



## Challenging Hydraulic Aspects of MPSO Project, Qatar's Showcase for Storm Water Outfall

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### Abstract

The purpose of the Musameer Pump Station and Outfall (MPSO) project is to receive storm water runoff and groundwater flows from the Abu Hamour Tunnel and to provide a pumping station, a 10 km marine outfall tunnel and a diffuser field to dispose of the flows into the sea. The project site is located immediately south of the land that was reclaimed for the newly constructed Hamad International Airport (HIA) at the eastern terminus of the Abu Hamour Tunnel which forms a link to allow discharge of storm flows collected in the southern and western parts of the Doha over a total catchment area of approximately 190 km<sup>2</sup>. Hydraulic Design for MPSO (Musameer pumping station and outfall) was implemented for dry weather flow of 1.9m<sup>3</sup>/sec and wet weather flow of 19.7m<sup>3</sup>/sec. The system was designed with increased operational redundancy including 2 screen channels, bar screens and grab rakes, each channel being able to handle the maximum design flow, 2 wet wells with grit removal and oil and grease removal system, 10 submersible pumps (9 duty+1 standby), outfall chamber, drop shaft, 10 km marine outfall tunnel and diffuser field comprising of 6 HDPE pipe branches and 84 non return diffuser ports-duckbill valves. Hydraulic Design calculations were cross verified by CFD modelling, physical modelling in 1:9 scale and surge analysis results concluding on final hydraulic design conclusions and recommendations. Hydraulic Design parameters presented in this paper were verified during operation and maintenance period of the project and will be demonstrated herewith.

