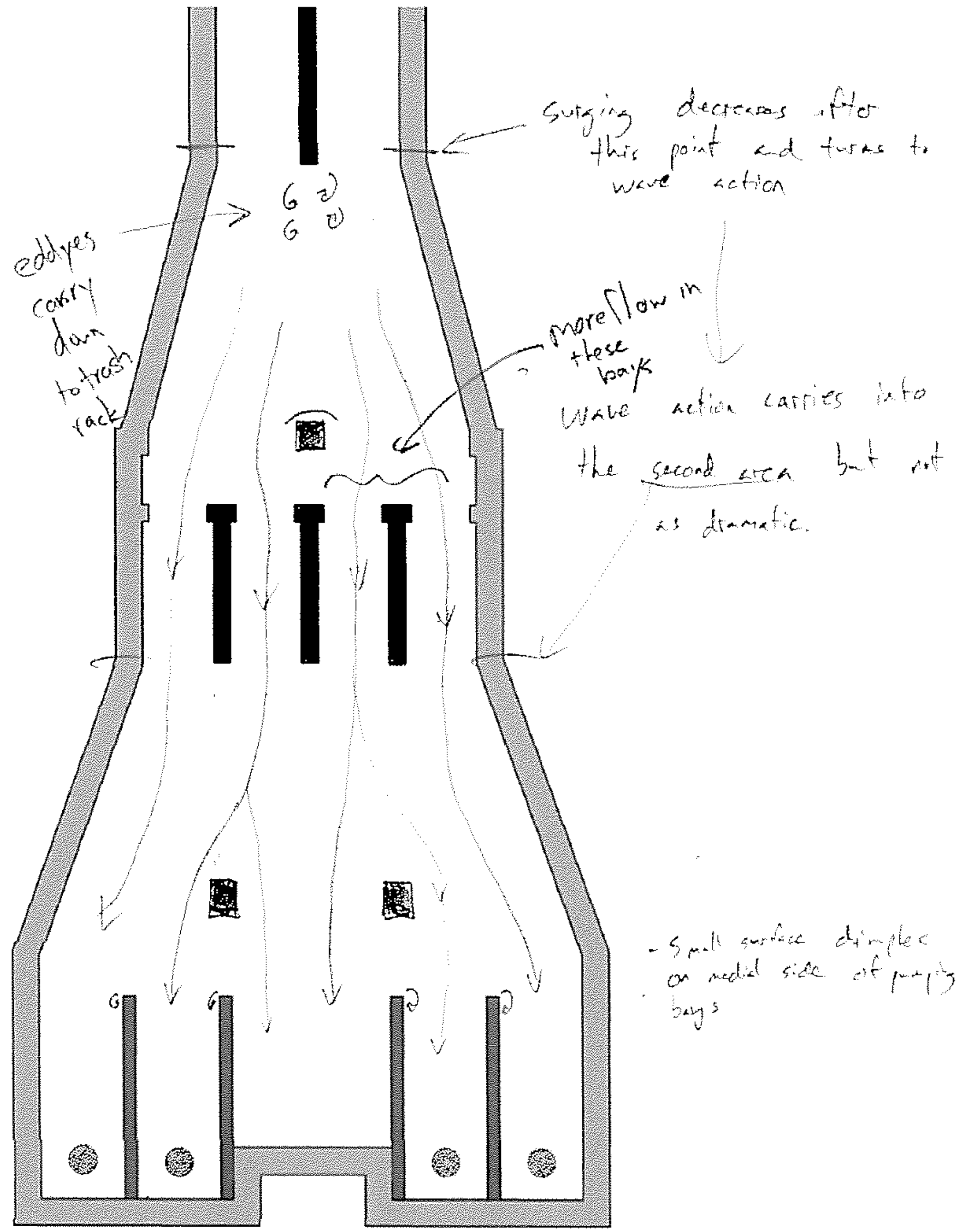


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 11 pumps 1-7

Run # SFL12 Notes by: Borg / MEL Date / Time: 6/21 10:15

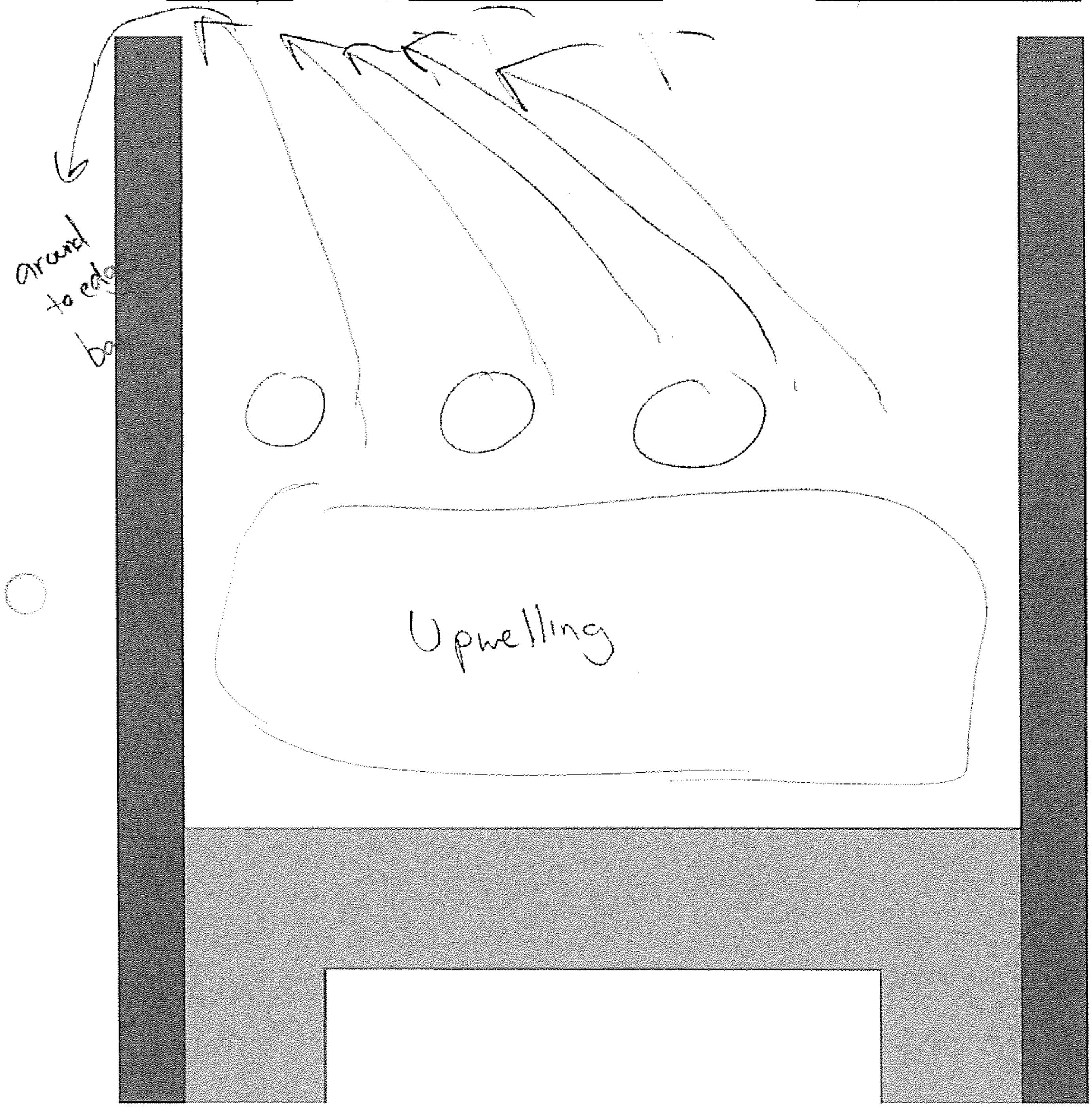


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description 11 Pumps 1-7

Run # S.F1 12 Notes by: RobG / MEL Date / Time: 6/21 10:30



Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

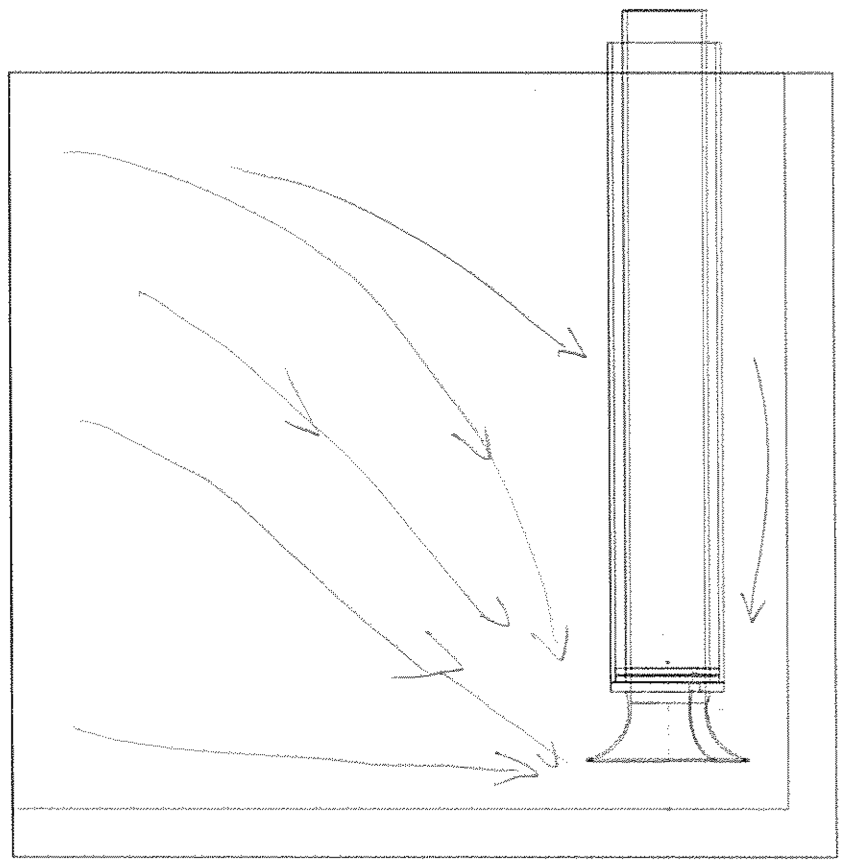
Broadway Pumping Station Vertical Pump Bay

Scenario # and Description: 11 Pumps 1-7 Bay: 4

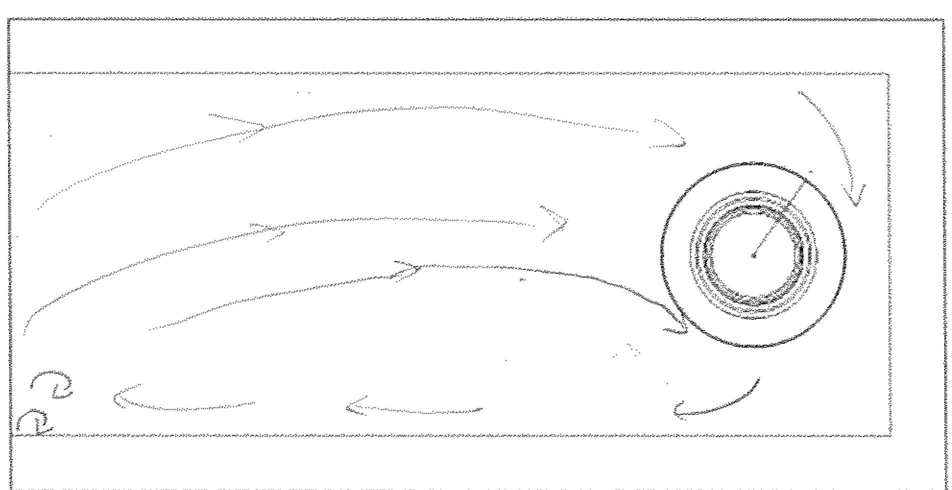
Run #: SaFL12 Notes by: Robb ML Date / Time: 6/21

TOP

-No surface dimples or swirls near the intake area



SIDE



Weak recirculation on medial side of bay

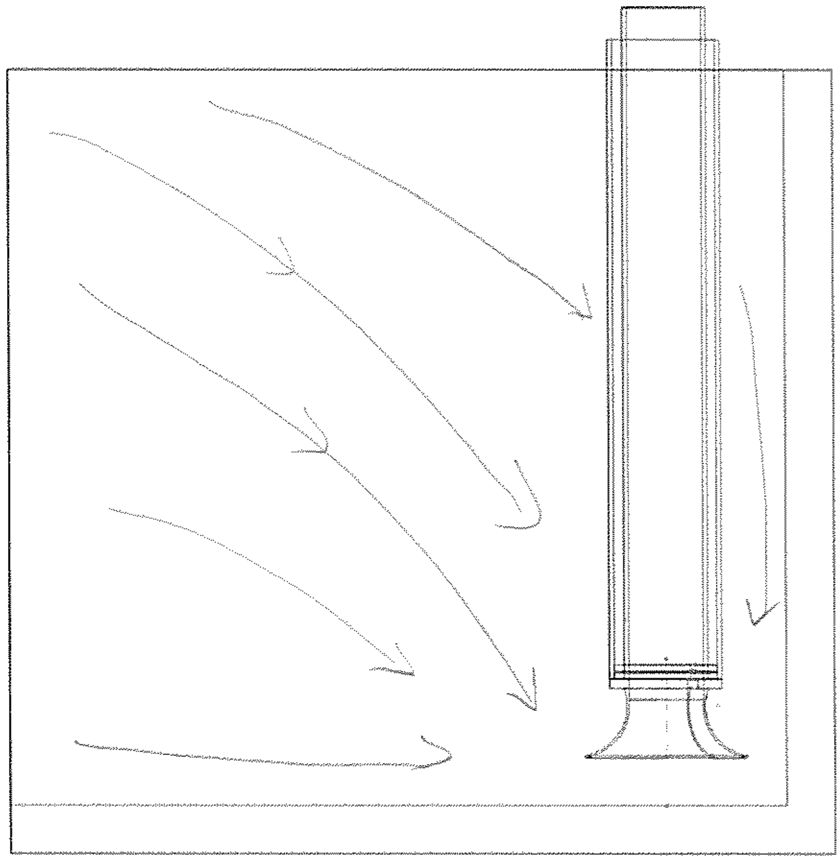
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 11 Pumps 1-7 Bay 5

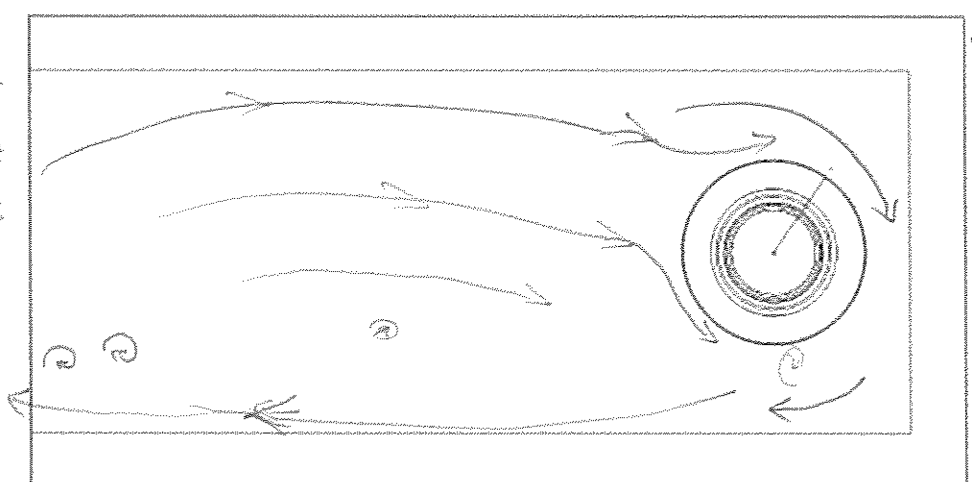
Run # SAFC 17 Notes by: Rob G Date / Time: 6/21

TOP



SIDE

- Small surface swirls in corner but no coherent cores at dimples



- Stronger recirculation than pump #4 on the medial side of the bay.

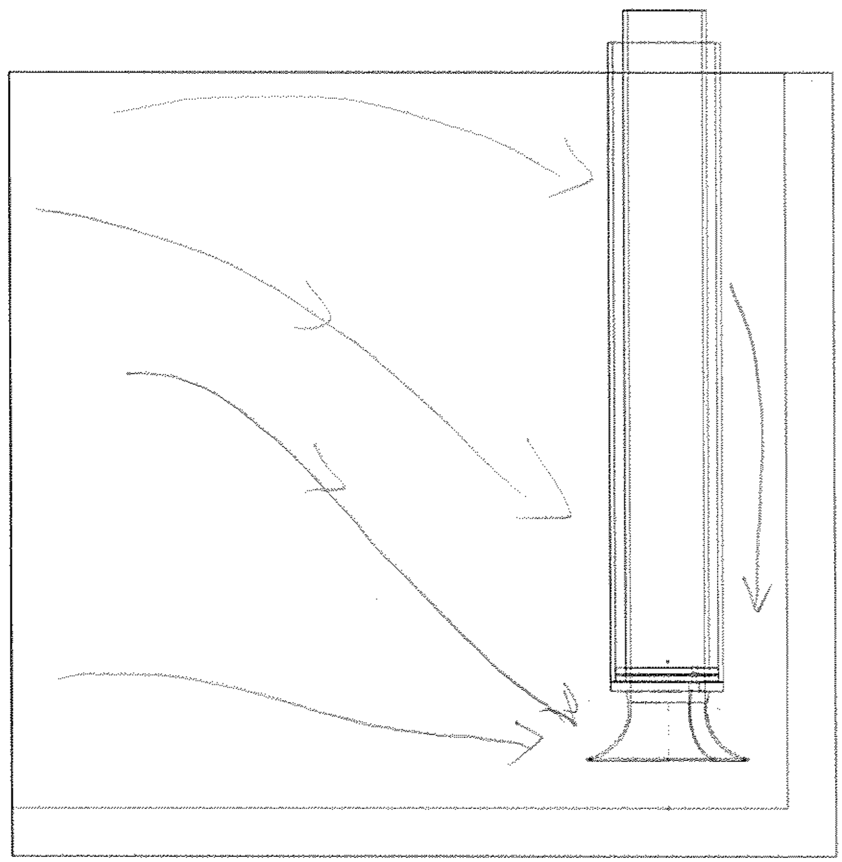
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description #11 Pumps 1-7 Bay 6

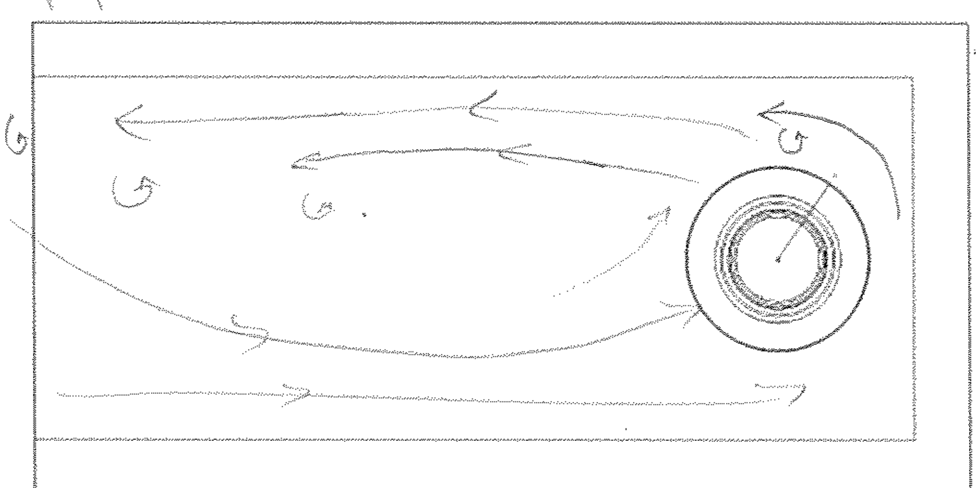
Run # SnFL 12 Notes by: BoBG Date / Time: 6/21

TOP



SIDE

- Some surface swirl on inside corner near pump but no dimples or cores form



- Strong recirculation at medial edge of bay

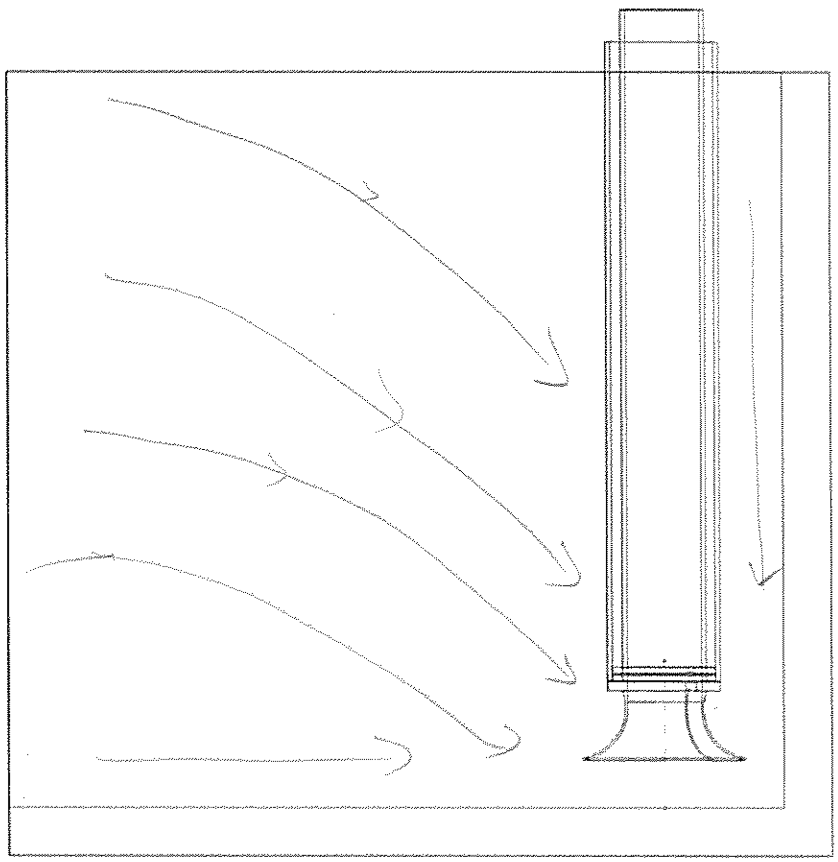
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 11 Pumps 1-7 Bay 7

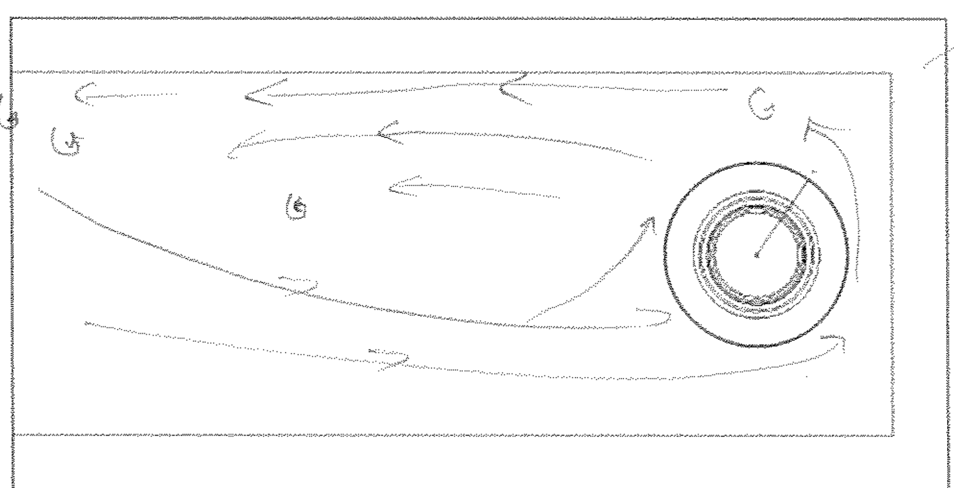
Run # SAFC 12 Notes by: Rob G Date / Time: 6/21

TOP



SIDE

Recirculation not as strong as bay 6 but still present.