**Keywords:** Hydraulic Design; CFD; Physical modelling; Bar screens; Diffuser field

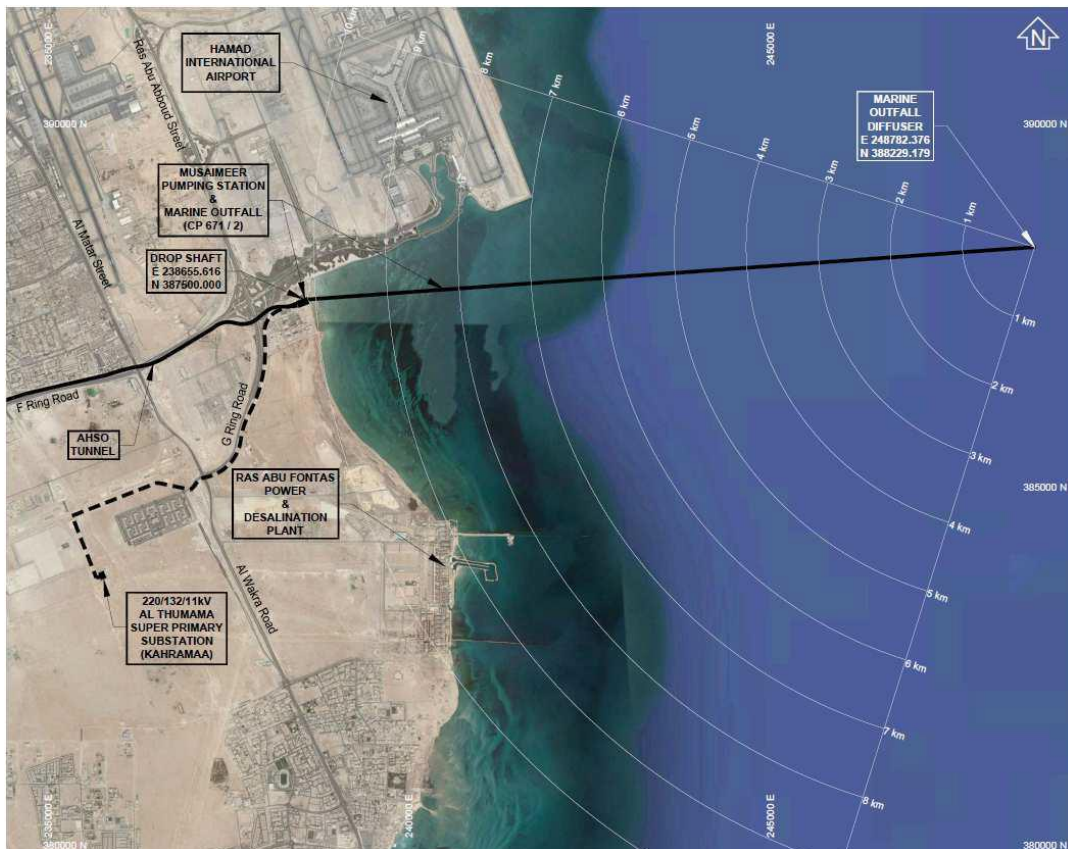
### 1 Introduction

Southern and Western Doha has been experiencing a rapid expansion and growth in recent years. Consequently, the need to increase drainage capacity to accommodate additional storm runoff and construction activities has become critical. In response, Drainage Networks Projects Department of the Public Works Authority (PWA) has undertaken significant studies and developed numerous projects that will provide an integrated approach for existing and future drainage systems for this

area. One such project is Musameer pumping station and outfall which provides for the installation of a collection tunnel, pumping station and marine outfall to discharge storm and groundwater drainage into the Arabian Gulf. The plan encompasses a drainage catchment area of approximately 190 km<sup>2</sup>. PWA has successfully completed the Musameer Pumping station and Outfall tunnel project on Sep 2022 enabling the effective discharge to the sea. The most challenging part of Design Works included the integrated Hydraulic Design which is presented in this paper.

## 2 Overview of the Project

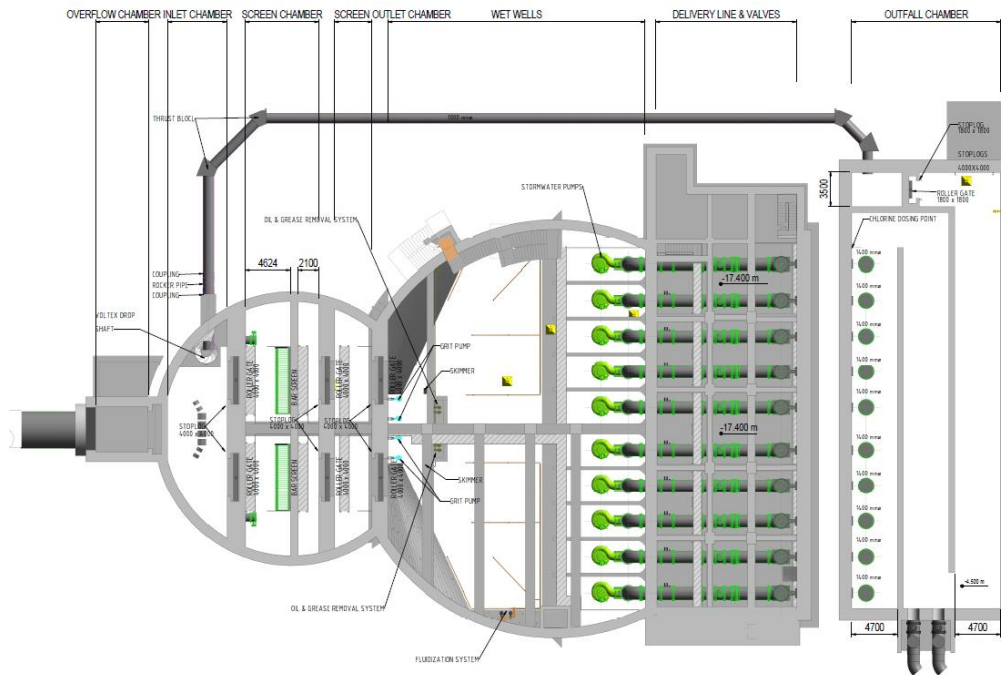
The project site is located immediately south of the land that was reclaimed for the newly constructed Hamad International Airport (HIA) at the eastern terminus of the Abu Hamour Tunnel which forms a link to allow discharge of storm flows collected in the southern and western parts of the Doha over a total catchment area of approximately 190 km<sup>2</sup>. Hydraulic Design was implemented considering all sections of works from Abu Hamour tunnel up to Marine discharge in 10km distance from shoreline. Abu Hamour tunnel, MPSO pumping station, MPSO tunnel and marine outfall diffuser field are presented in the location plan in Figure 1. The pumping station plot is 100m x 160m with its eastern boundary at approximately elevation zero Qatar National Height Datum (QNHD). The site was graded to generally have a final elevation between 2.6m at its westerly boundary to 4.5m at its easterly boundary. The design high water level (surge tide) of 2.00m QNDH takes into consideration climate change effects to the year 2060.