Some surface swirl but no dimples.

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Pump Intake Design — 2012

Nothing above type 1

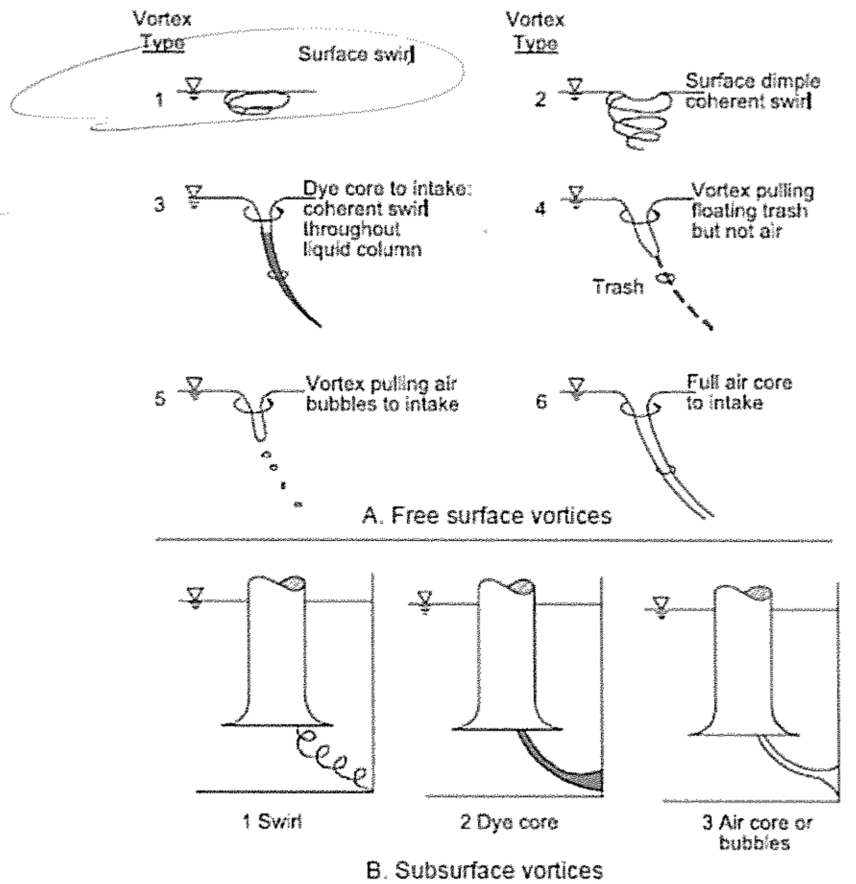


Figure 9.8.4.5a — Classification of free surface and subsurface vortices

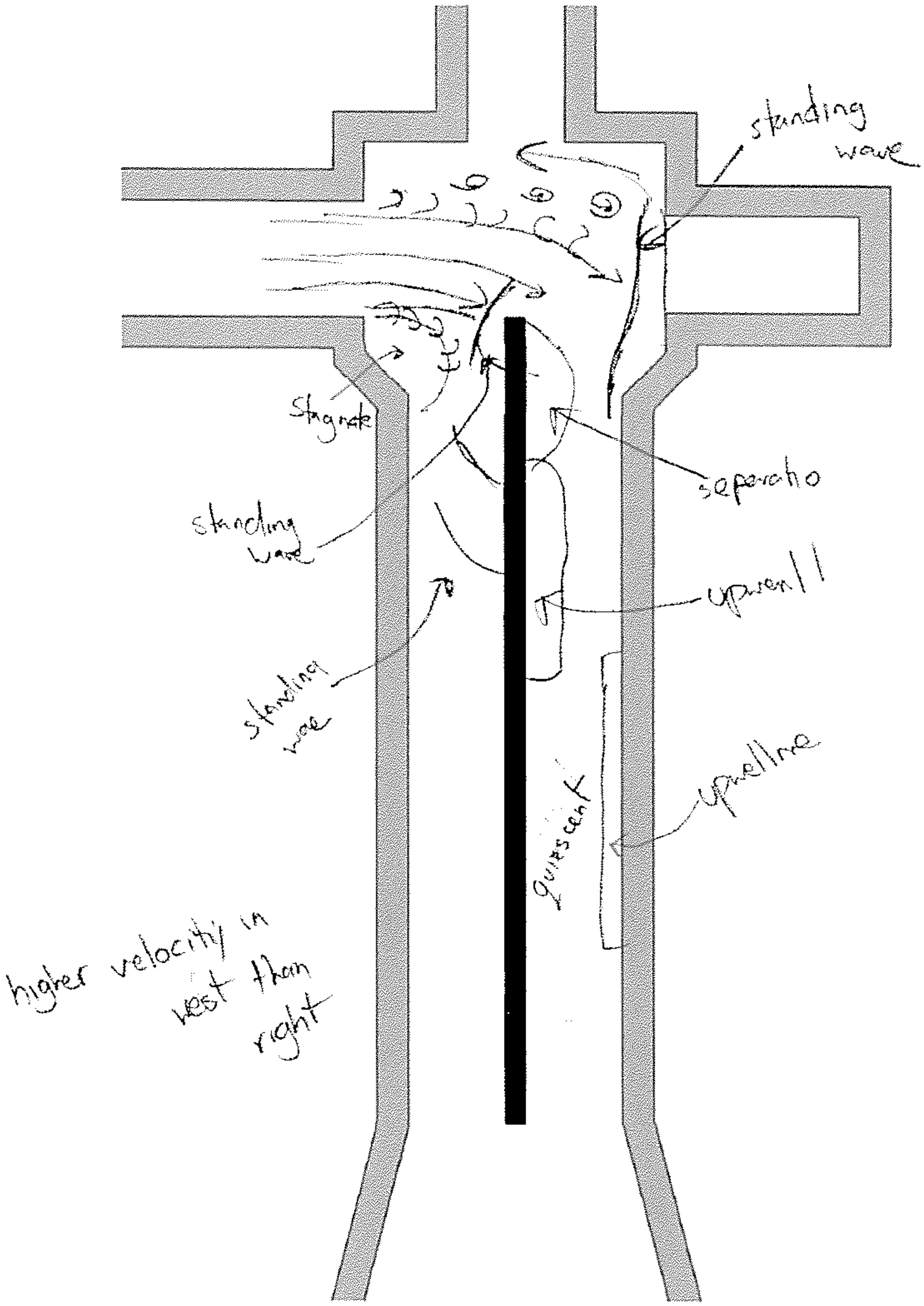
Wave action from the surging upstream could be disrupting any surface swirl

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 11 A Pumps 1-7 Wsd Supply

Run # SAFL 13 Notes by: Poi3Gi ML Date / Time: 6/21

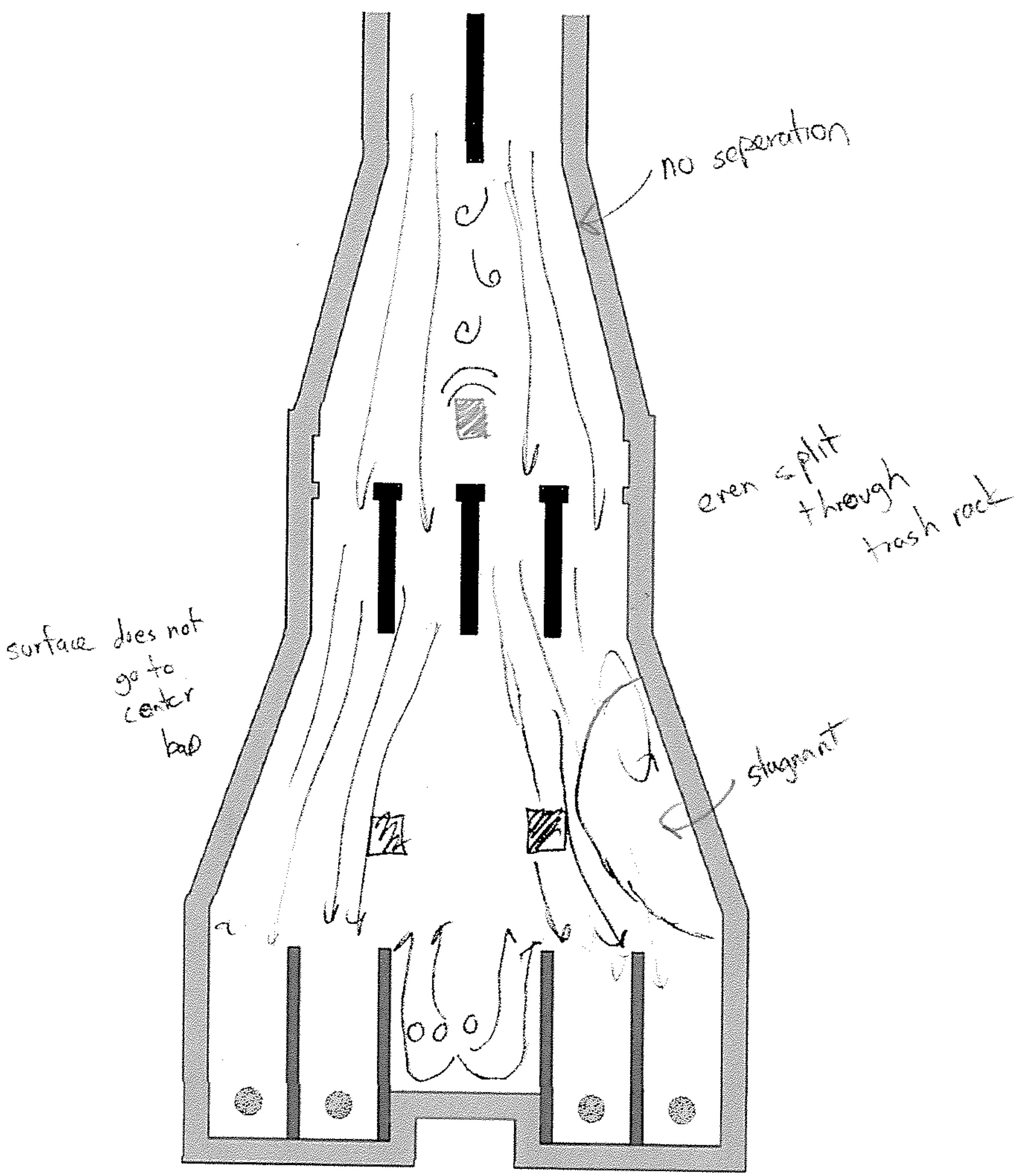


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 11 A Pumps 1-7 West Supply

Run # SAFL 13 Notes by: POBG ML Date / Time: 6/21

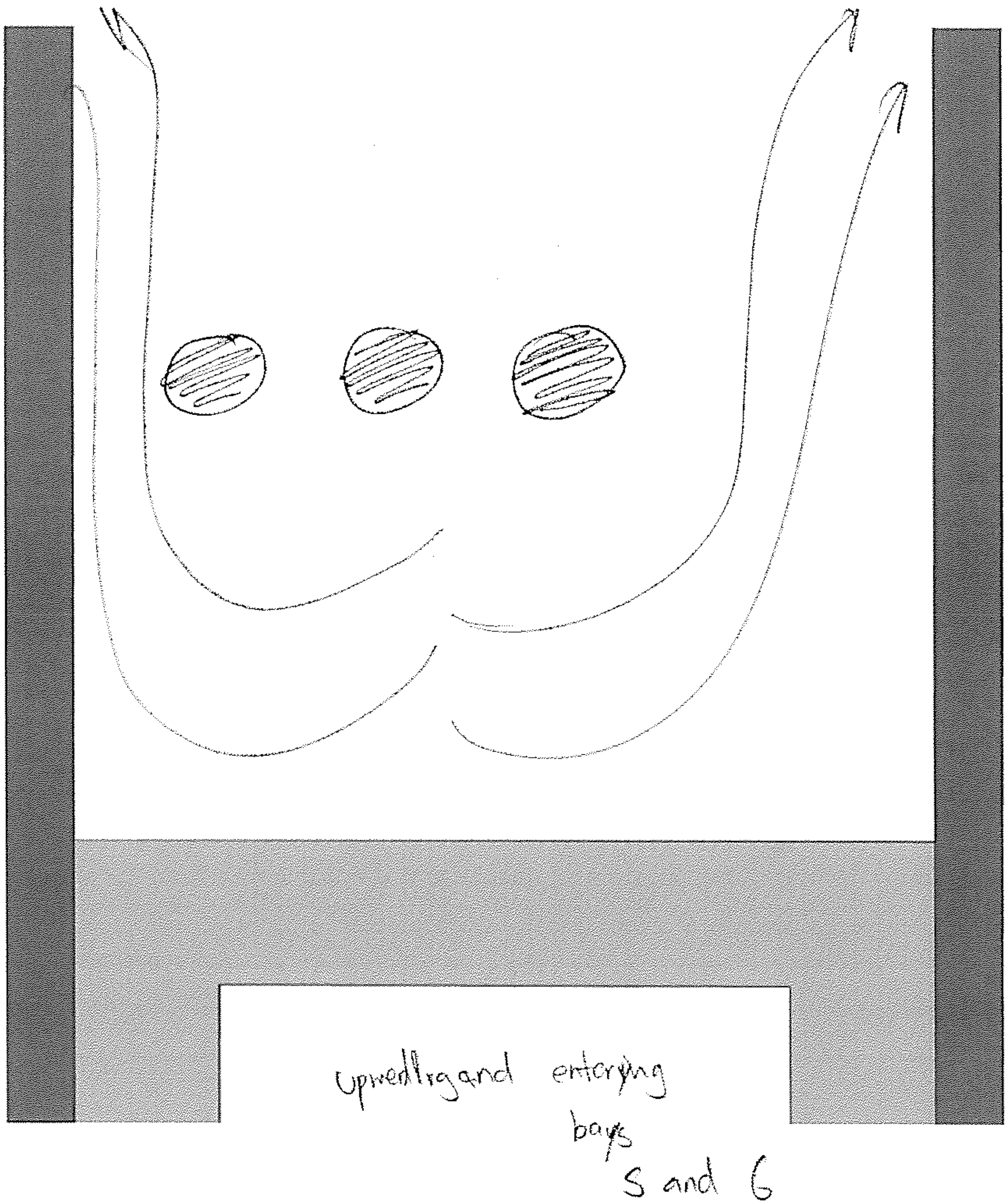


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description 114 Pumps 1-7 West supply

Run # SAFL 13 Notes by: RORG ML Date / Time: 6/21

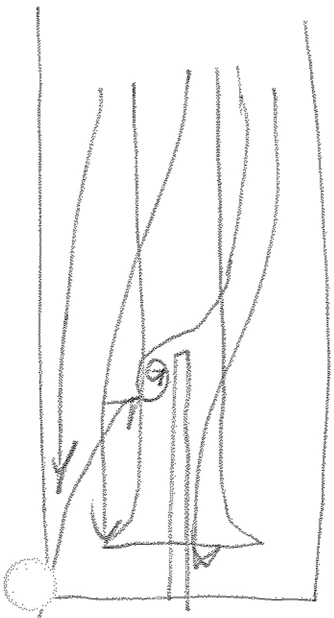


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 11A Pumps 1-7 Wet Supply Bay 4

Run # SAFL 12 Notes by: Rob Lo ML Date / Time: 6/21



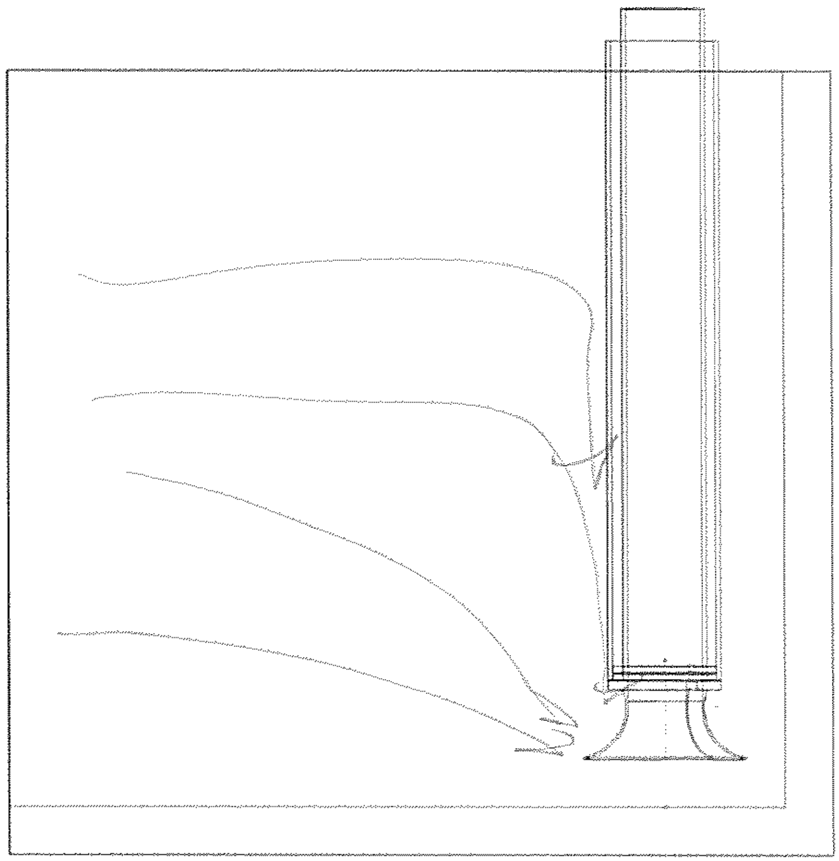
end view 4 and 5 intake

swirl next to splitter

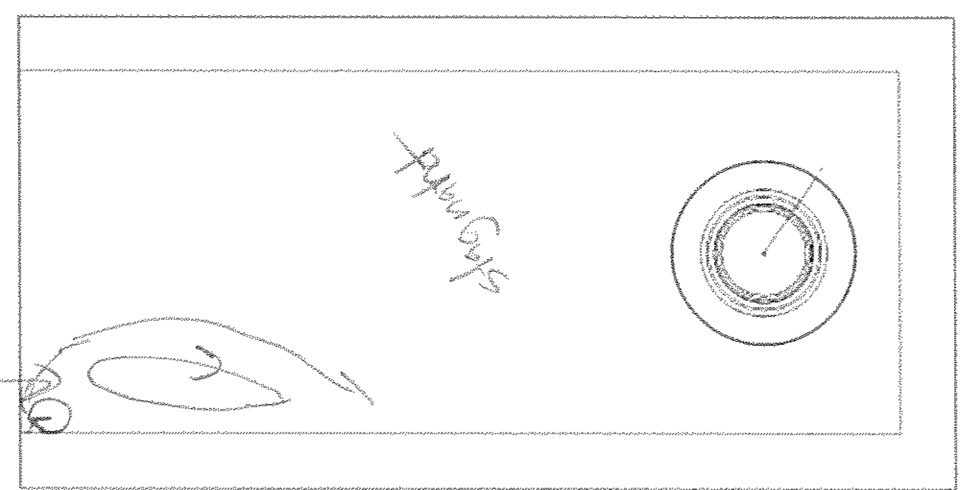
6 and 7 opposite

no coherent rotatio

TOP



SIDE



recirc

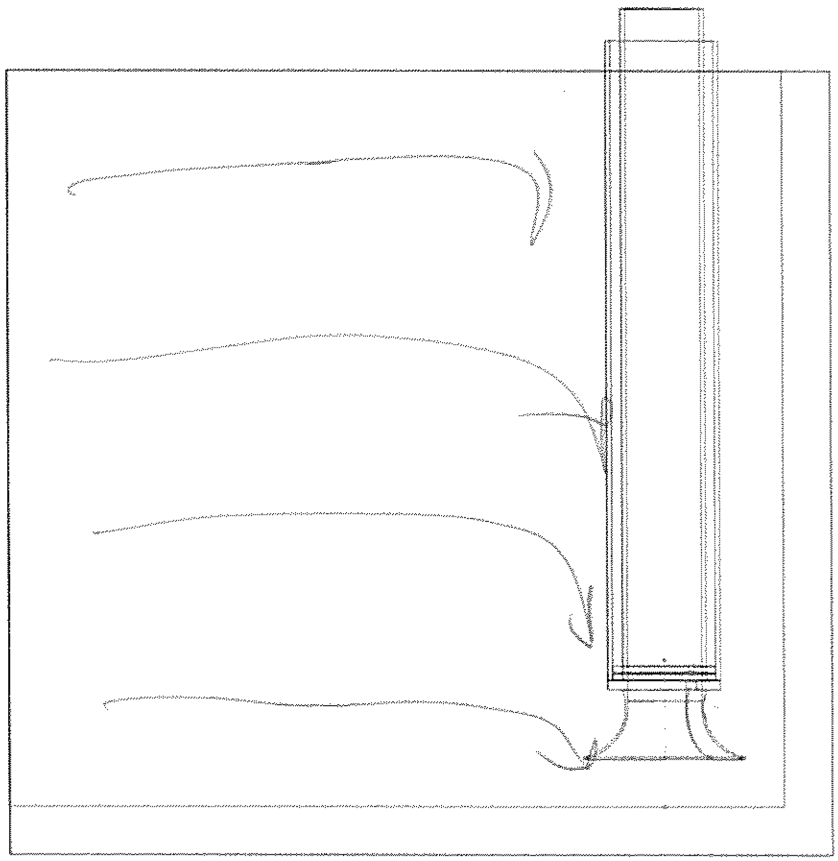
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

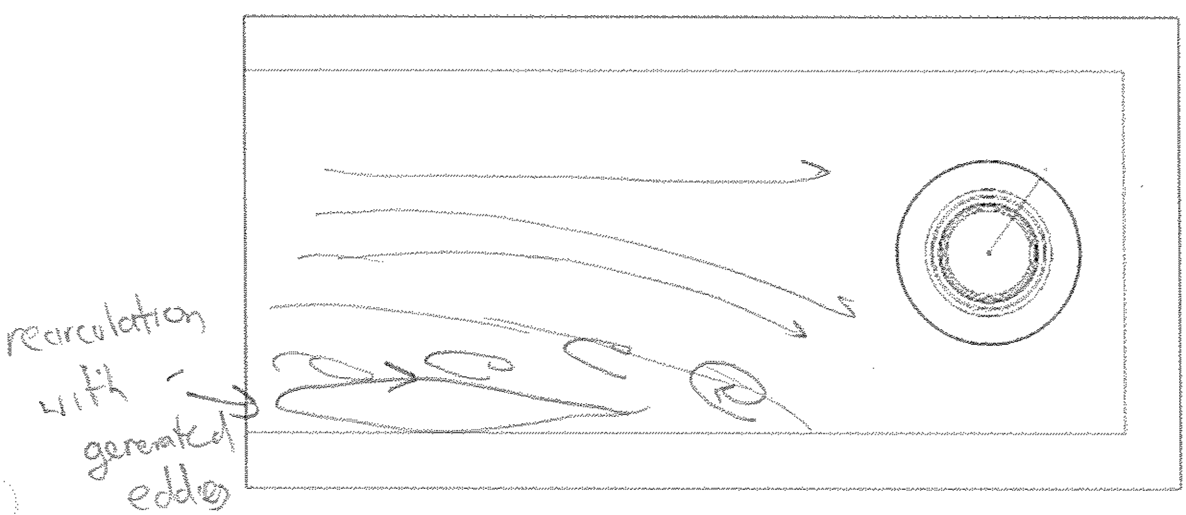
Scenario # and Description 11A Pumps 1-7 West Supply Bay 5

Run # SAFL 13 Notes by: PoBLG 14L Date / Time: 6/21

TOP



SIDE



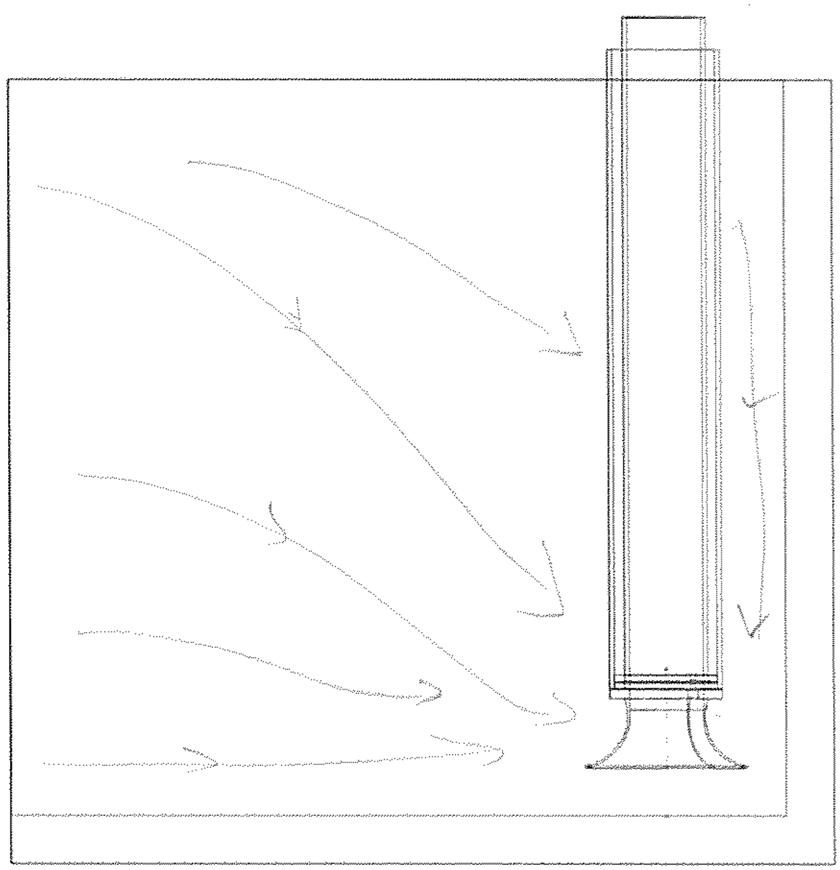
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

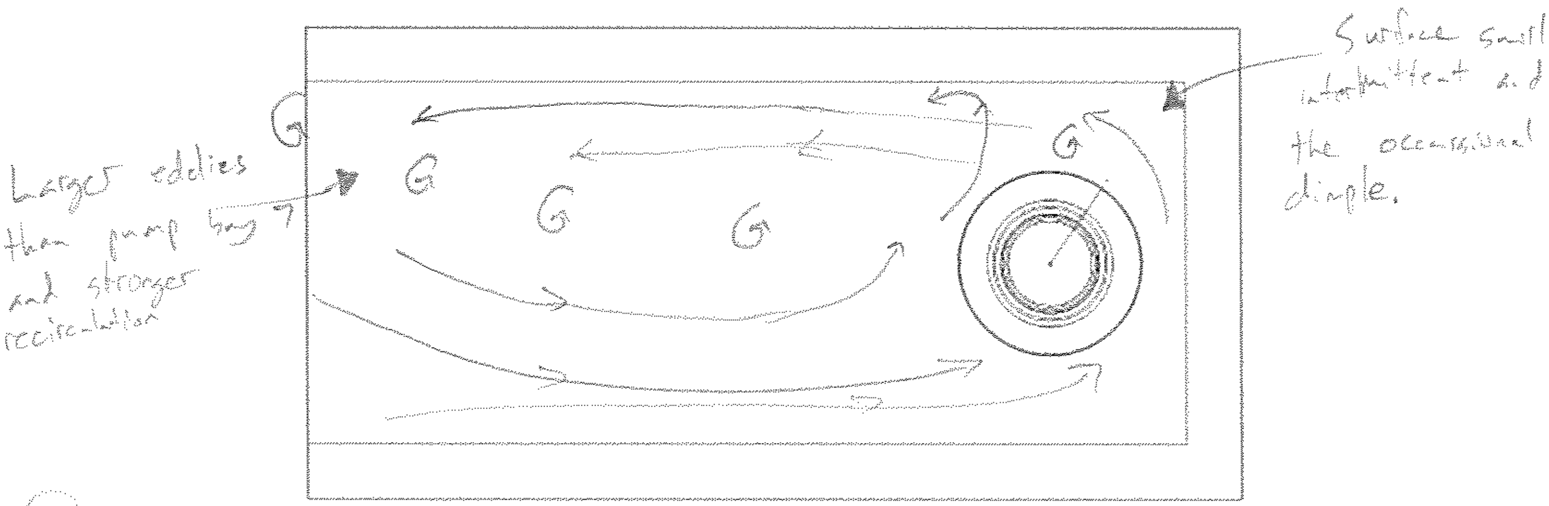
Scenario # and Description 11A Pumps 1-7 West Supply Bay 6

Run # SAFL 13 Notes by: RUBG ML Date / Time: 6/21

TOP



SIDE



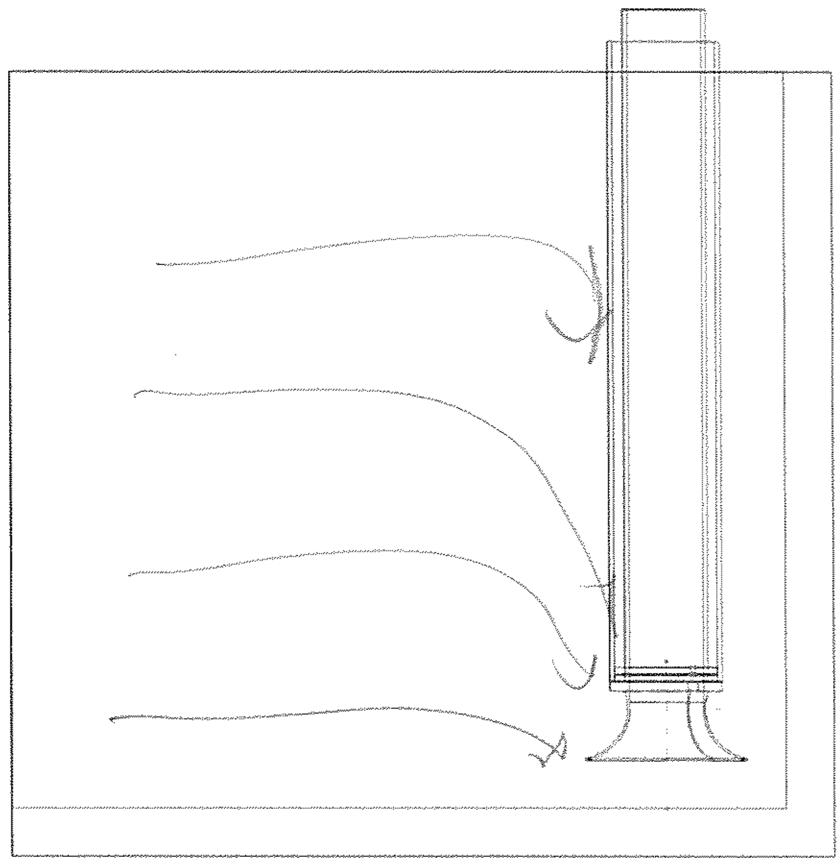
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

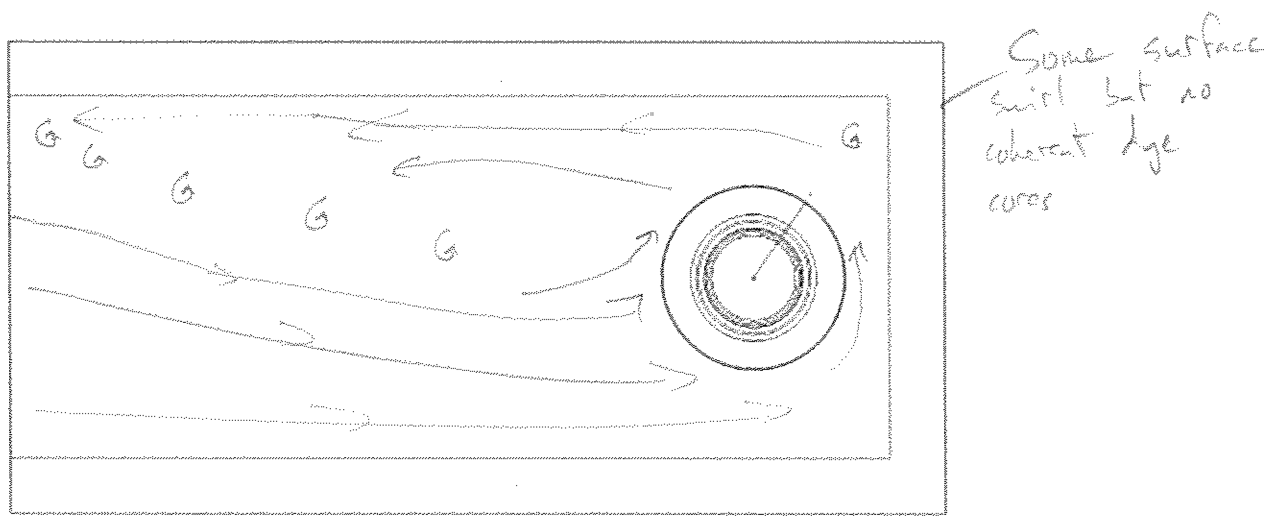
Scenario # and Description 11A Pumps 1-7 West Supply Bay 7

Run # SAFL 13 Notes by: RoBG ML Date / Time: 6/21

TOP



SIDE

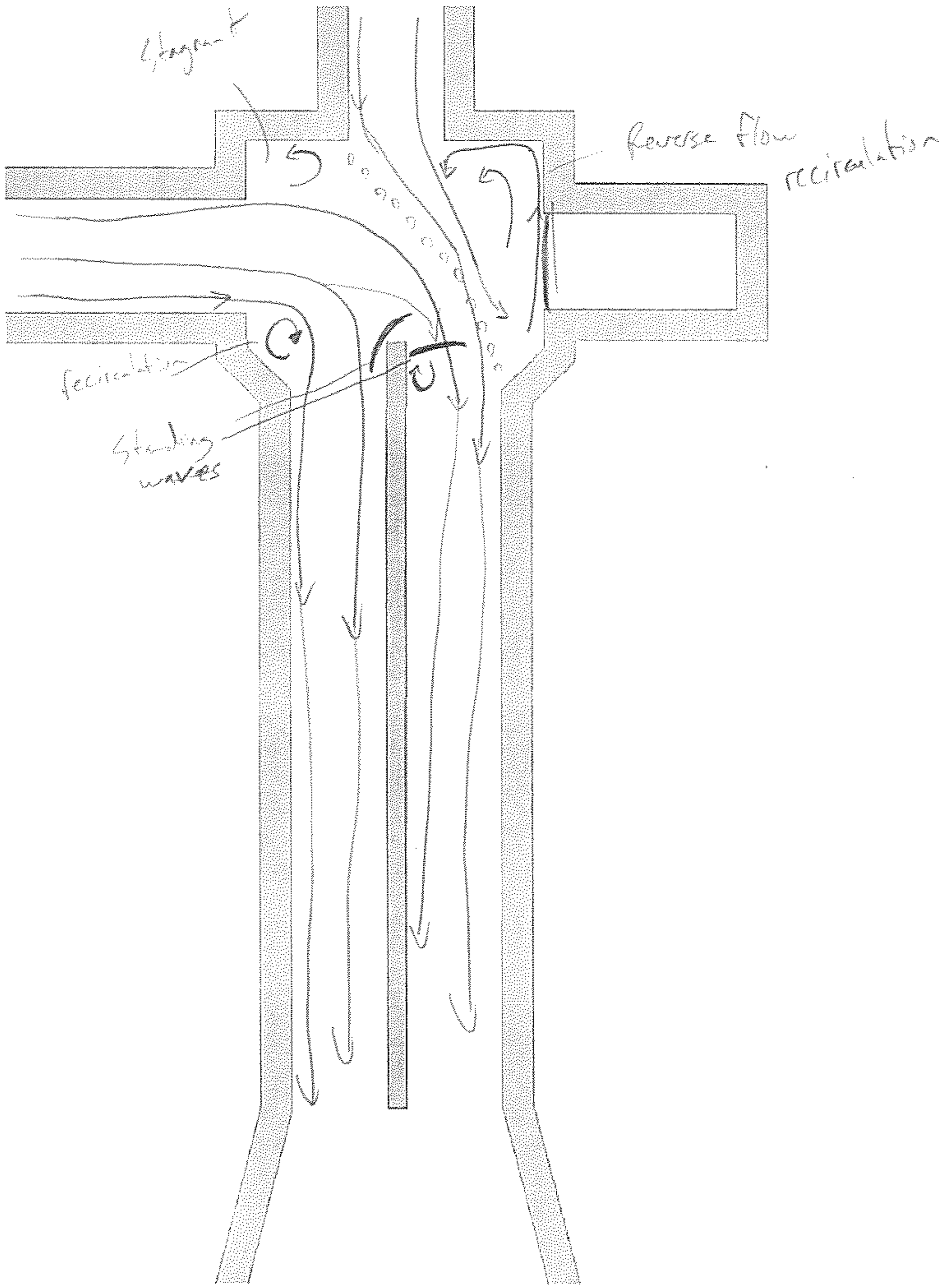


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 12 Pumps 1-7 25% North 75% West

Run #__________ Notes by: Rob G Date / Time: __________

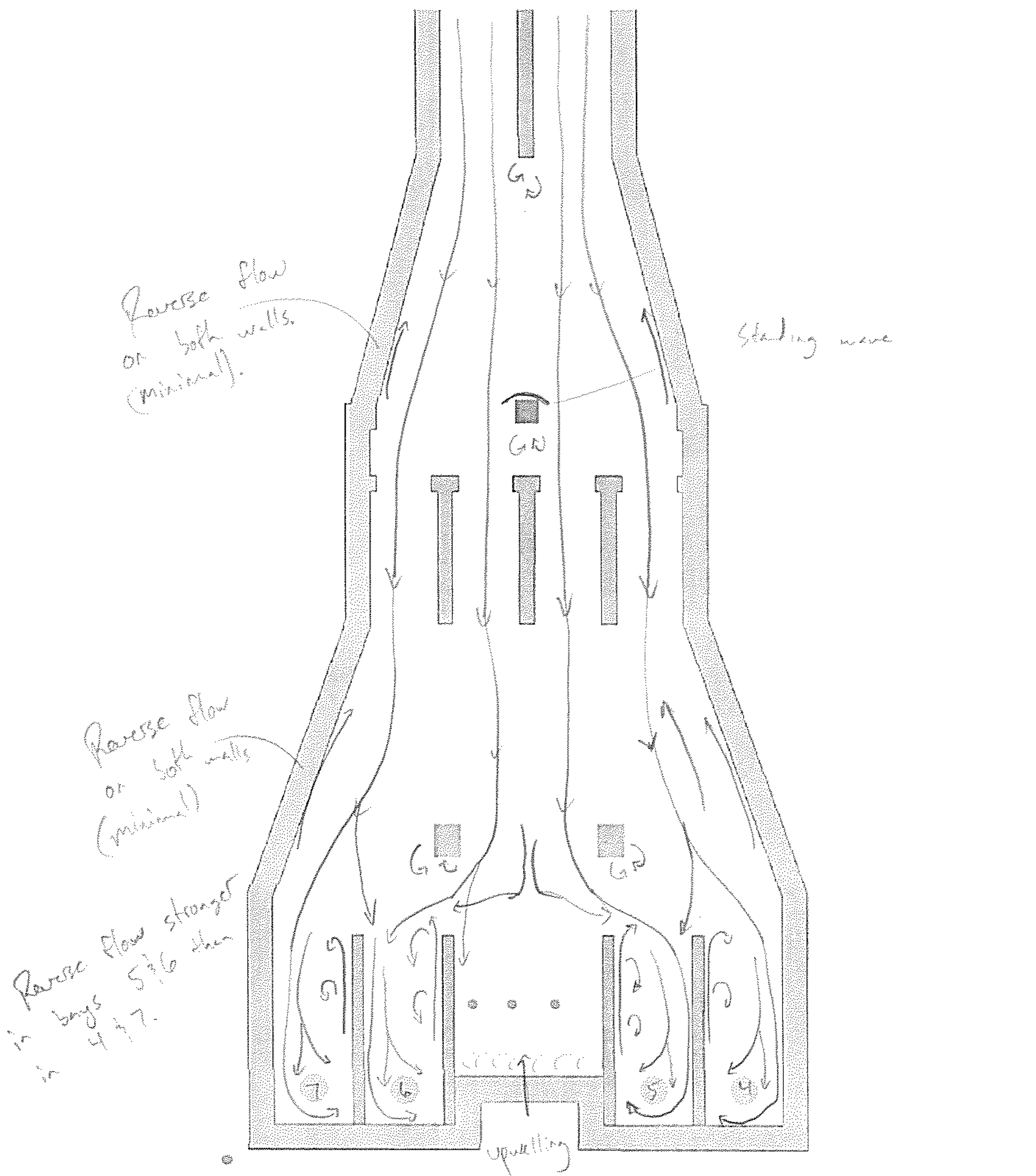


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 12 Pumps 1-7 25% North 75% West