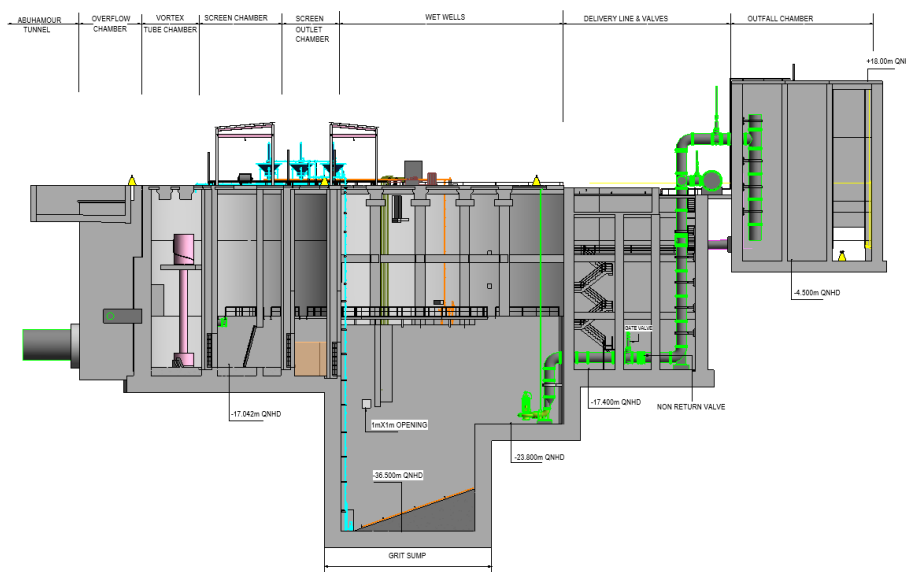
**Fig. 1:** Location plan for MPSO project

Pumping station comprise of overflow chamber, inlet, screen & outlet chambers, wet wells, delivery lines & valves and outfall chamber (Figure 2 & 3). The Pumping Station shall receive ground water and storm water from the Abu Hamour Storm Outfall (AHSO) Tunnel. Subsequently, the received flows shall be pumped to the Outfall Chamber and will flow by gravity to the subsea outfall tunnel

and the diffuser field. Gravity flow system includes the outfall chamber and drop shaft, the 10km, 3.7m I.D. SFRC lining tunnel as well as marine discharge system, riser shaft, manifold and diffuser field (Figure 4).