Run #__________ Notes by: ____________________ Date / Time: ____________________

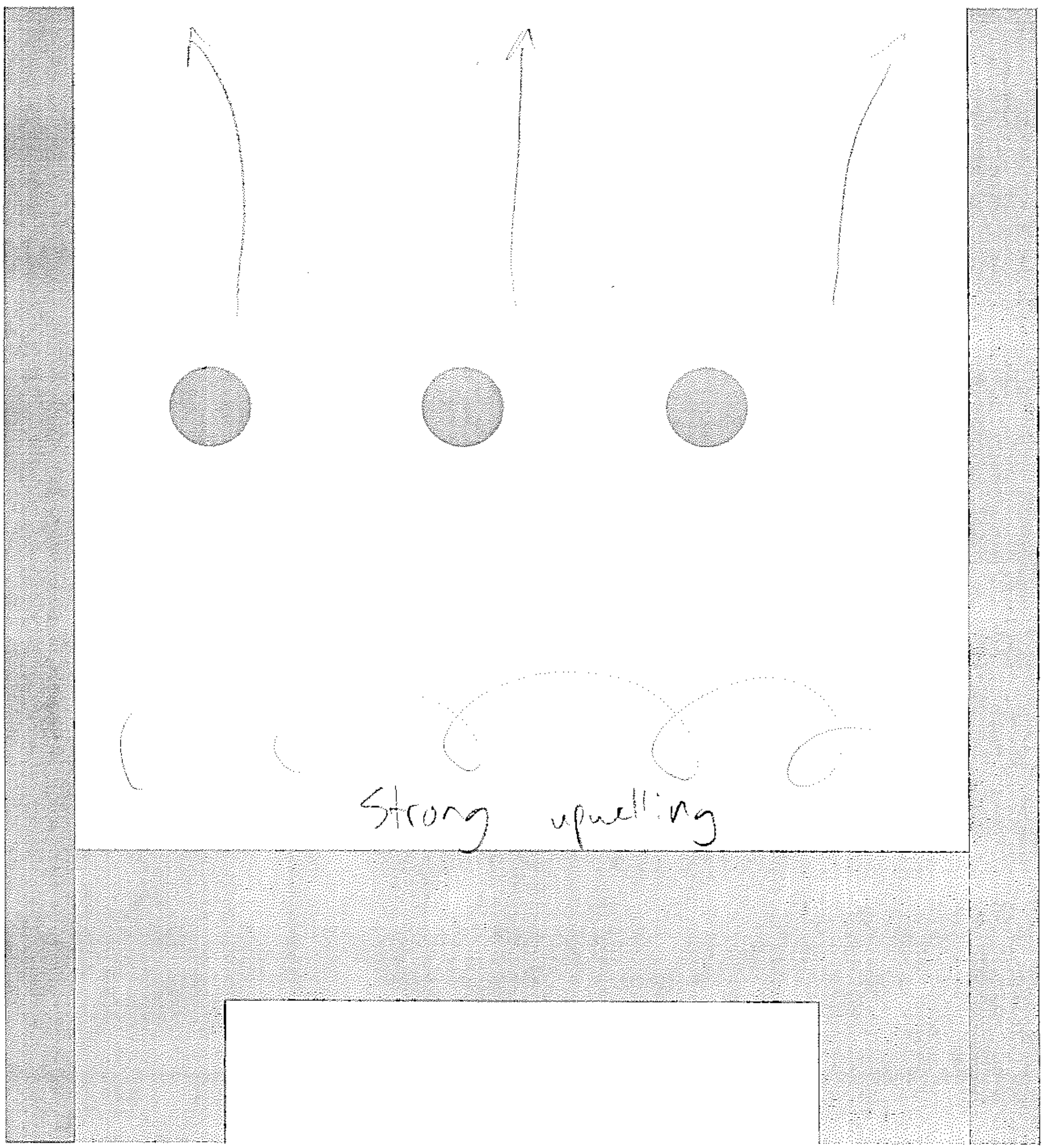


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description 12 Pumps 1-7 25% North 75% West

Run #__________ Notes by: ______________________ Date / Time: ______________________



Difficult to track movement because of the upwelling

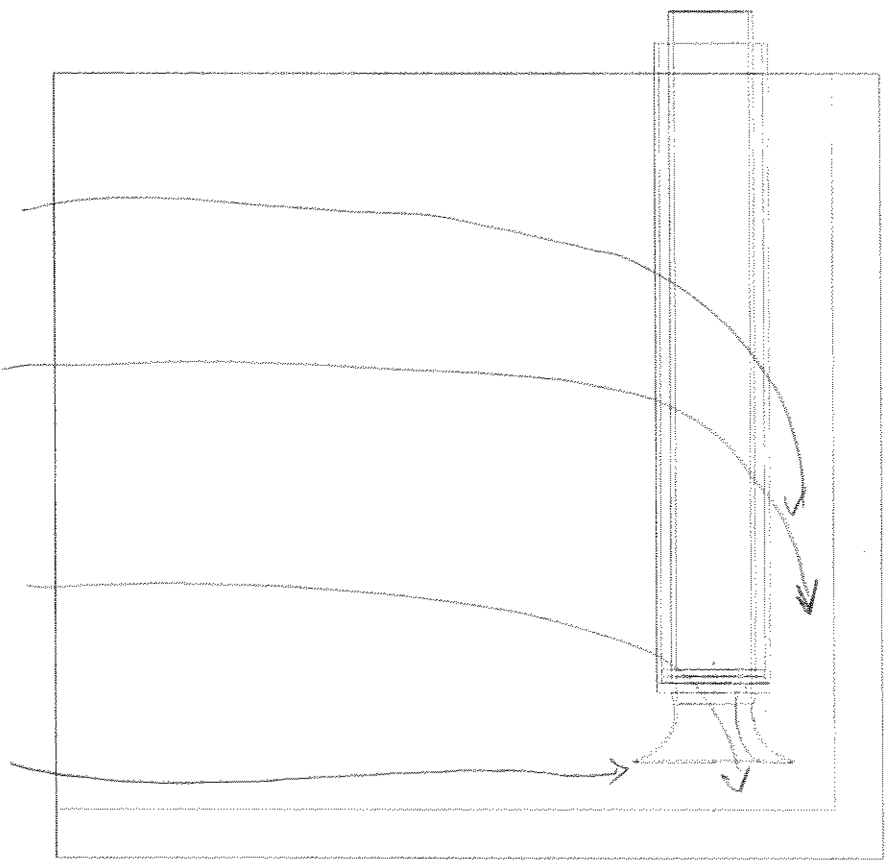
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 12 Pumps 1-7 25% North 75% West Bay 4

Run # ________ Notes by: Rob G Date / Time: ________

TOP



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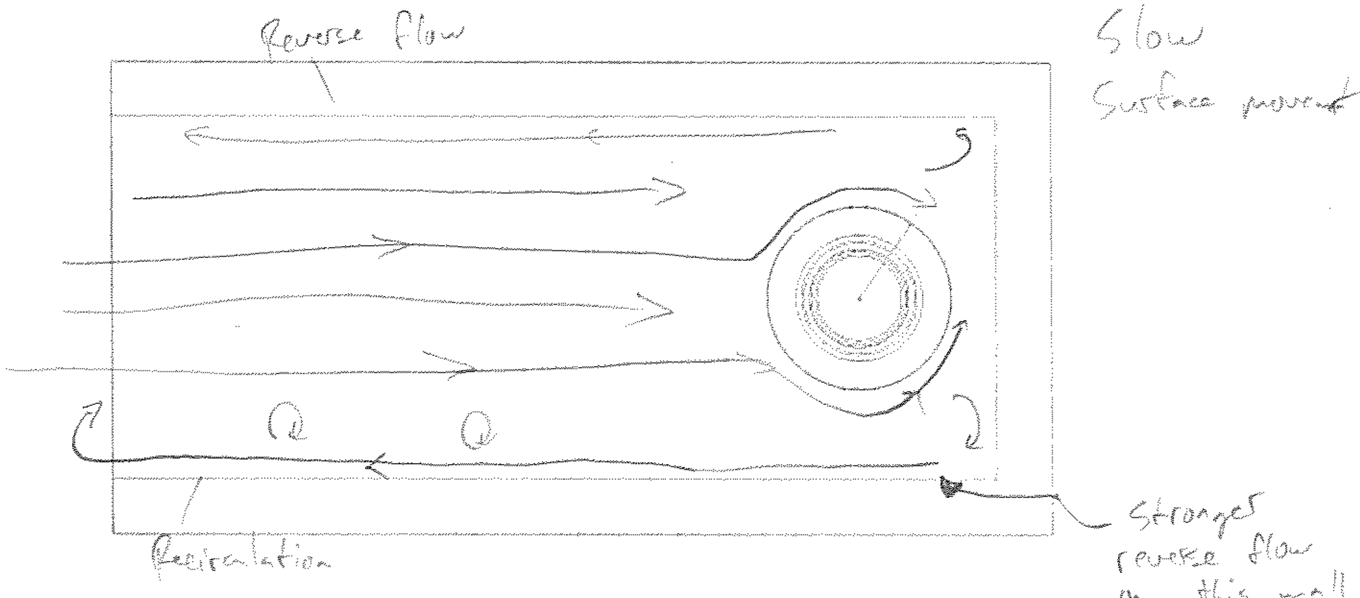


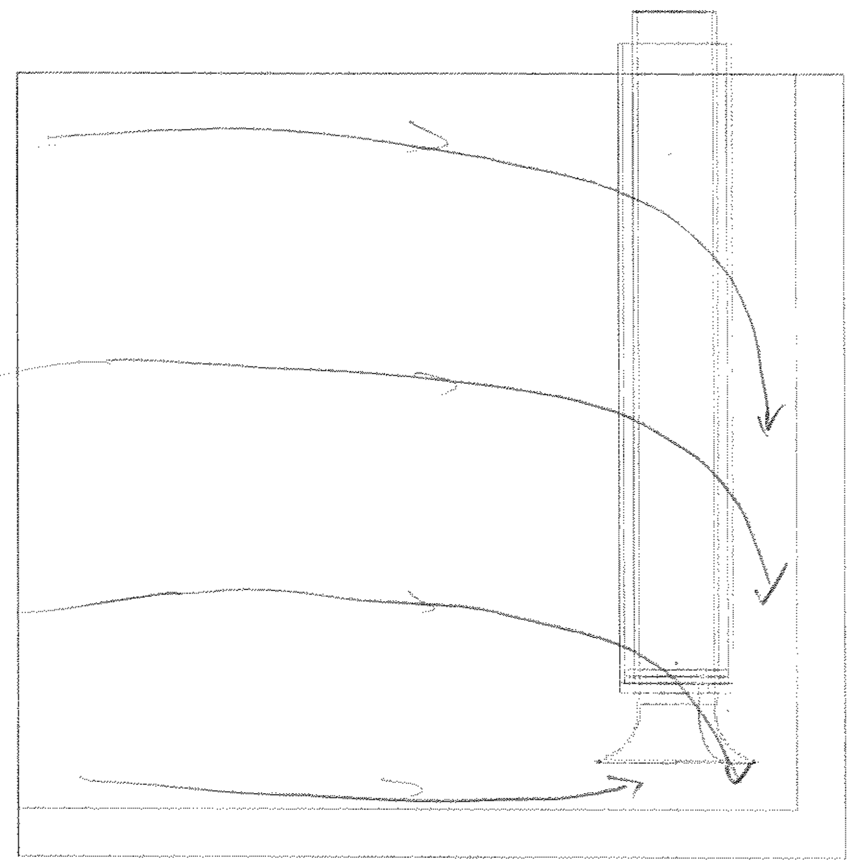
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 12 Pumps 1-7 25% North 75% West Bay 5

Run #__________ Notes by: Rob G Date / Time: __________

TOP



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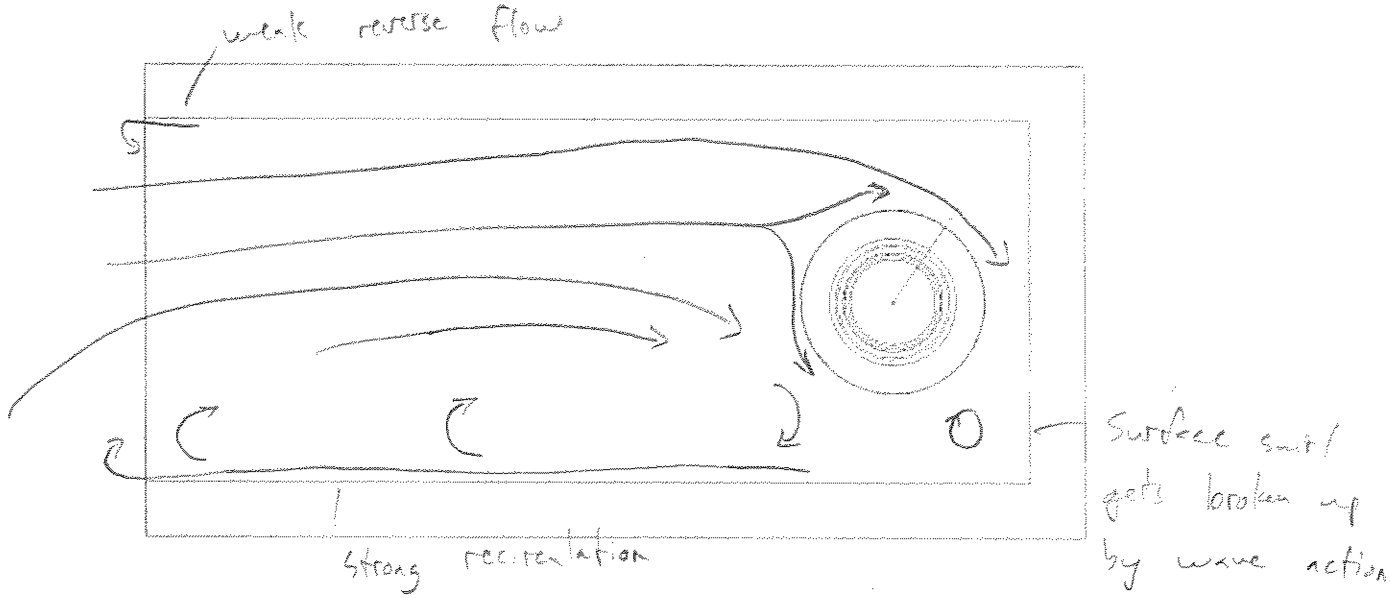


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

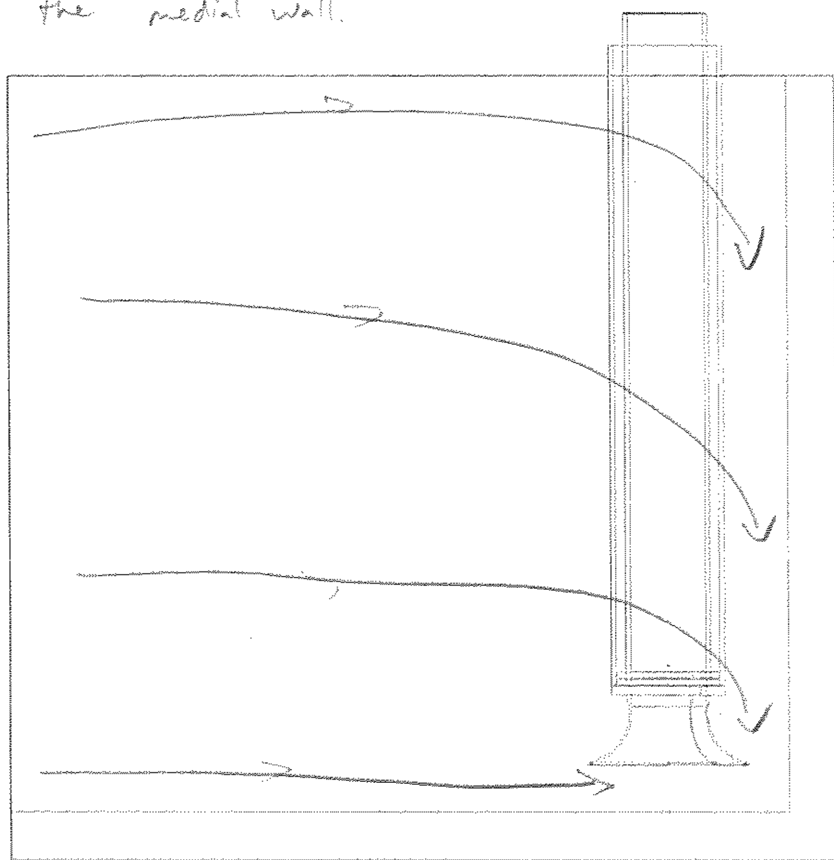
Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 12 Pumps 1-7 25% North 75% West Bay 6

Run # __________ Notes by: Rob G. Date / Time: __________

- Bay 6 might have the strongest recirculation on the medial wall.

TOP



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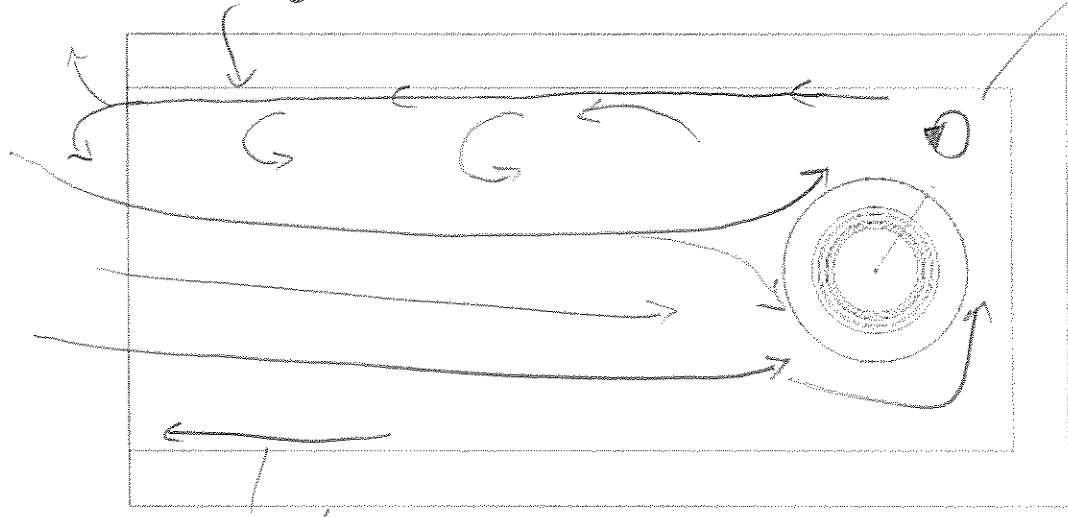


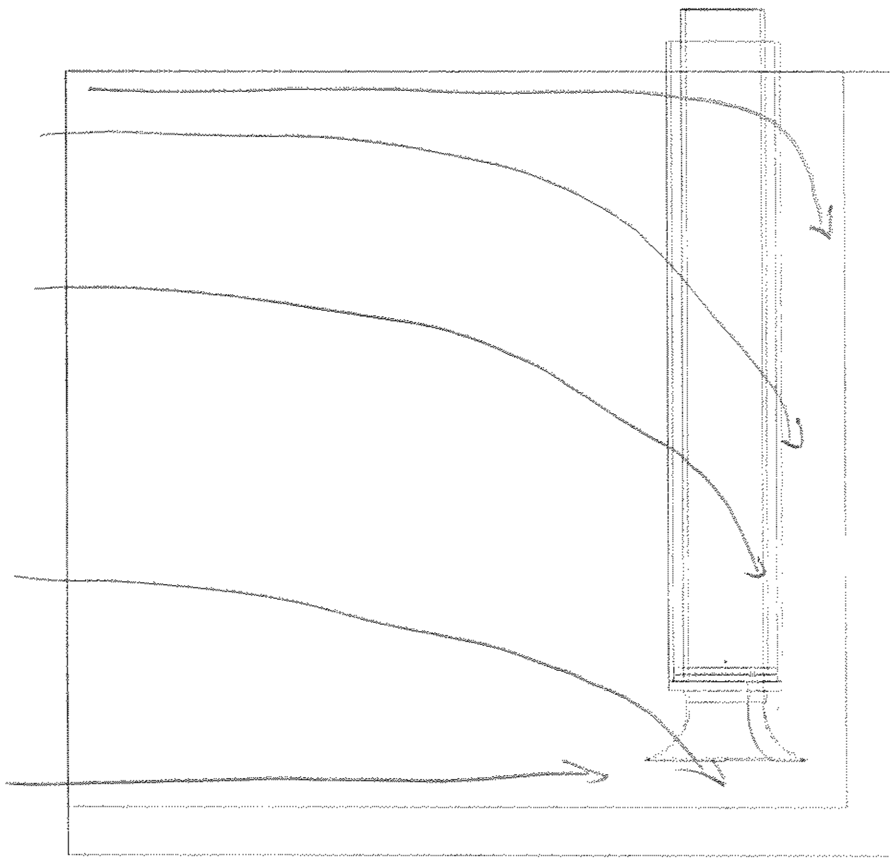
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 12 Pumps 1-7 25% North 75% West Bay 7

Run #__________ Notes by: Rob G Date / Time: __________

TOP



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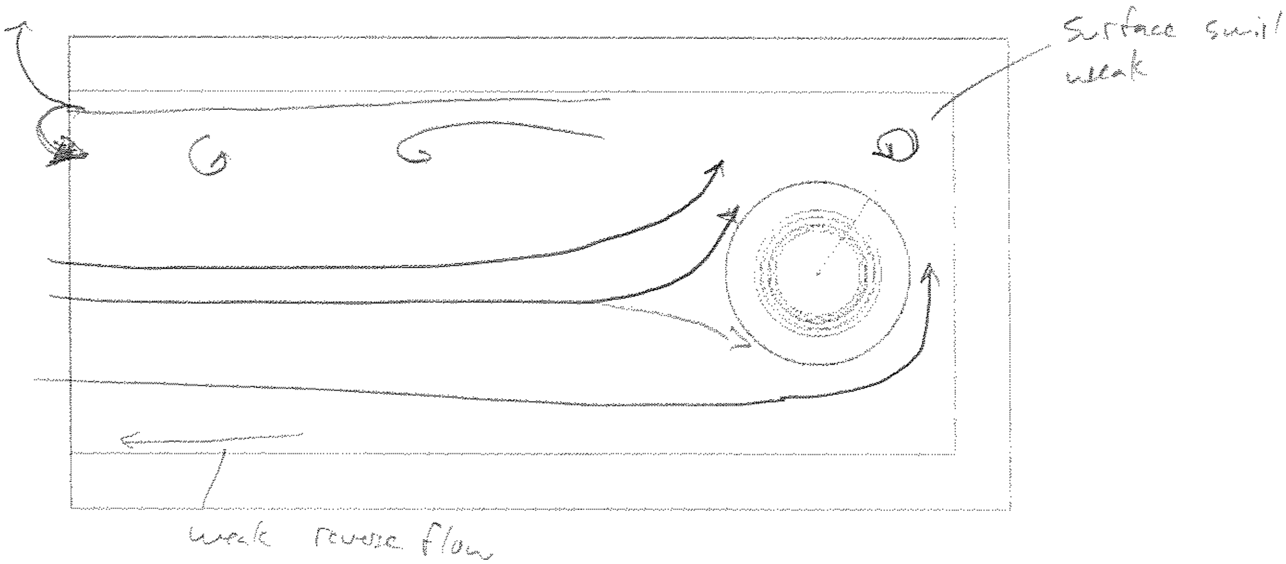
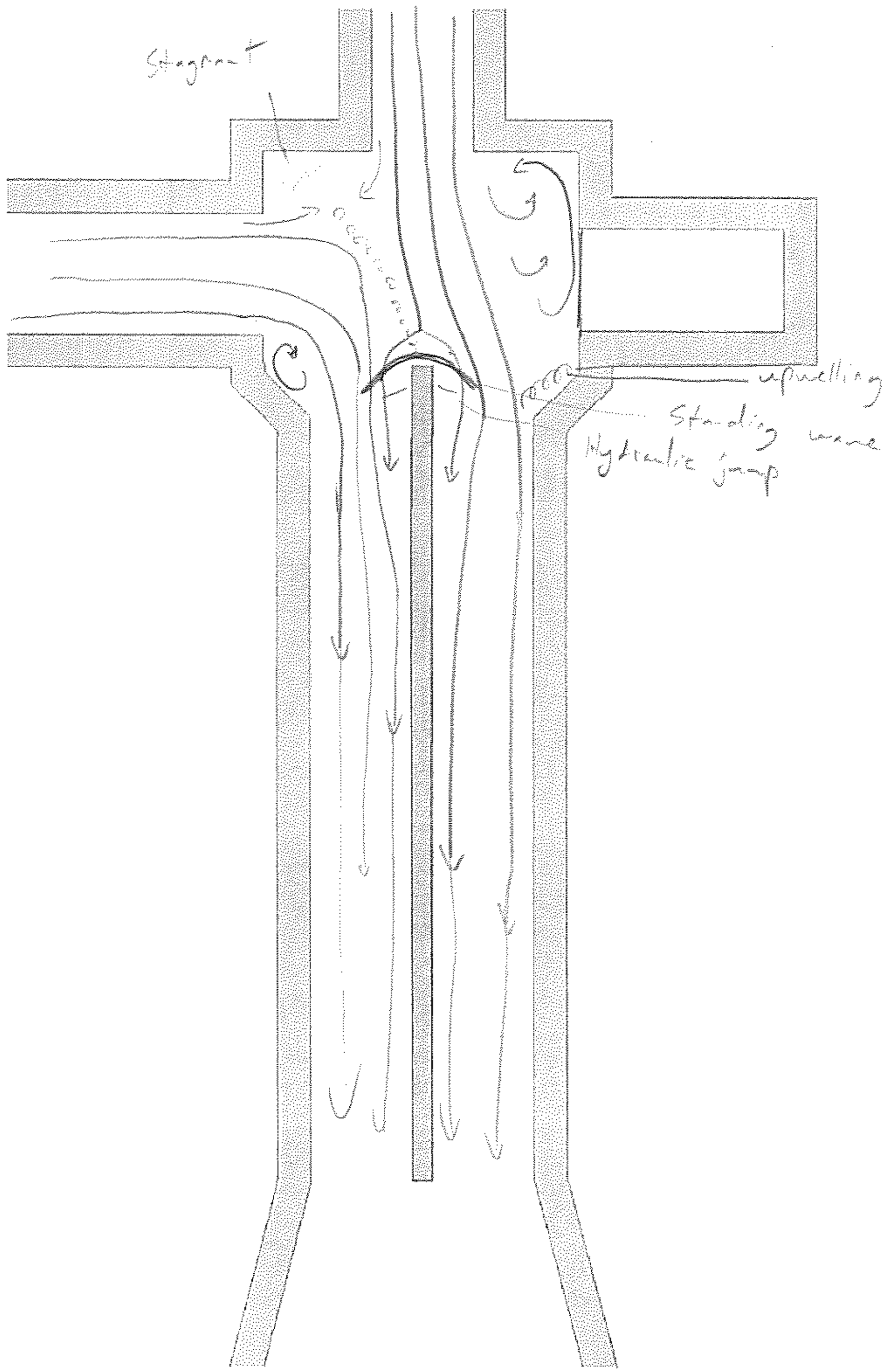


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 13 Pumps 1-7 50/50 North & West

Run #________ Notes by: RobG Date / Time: ________

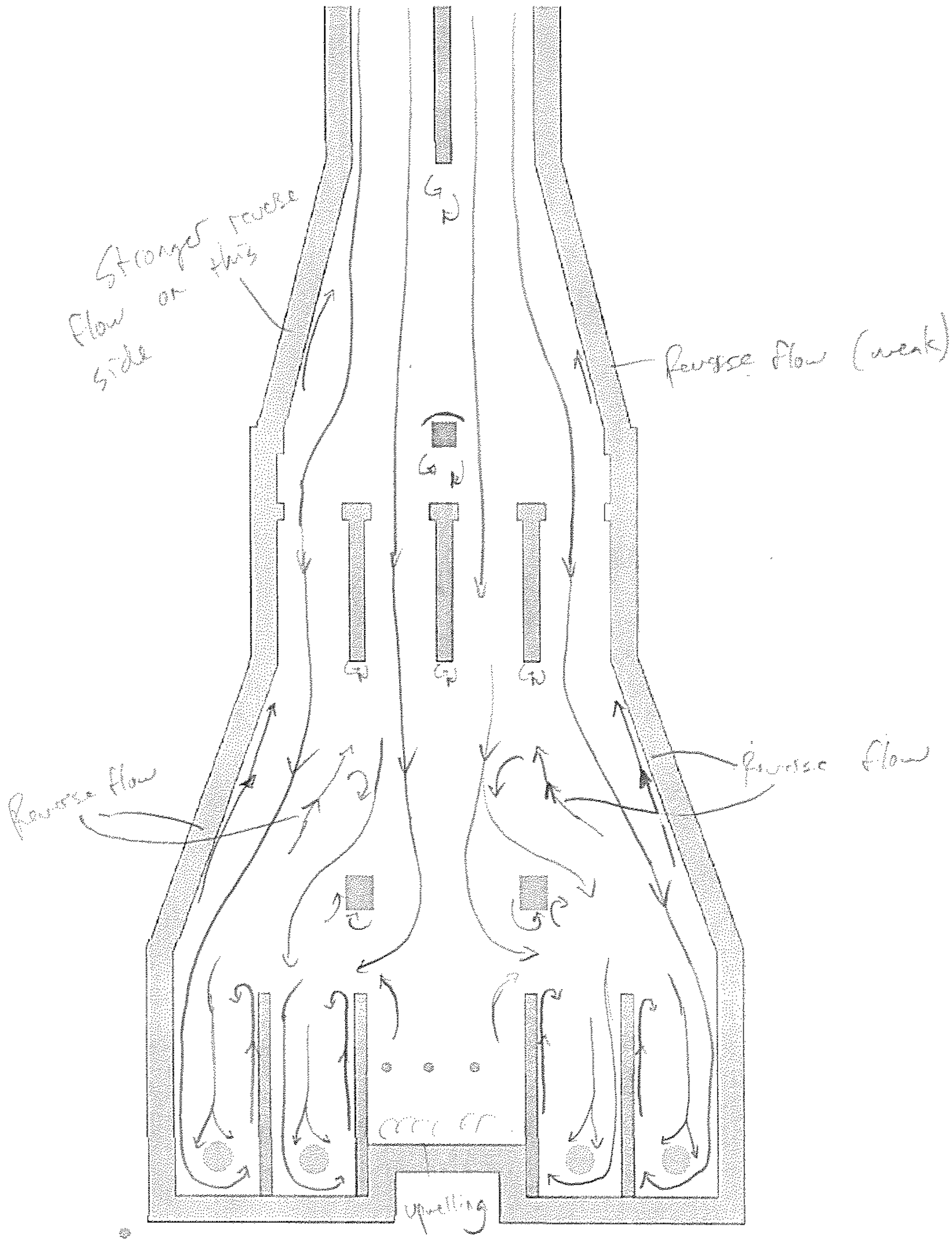


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 13 Pumps 1-7 50/50 North & West

Run #__________ Notes by: Rob G Date / Time: __________

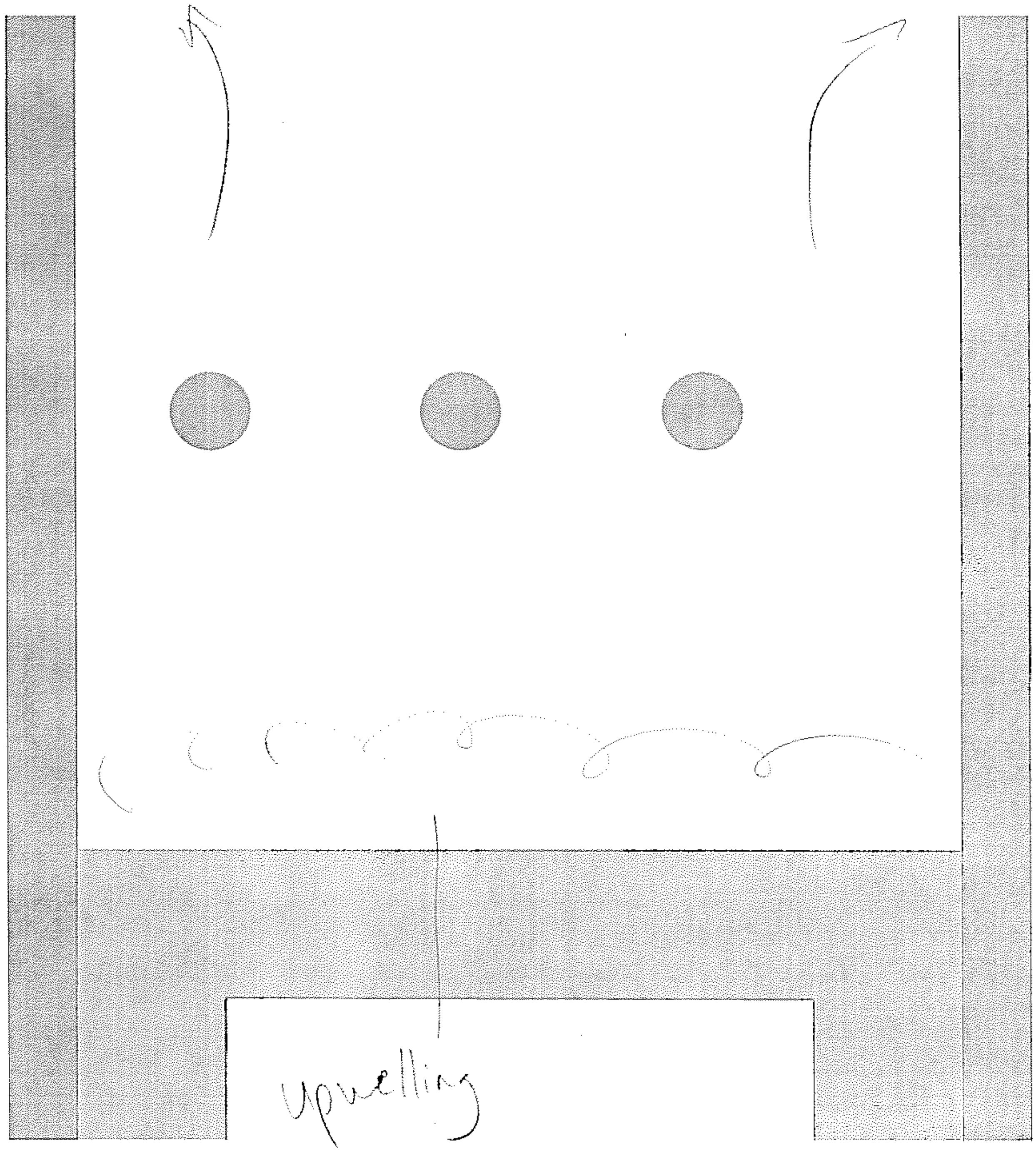


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description 13 Pumps 1-7 50/50 North & West

Run #_________ Notes by: Rob G Date / Time: __________________



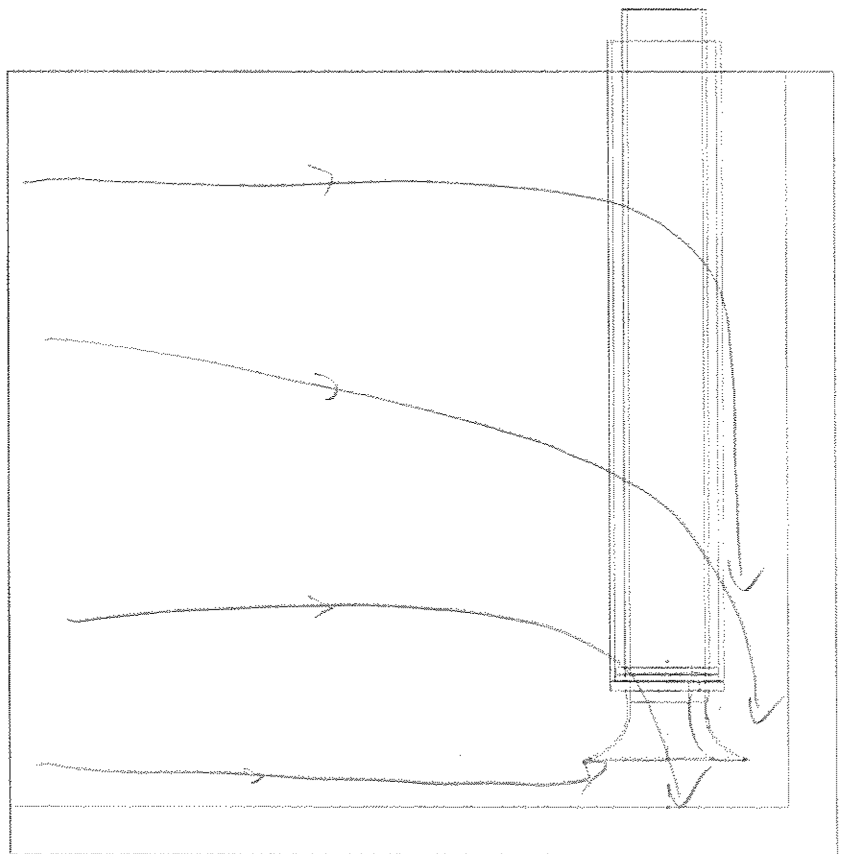
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 13 Pumps 1-7 50/50 North & West Bay 4

Run #__________ Notes by: ____________________ Date / Time: ____________________

TOP



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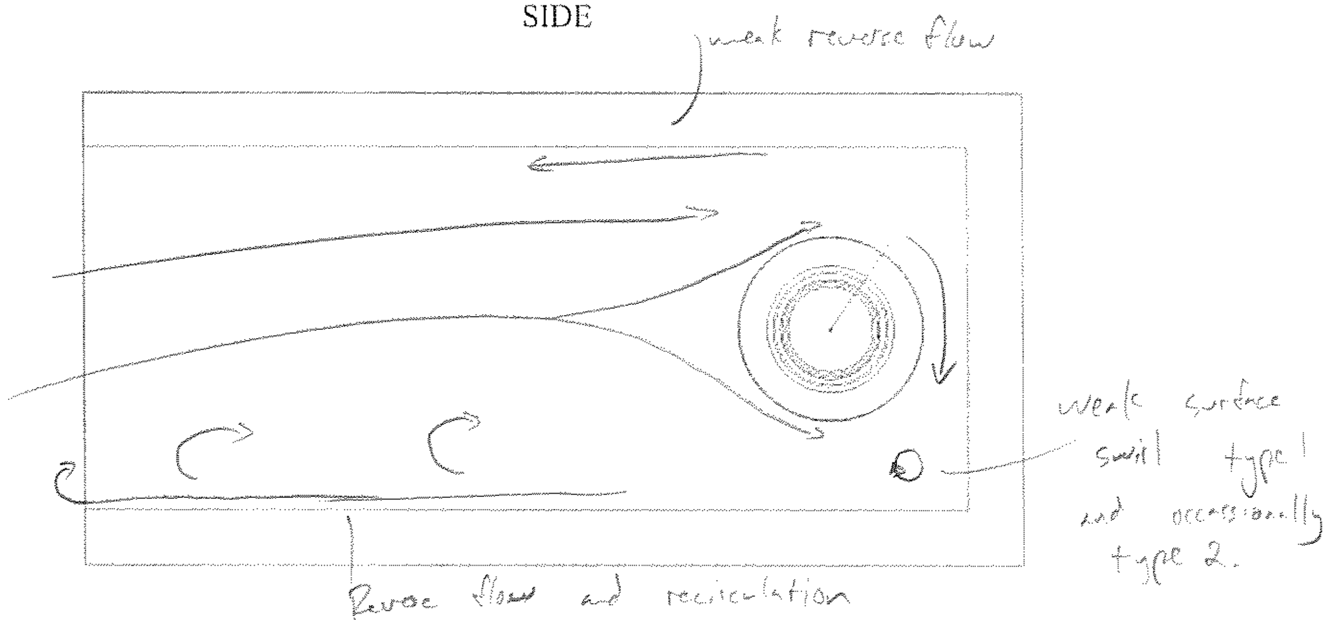


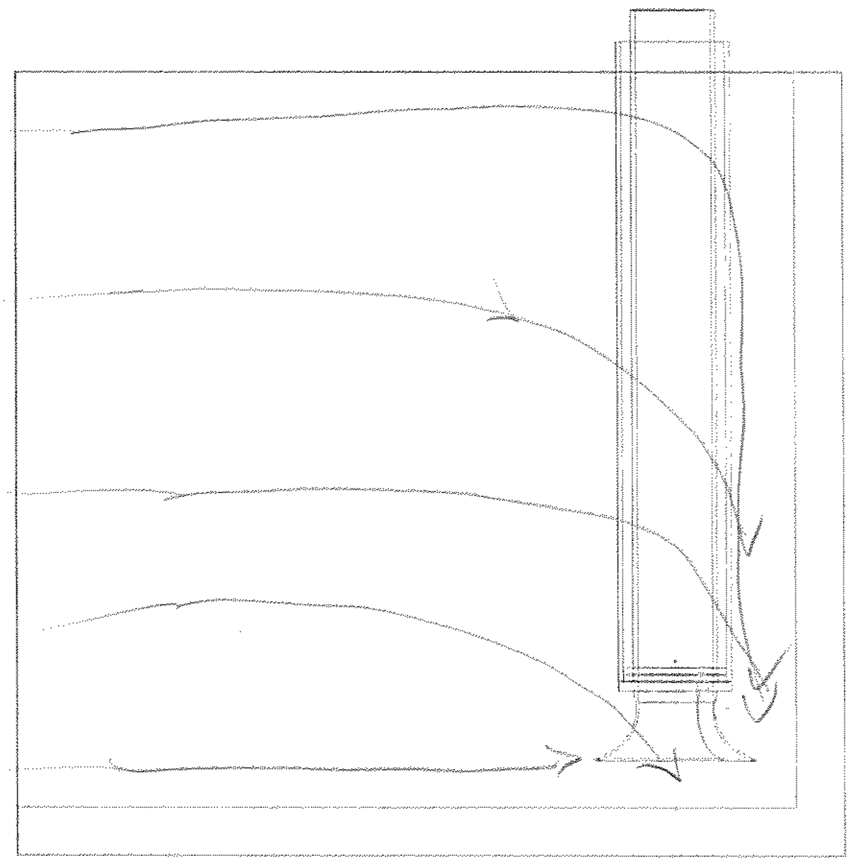
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 13 Pumps 1-7 50/50 North & West Bay 5

Run #________ Notes by: Bob G Date / Time: ________

TOP



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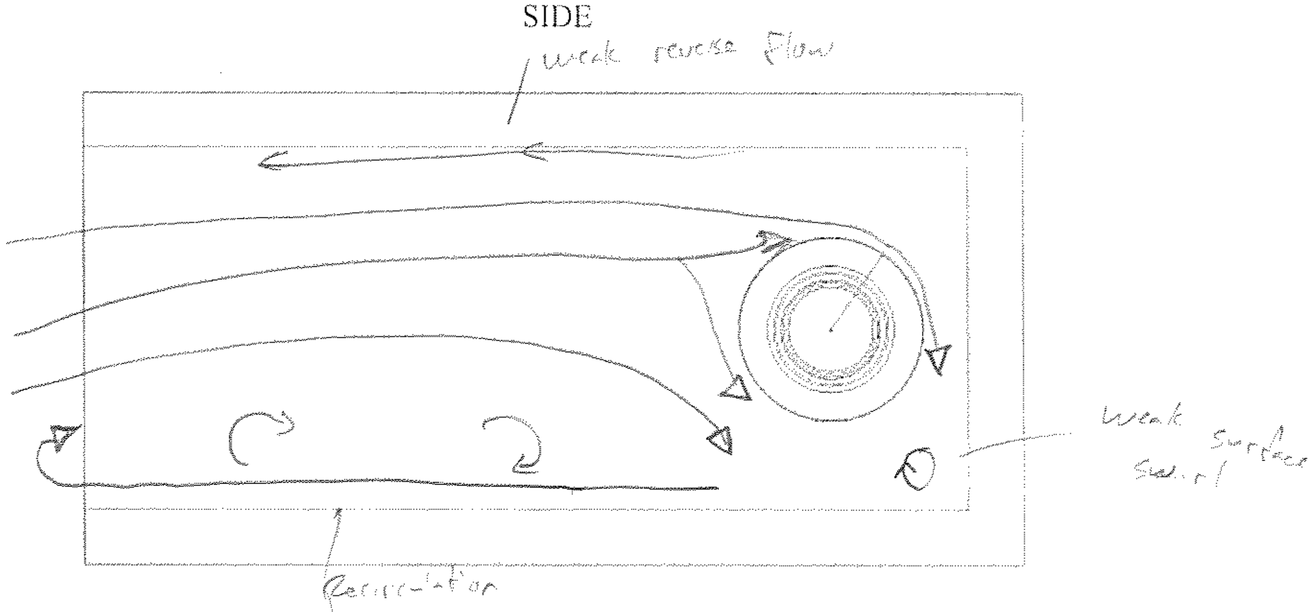