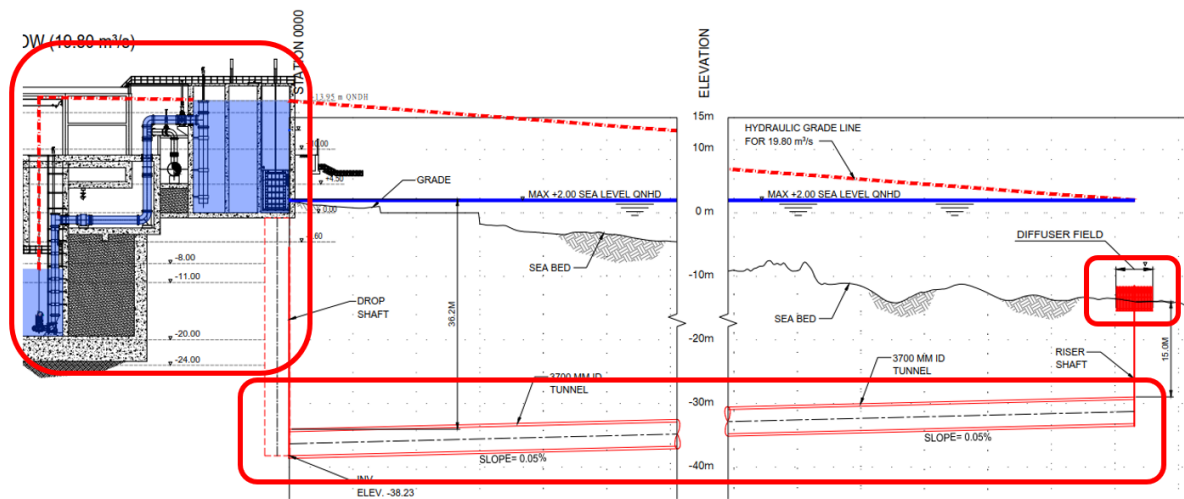


**Fig. 2:** Pumping station layout



**Fig. 3:** Hydraulic profile of pumping station

The (upstream) water level in drop-shaft required to drive both dry and wet weather discharge flow was calculated by taking into consideration the pressure head-losses through the system and corresponding hydrostatic head for both normal and high-tide sea level scenarios. Apart from stability and durability of the system, the main concerns of design are flow distribution in manifold pipes and duckbill valves as well as the maintenance requirements.



**Fig. 4:** Gravity flow system

### 3 Hydraulic Design Parameters & Scenarios

Major hydraulic design criteria were set out by the client (Public Works Authority) in contract documents during the preliminary/tender design stage and after coordination with various stakeholders regarding the extent of the catchment area, the upstream surface and groundwater collection system as well as the discharge location into the marine environment.

**Table 1:** General Design Parameters

Parameter	Value	Unit
Design Storm flow	19.70	[m <sup>3</sup> /s]
Dry weather flow	1.90	[m <sup>3</sup> /s]
Pumps (duty/standby)	9+1	N/A
Flow per pump	2.20	[m <sup>3</sup> /s]
Min. number of duty screens	2	N/A
Screen Bar width	20	mm
Spacing between Screen Bars	30	mm
Bar screen redundancy	One screen 50% blinded	N/A
Estimated grit quantity (1:25-years storm, 4 hours duration):	244	[metric tons]:

Pump station shall maintain continuous operation under all flow conditions including discharge to the Outfall Chamber during different ground and storm water flow conditions, discharge to the re-use areas, and operation under emergency conditions (either overflow at overflow chamber or overflow at outfall chamber). Based on the above, a number of defined operating scenarios presented in table 2 were analyzed in order to evaluate hydraulic performance of pump station and its related components under the relevant flow conditions.

**Table 2:** MPSO Operating Scenarios

S/N	Hydraulic scenario	Case 01	Case 02
1	Dry Weather Flow	Both bar screen channels in duty	One 50% blinded bar screen channel in duty
2	Wet Weather Flow	Both bar screen channels in duty	One 50% blinded bar screen channel in duty
3	Re-Use Flow	Both bar screen channels in duty	One 50% blinded bar screen channel in duty

4	Pump Station Maximum Level/Flooding	Both bar screen channels in duty	One 50% blinded bar screen channel in duty
5	Flow Through Outfall Chamber Overflow Weir	Both bar screen channels in duty	One 50% blinded bar screen channel in duty

#### 4 Hydraulic Design Calculations

All hydraulic systems, pumps, wet wells, and pipes were designed in accordance with best practices worldwide for conveying of storm water. Proposed hydraulic designs are suitable for the full range of flow and operating conditions followed by criteria such as a minimum freeboard of 0.50m to be maintained under all flow and operating conditions and flow velocities were designed to keep grit in suspension in pipes and conduits and allow grit to settle at the grit sump. The requirement of selected design scenarios was to analyze Hydraulic flow performance through Musameer Pump Station compartments, performance of bar screens and performance of submersible storm water pumps.