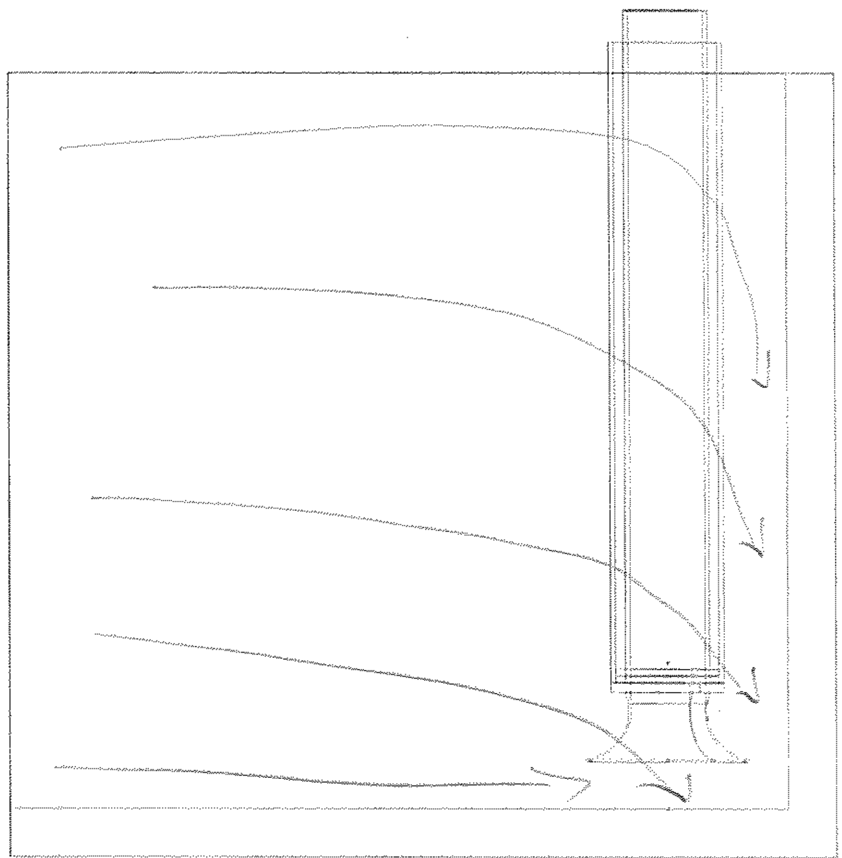
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 13 Pumps 1-7 50/50 North & West Bay 6

Run #__________ Notes by: Rob G. Date / Time: __________

TOP



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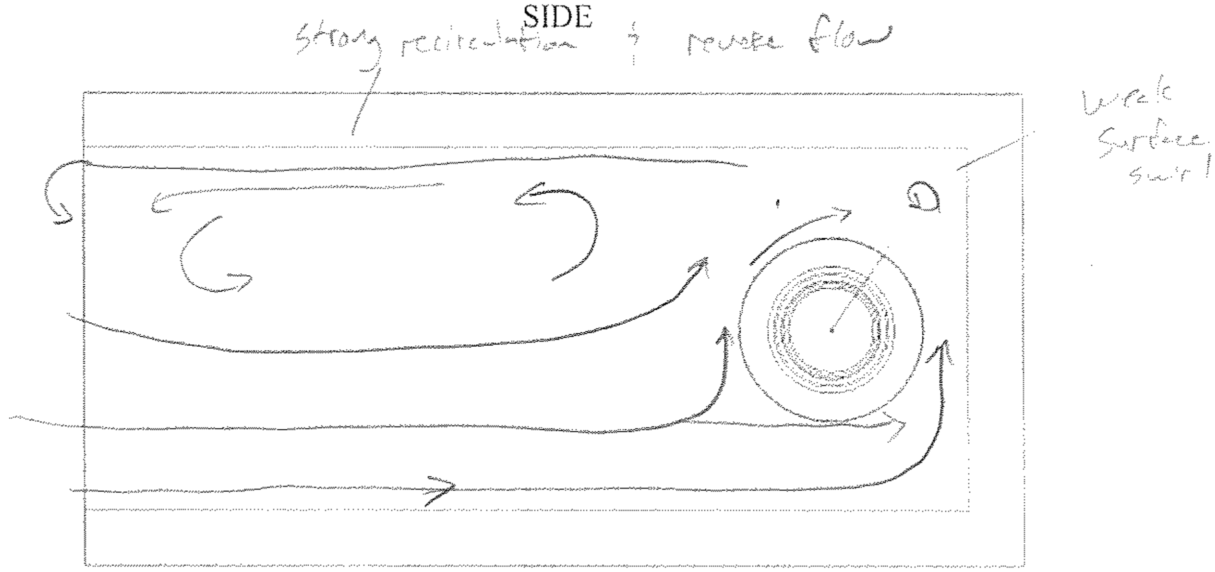


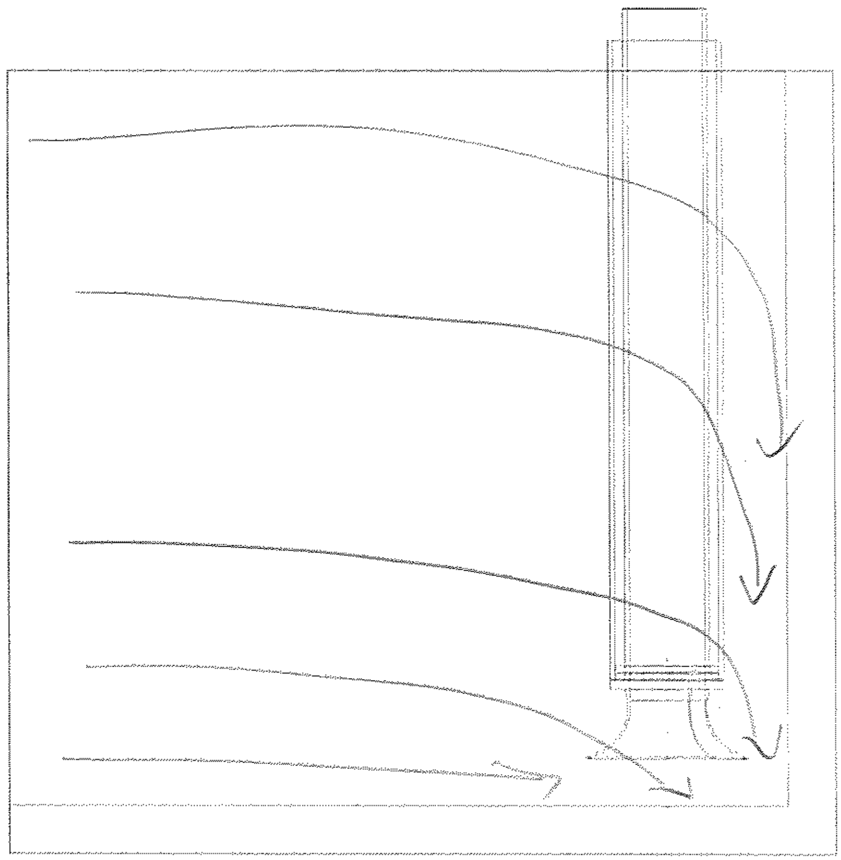
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 13 Pumps 1-7 50/50 North & West Bay 7

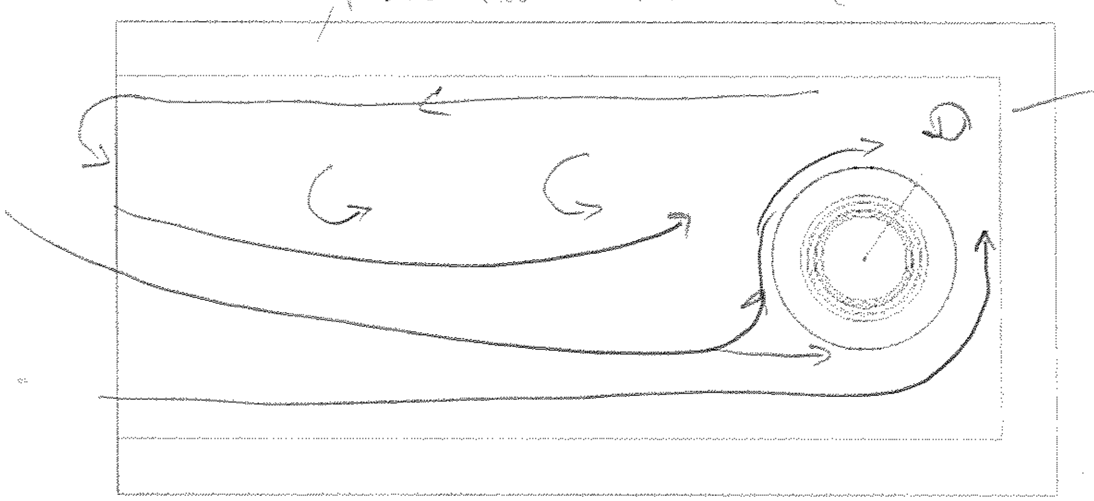
Run #__________ Notes by: Rob G Date / Time: ____________________

TOP



SIDE

Reverse flow & recirculation (Not as strong as bay #6)

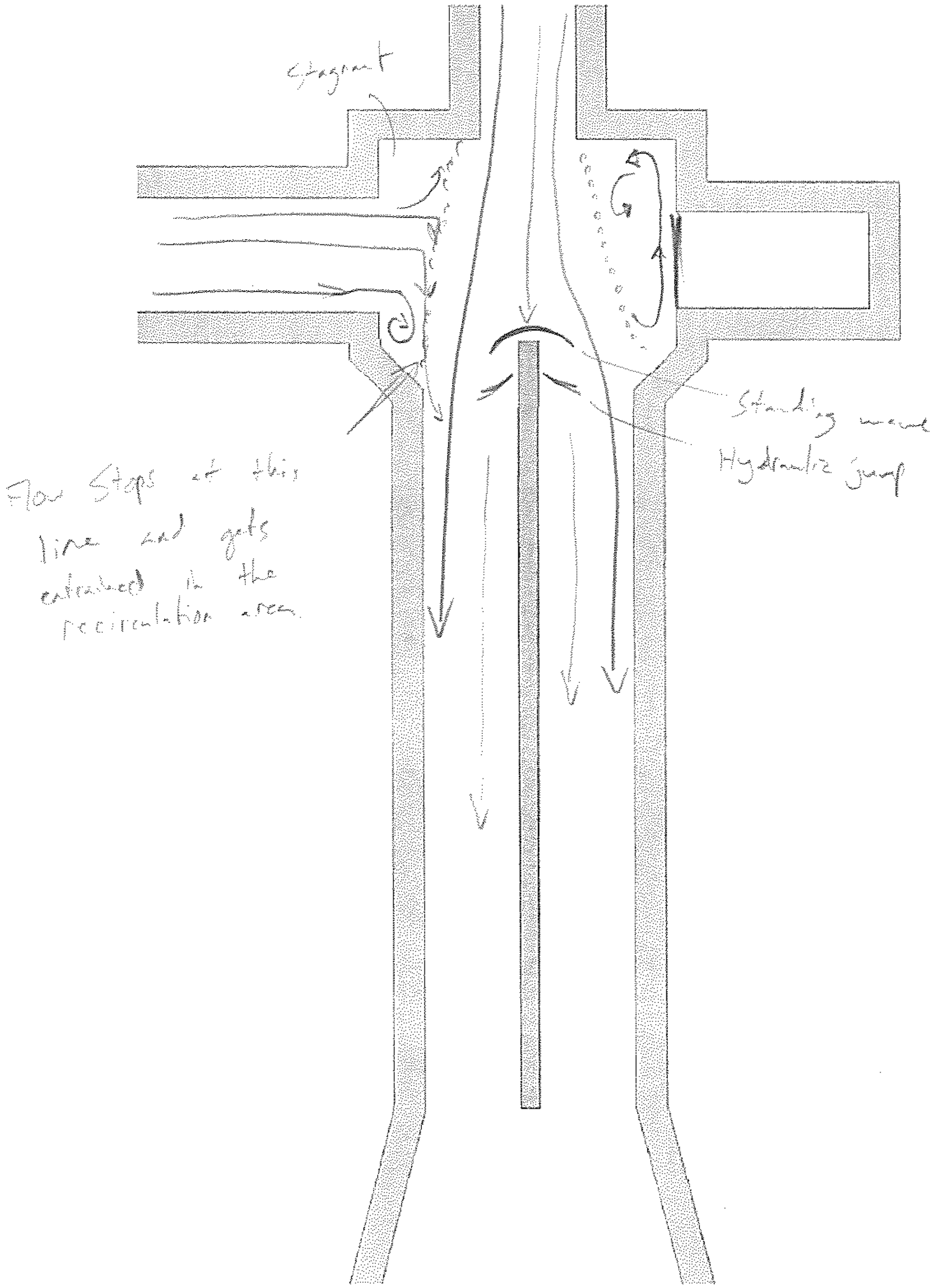


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description 14 Pumps 1-7 75% North 25% West

Run #__________ Notes by: RoBGr Date / Time: ______________

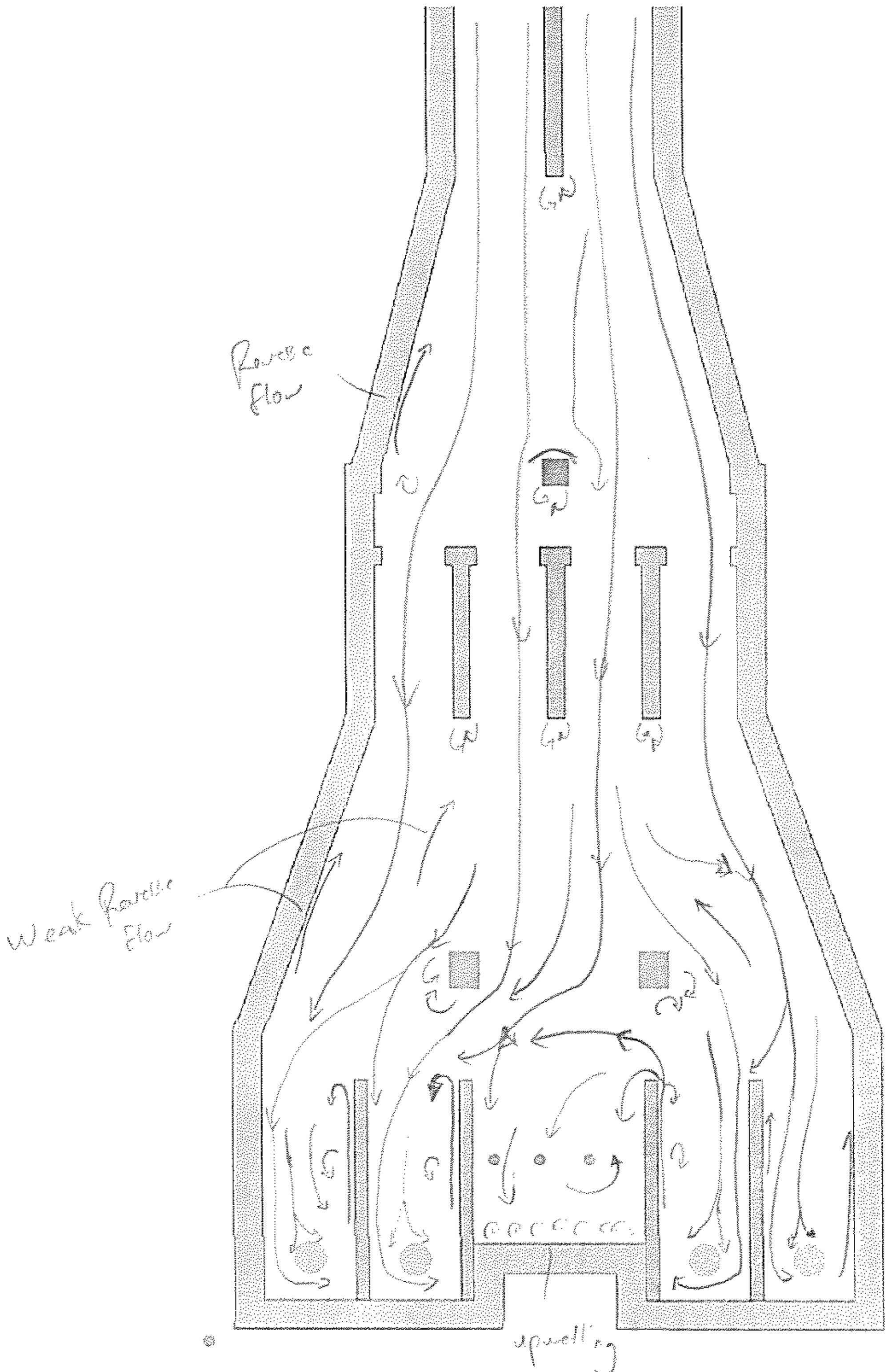


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description 14 Pumps 1-7 75% North 25% West

Run #__________ Notes by: Rob G Date / Time: __________

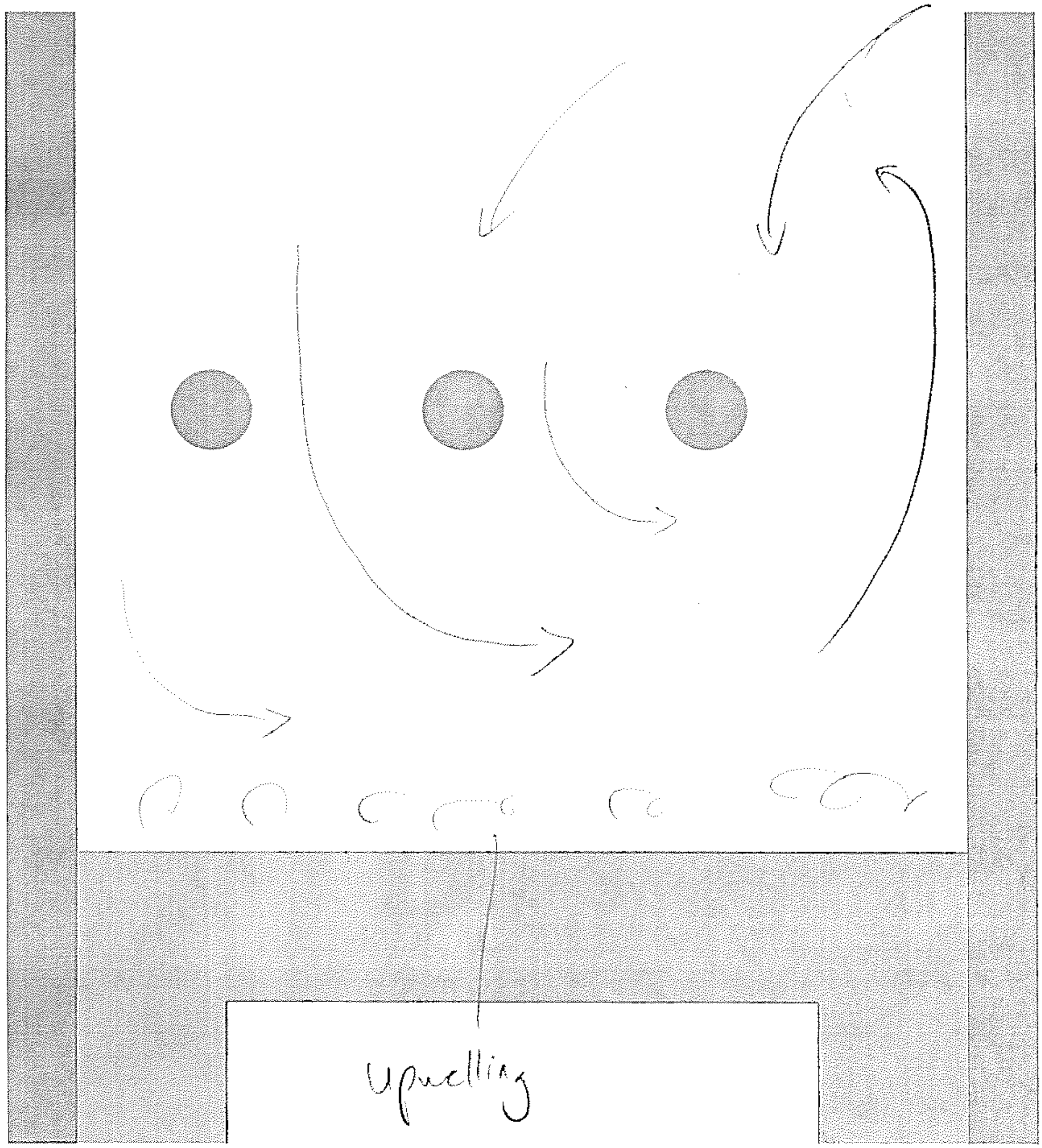


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description 14 Pumps 1-7 75% North 25% West

Run #__________ Notes by: RobG Date / Time: ____________________



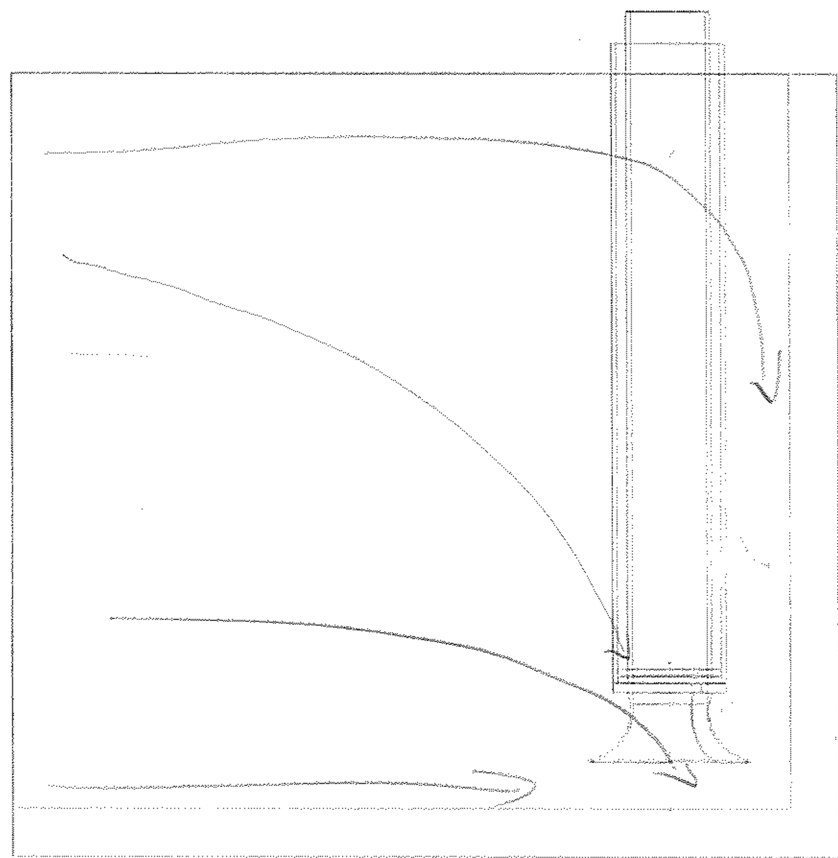
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 14 Pumps 1-7 75% North 25% West Bay 4

Run #________ Notes by: Rob G Date / Time: ________

TOP



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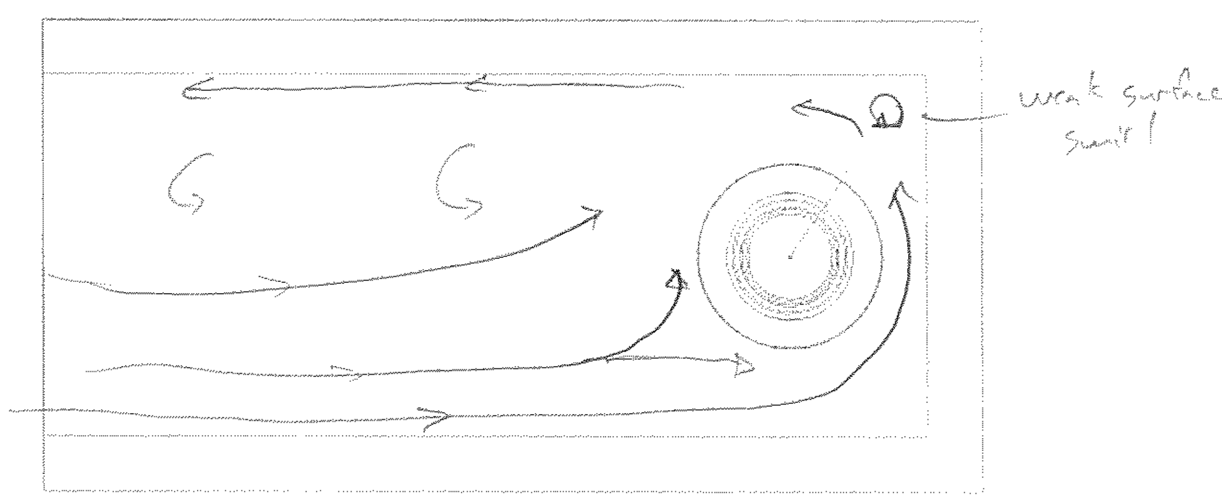


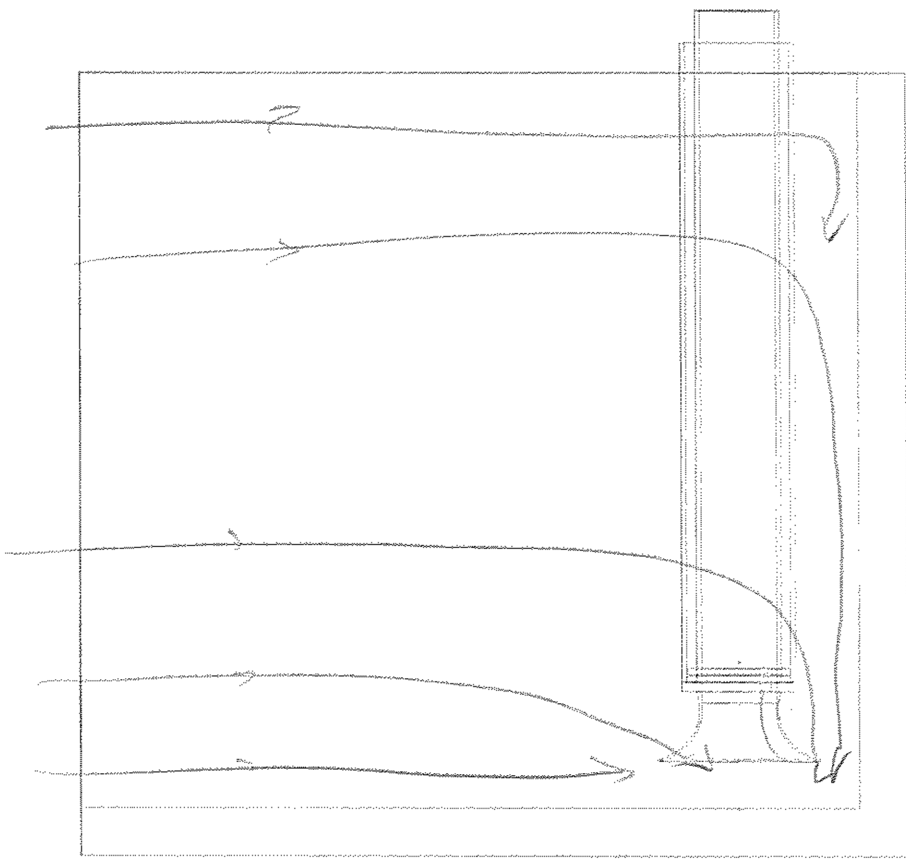
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 14 Pumps 1-7 75% North 25% West Bay 5

Run #__________ Notes by: ROB G Date / Time: __________

TOP



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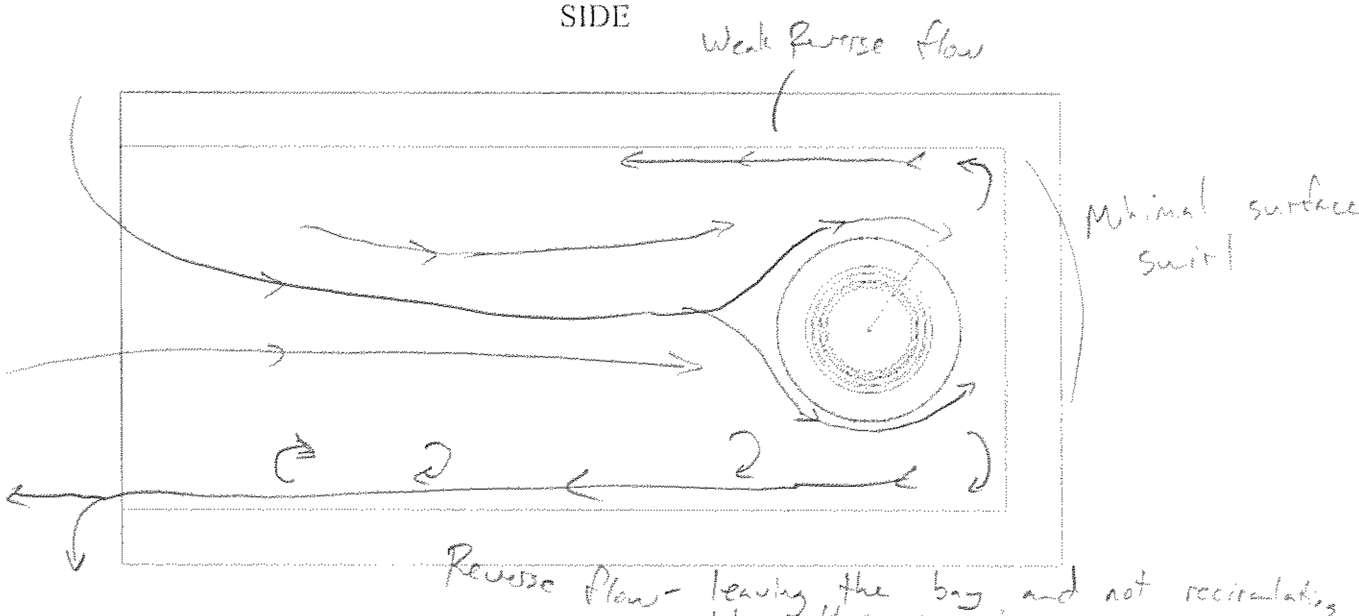


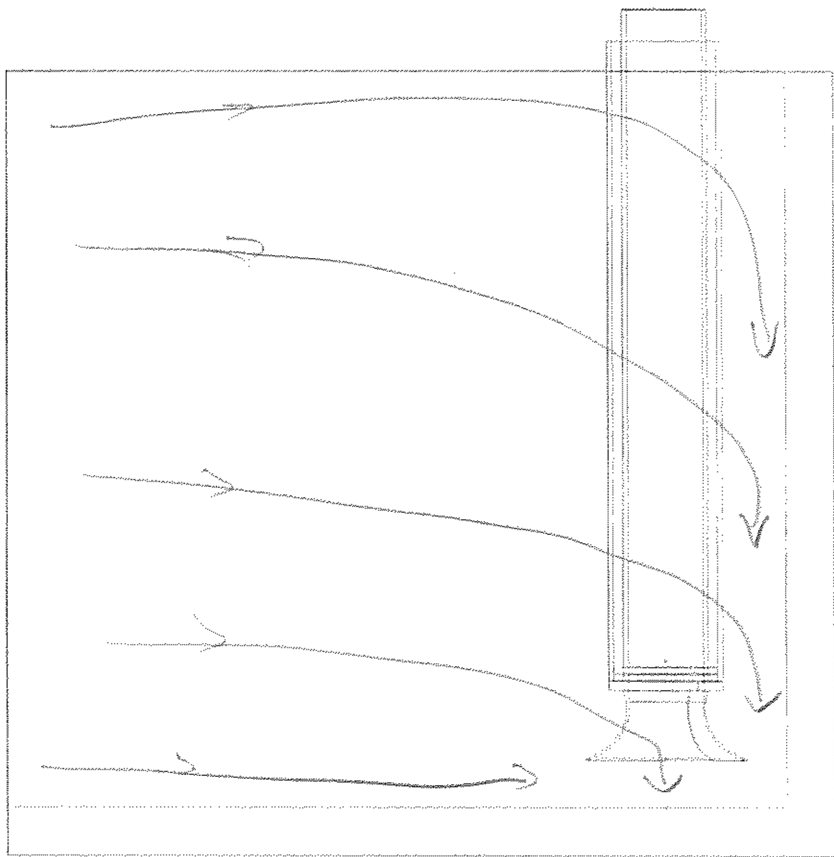
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 14 Pumps 1-7 75% North 25% West Bay 6

Run # ________ Notes by: ______________ Date / Time: ______________

TOP



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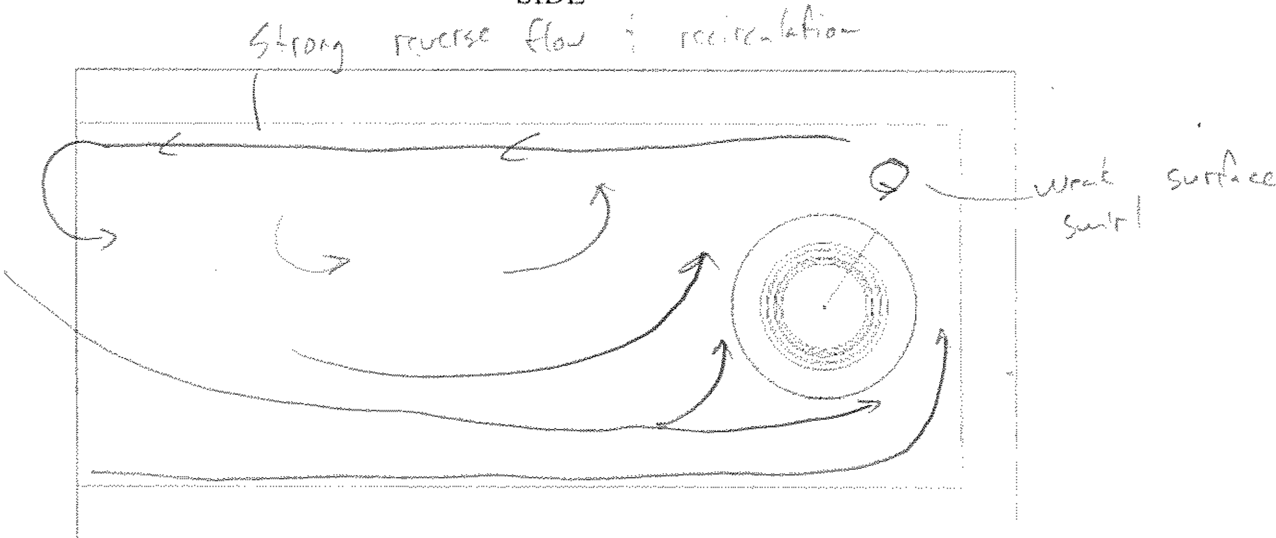


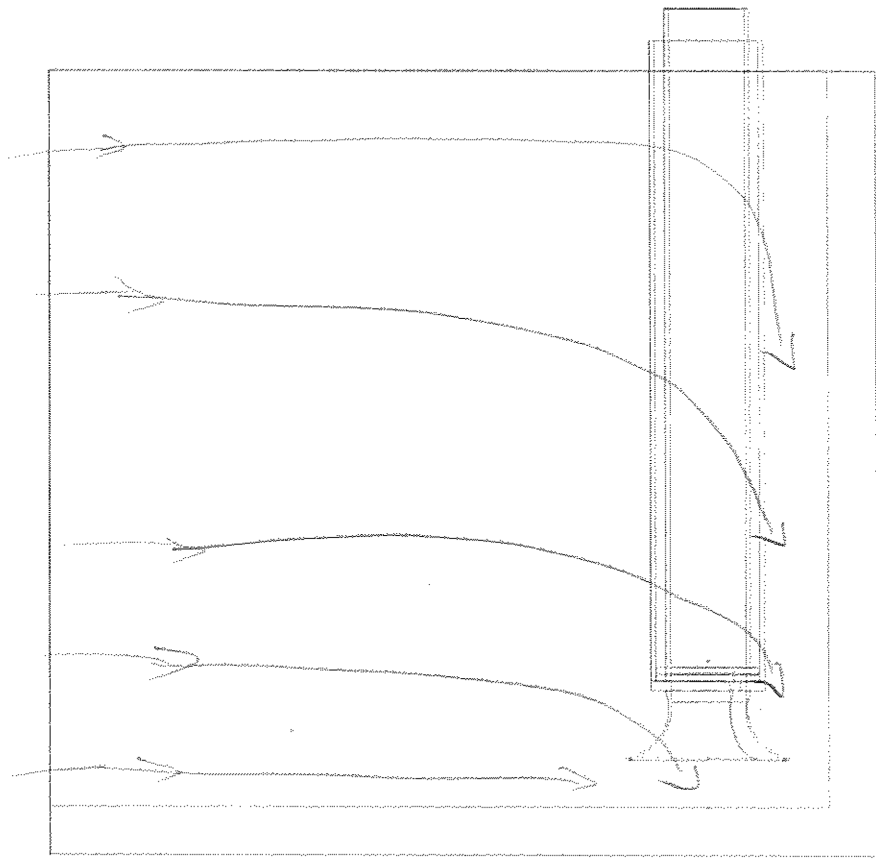
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description 14 Pumps 1-7 75% North 25% West Bay 7

Run #__________ Notes by: ____________________ Date / Time: ____________________

TOP



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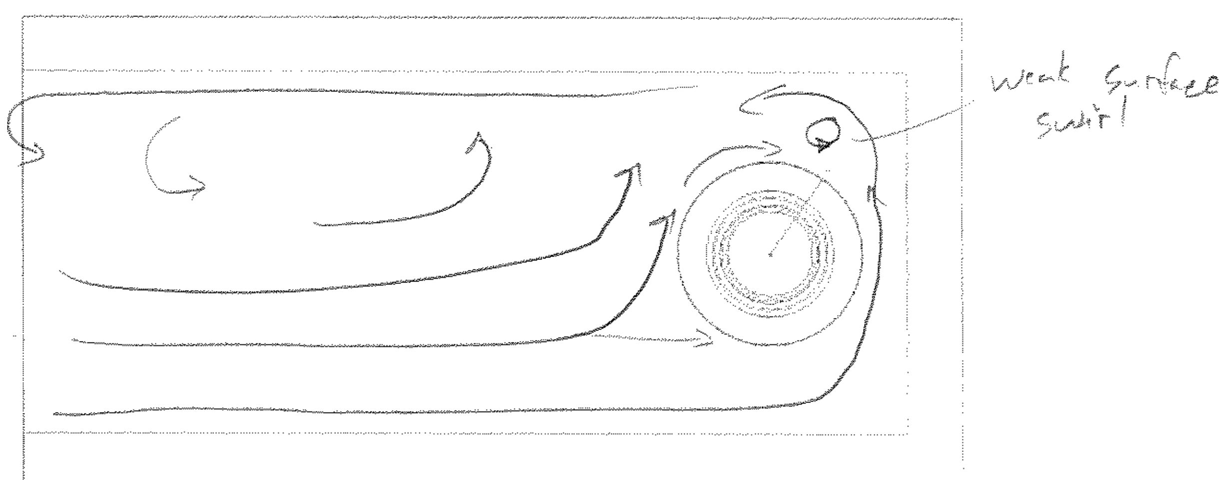


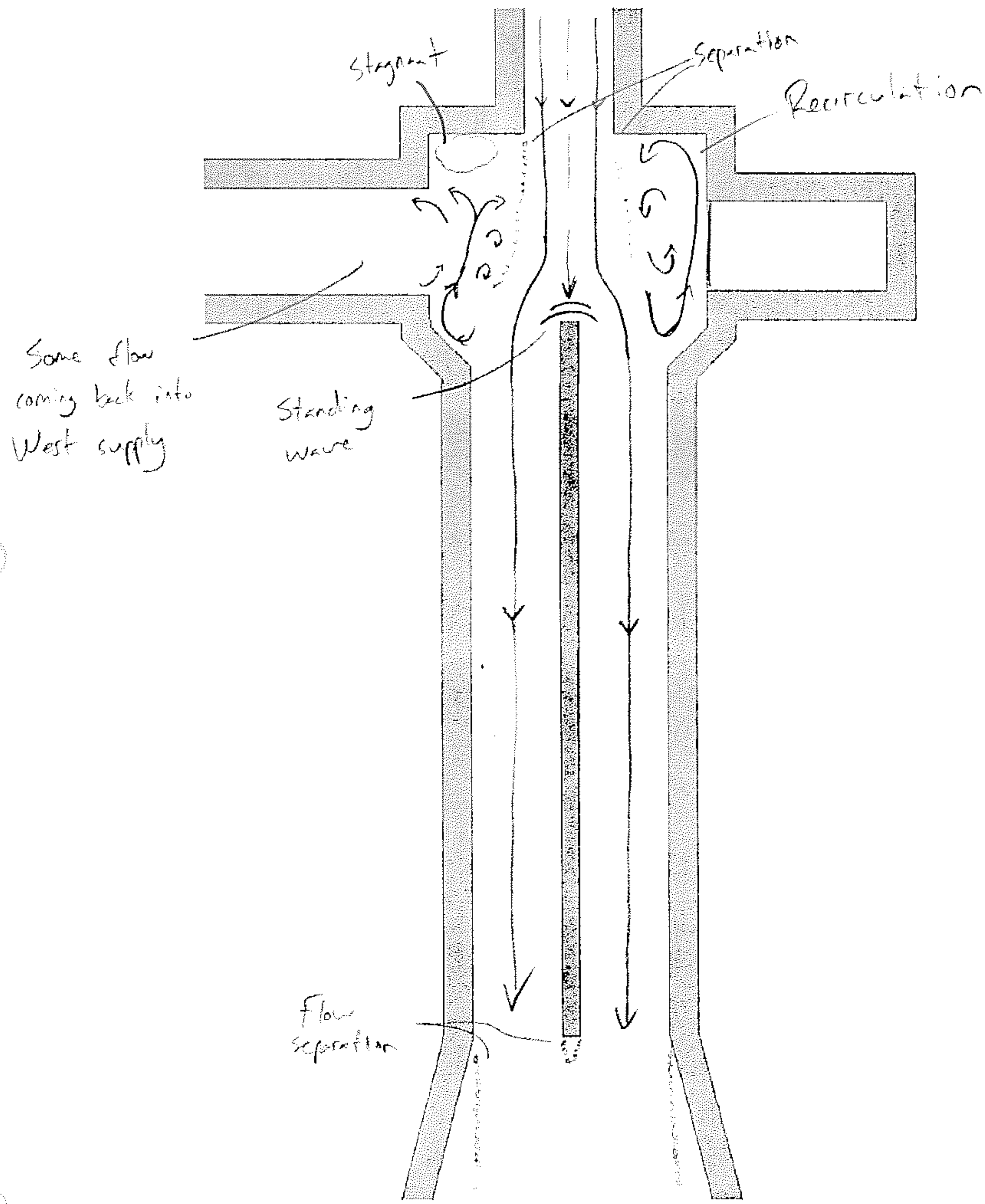
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

General Trends

Broadway Pumping Station Junction Box and Box Culvert

Scenario # and Description (All) General from North Supply

Run # – Notes by: RoBG Date / Time:

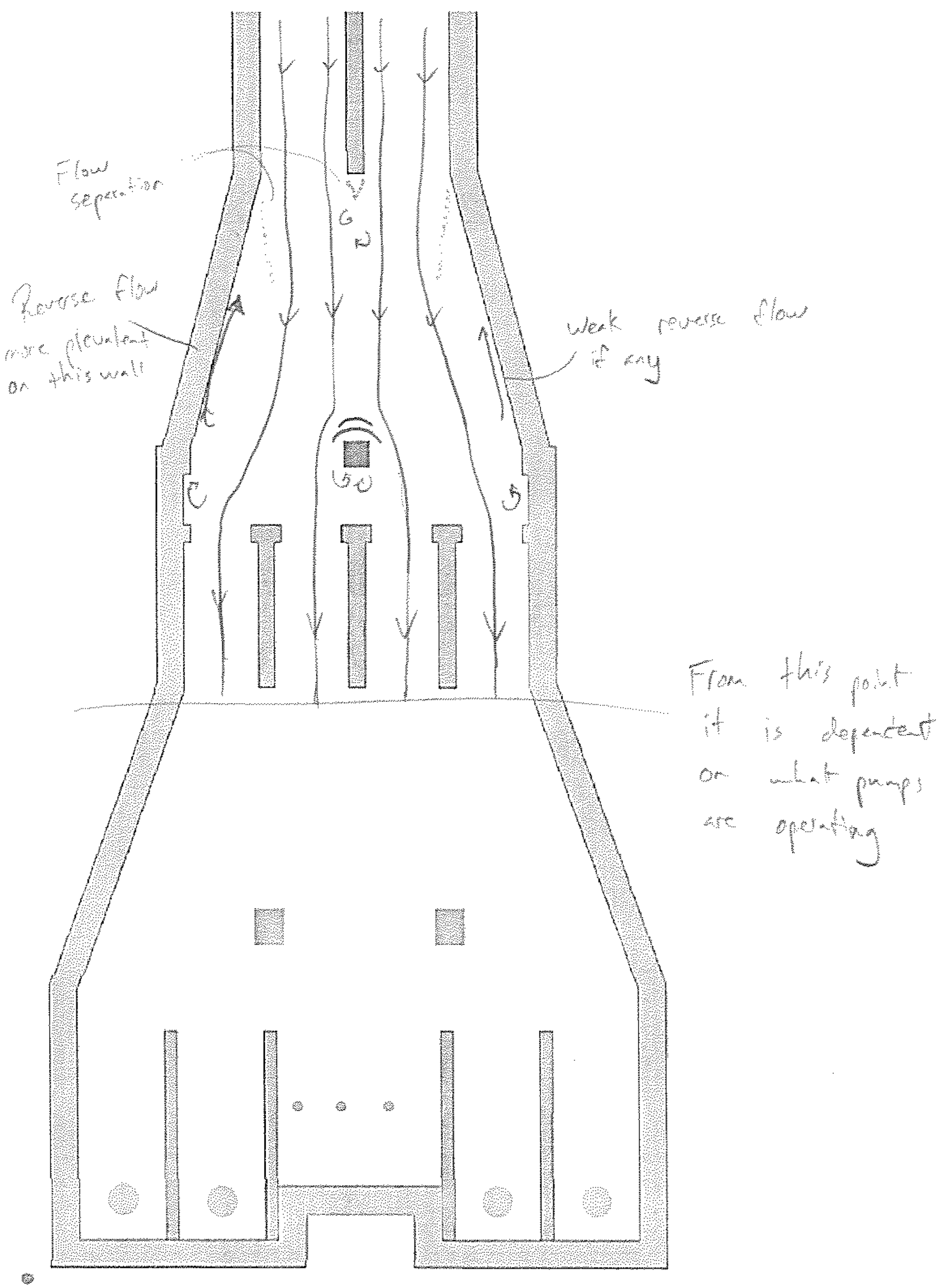


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station

Scenario # and Description (All) General flow North Supply

Run #__________ Notes by: ____________________ Date / Time: ____________________



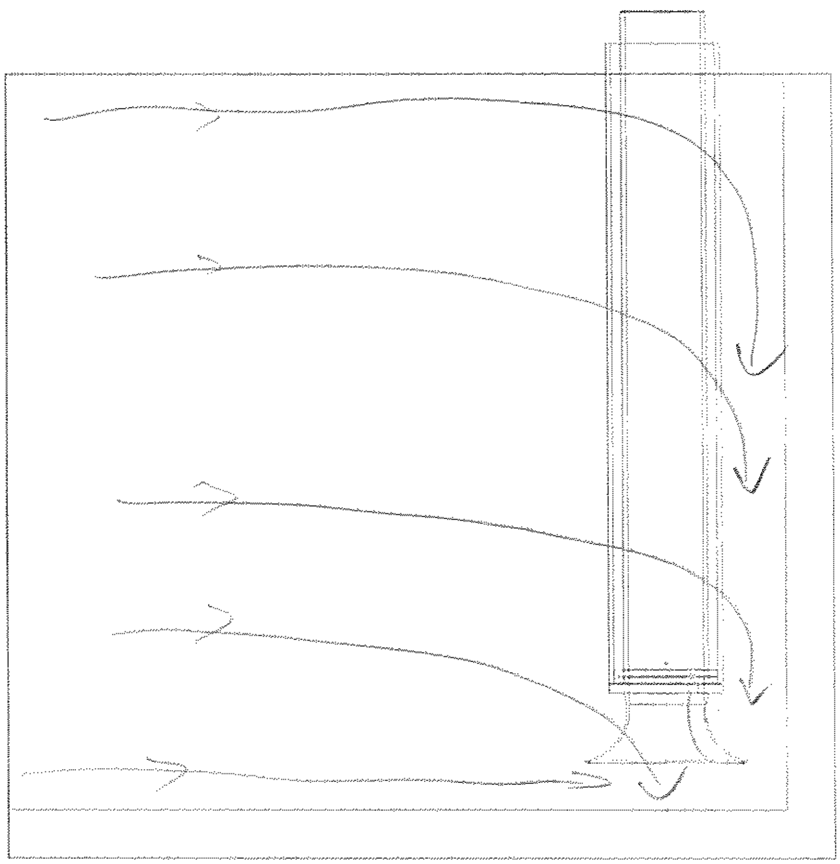
Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description: Pump 4 general   Bay: 4

Run #: ______ Notes by: ______ Date / Time: ______

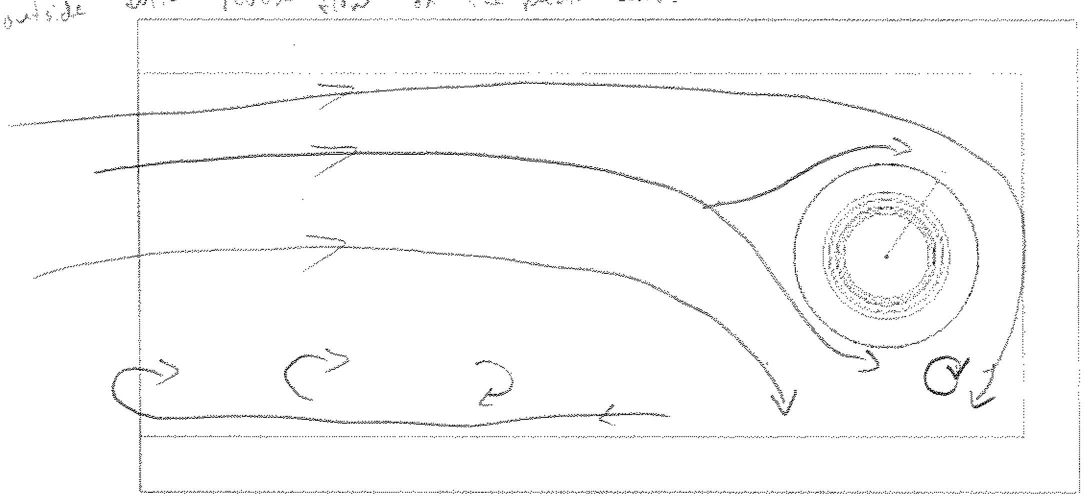
TOP



Flow goes to the back of the bay before going into pump.

With the exception of scenario 14 the flow comes in on the outside with reverse flow on the medial wall

SIDE



Surface swirl generally clockwise on surface

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description Pump 5 general Trend Bay 5

Run #_______ Notes by: _____________ Date / Time: _____________

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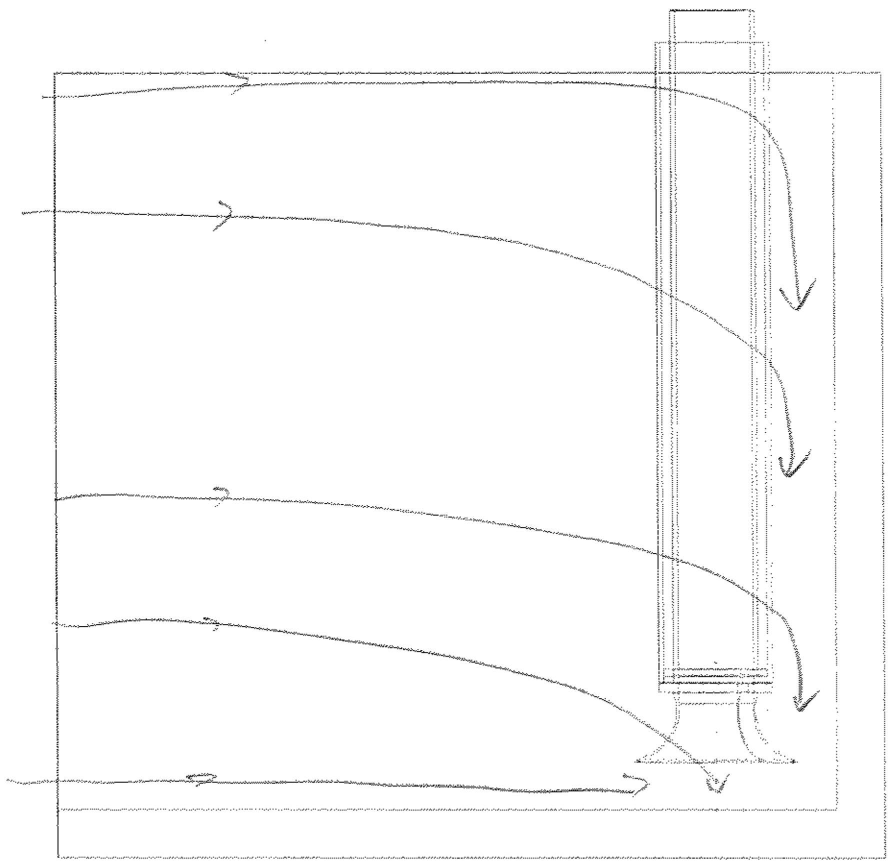
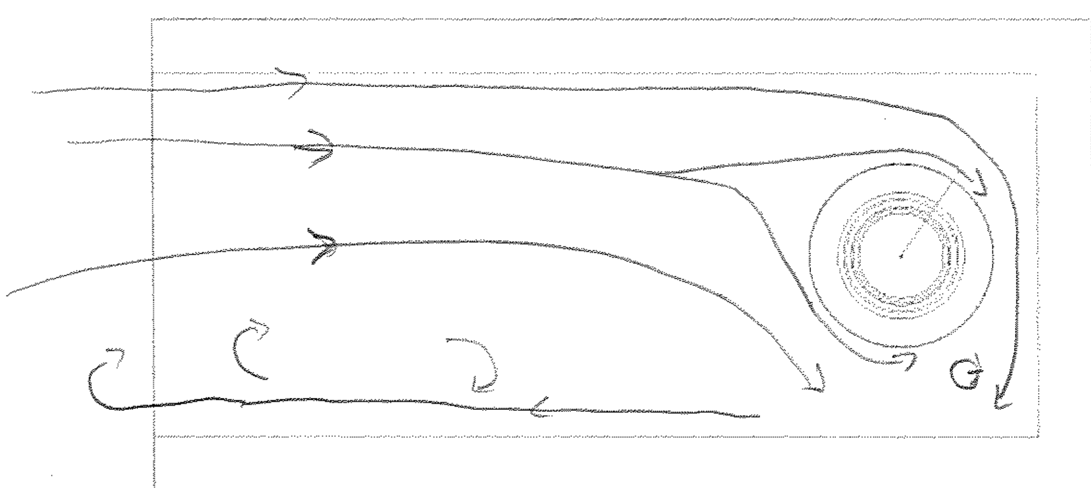


Water travels to the back of the bay then down.

SIDE



Water enters along outside wall and reverse flow/ recirculation on medial wall.

Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Vertical Pump Bay

Scenario # and Description Pump 6 + 7 Bay 6 + 7

Run #__________ Notes by: ____________________ Date / Time: ____________________

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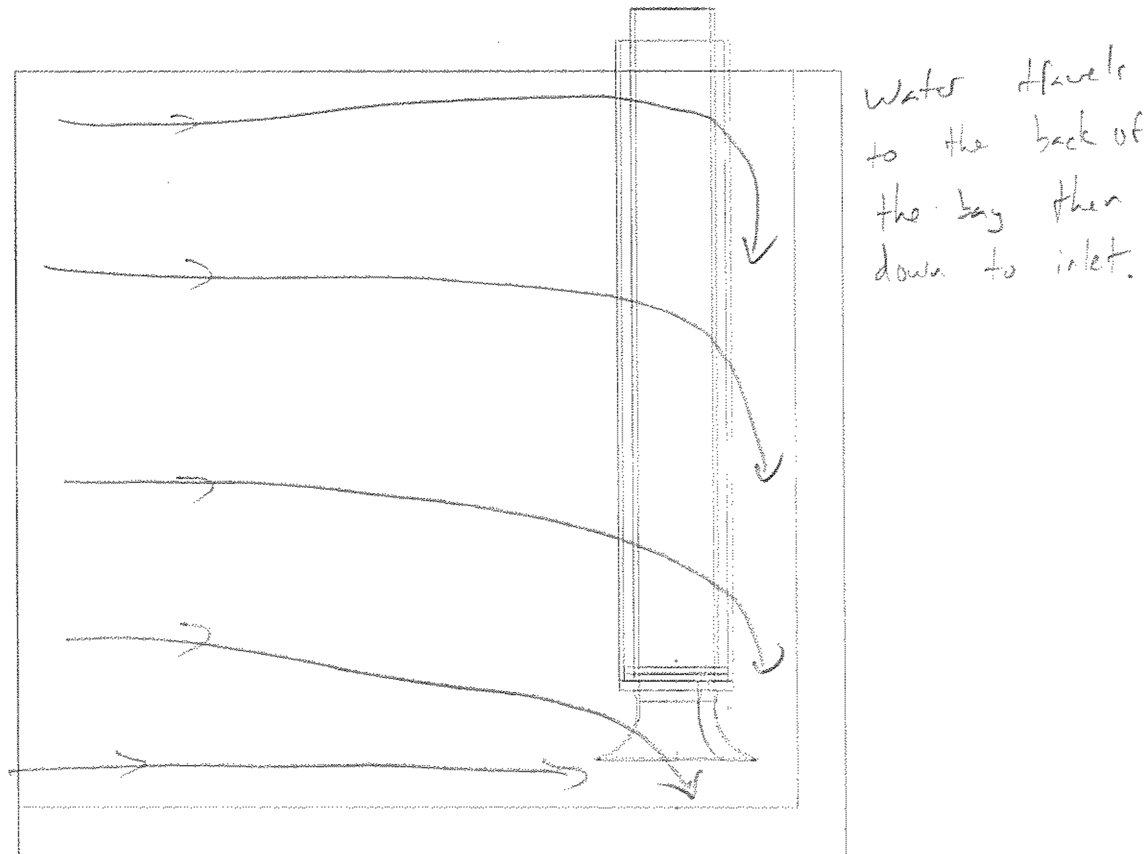

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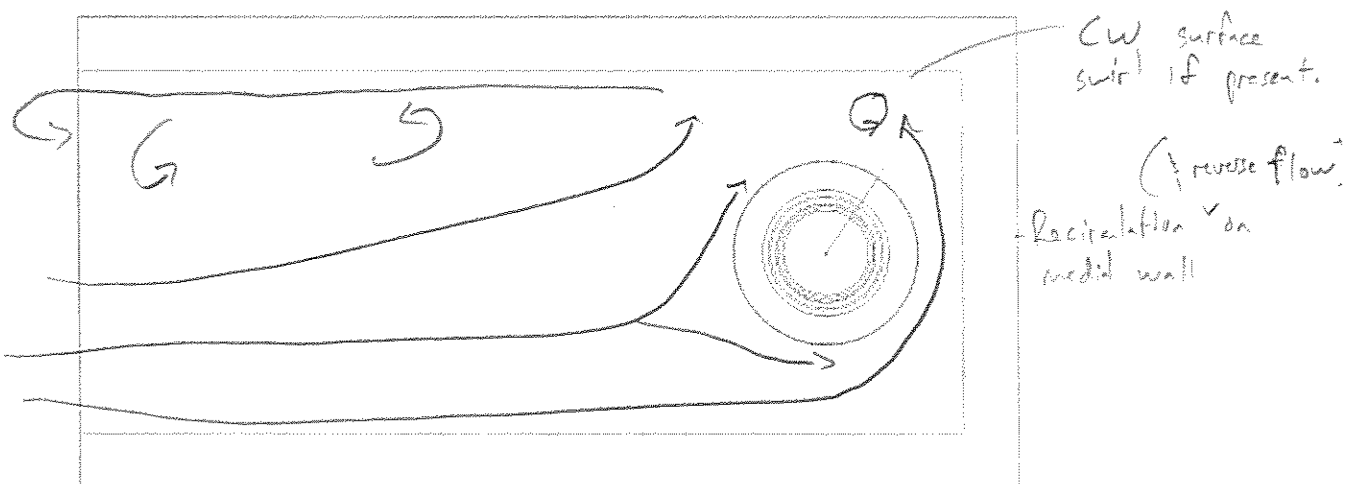
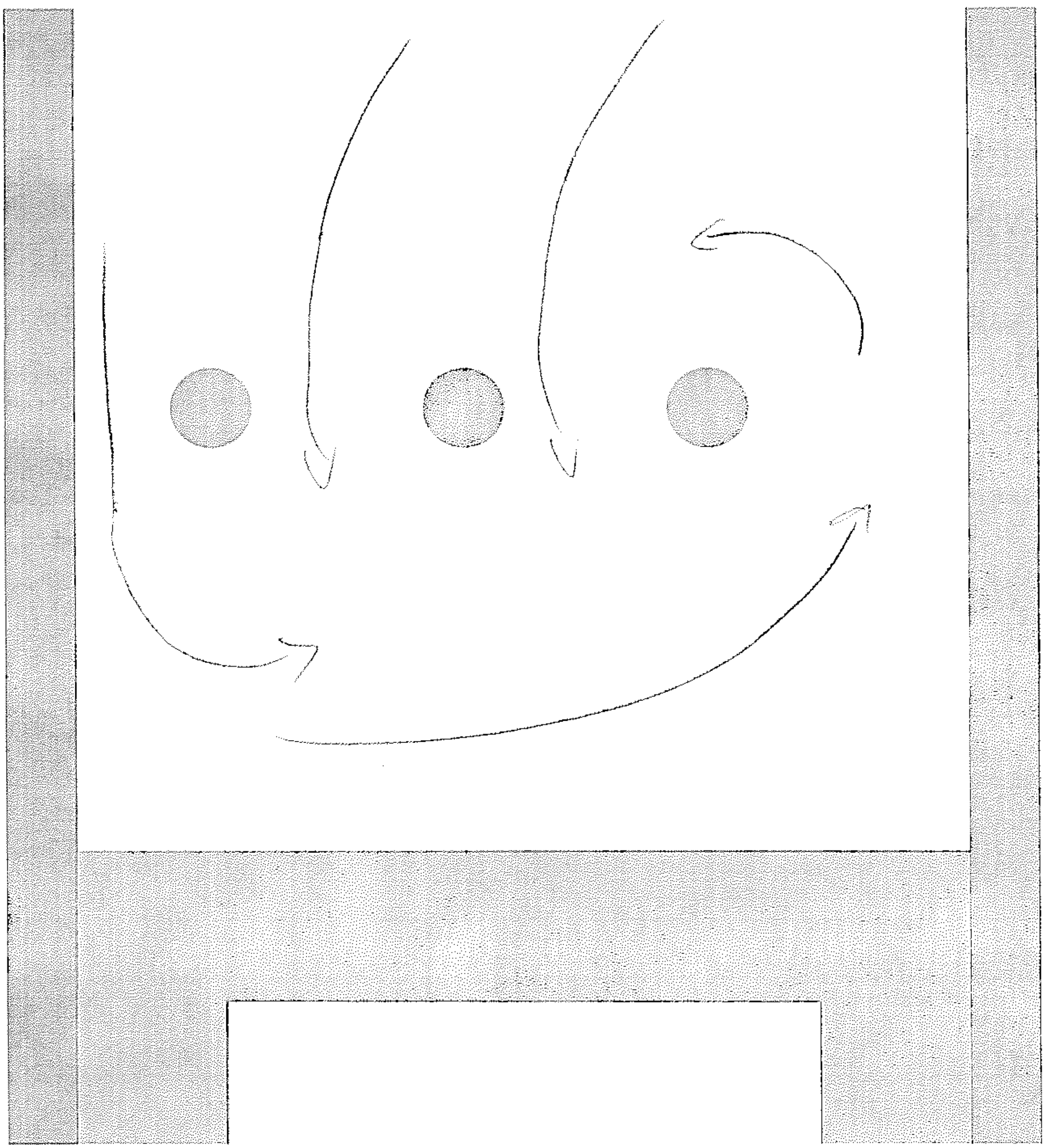


Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic

Broadway Pumping Station Center Bay

Scenario # and Description A(1) (General Trend)

Run #__________ Notes by: ____________________ Date / Time: ____________________



Note areas of recirculation, flow separation, reverse flow, surging, and other flow phenomenon on graphic