##### 4.1 Inlet, Outlet and Forced Flow System

The objective of the Hydraulic Design calculations was to describe the investigations, analyses, calculations, conclusions and recommendations for the pumping system and outfall. In particular it included analysis of AHSO discharge level (to the PS Intake Works) under given design flows and all operating conditions, definition and analysis of relevant hydraulic scenarios where flows, levels and velocities may affect the required performance of the Pumping Station and Outfall System. Provision of hydraulic design calculations for the defined scenarios where Musameer Pump Station is either under normal operation (dry and wet weather flows) with both screen channels in operation or one of the screen channels is out of service as per Qatar Sewerage and Drainage Manual recommendations. Defining Wet Well operating levels for each of the specified scenarios and analysis of required level of outfall chamber. Hydraulic calculations were based on the table 3 formulas according to international practice:

**Table 3:** Hydraulic Design formulas

S/N	Design section	Applicable formula
1	Pipeline losses	Darcy Weisbach formula
2	Rectangular weir losses	Sharp and Broad-crested Weirs formula
3	Opening losses	Submerged Orifice formula
4	Sloped channel losses	Chezy formula
5	Partially full pipe	Manning formula
6	Head losses through screens	Coarse screen head loss formula
7	Main pipework head losses	Stringent value from friction loss theory by Miller, theory of Thorley and manufacturer's data

Validation of the suitability of the proposed pumps for MSPO was implemented by the Designer performing calculations of minor losses in the rising main using three different methods (item 7 of table 3). Pumps are required to achieve a duty of 2.2 m<sup>3</sup>/sec under maximum friction for a calculated total static head of 30.3m. The performed analysis and comparison between different calculations methods identified that the theoretical head losses calculations on the piping system is 1.63m and the



pumps would be able to deliver a total head of 31.93m meeting the project's requirements. All the above values have been cross checked and verified during main pumps testing and commissioning procedure.

## 4.2 Gravity Flow System

The MPSO outfall tunnel is designed for the gravity flow regime being driven by the difference of (free surface) water levels between the drop-shaft and the recipient (the sea) as illustrated in Figure 4. The drop-shaft is vertical, cylindrical RC concrete structure with the internal diameter of 10.00m which receive the storm water from MPSO discharge chamber by gravity. The anticipated bottom of drop-shaft is at level -40.0 mQNHD. The marine outfall is proposed as the approximately 10 km long, 3.7m internal diameter stell fibre RC concrete subsea tunnel. At its downstream end, the tunnel is equipped with a 3000mm diameter riser shaft and diffuser (manifold) system which includes 84 duckbill diffuser nozzles connected to HDPE pipes arranged in three parallel lines.

Regarding the assessment of hydraulic performance of the outfall chamber, drop shaft, marine outfall tunnel and diffuser field at the downstream end, a one-dimensional hydraulic model was created using WANDA software Version 4.5. The purpose of the assessment was to calculate the required free surface levels inside the MPSO outfall chamber and drop-shaft to provide the conveyance of the design flows related to both wet and dry weather discharge. Balanced flow criterion was prioritized considering acceptable flow balancing deviation of  $\pm 10.00\%$  during dry weather flow conditions and  $\pm 5.00\%$  during wet weather flow conditions.

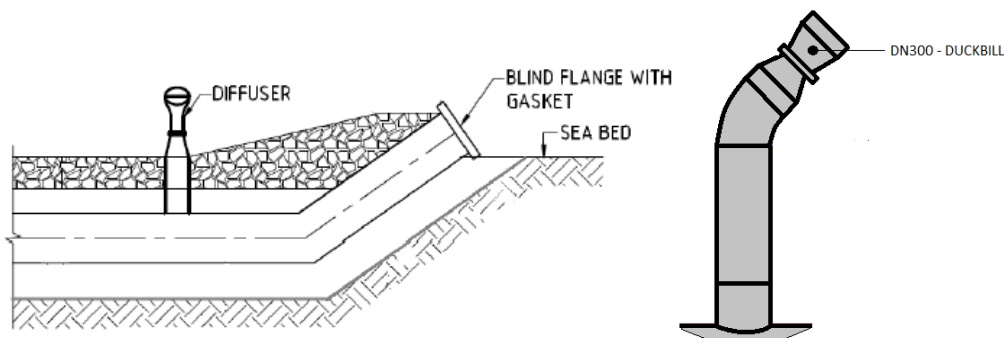
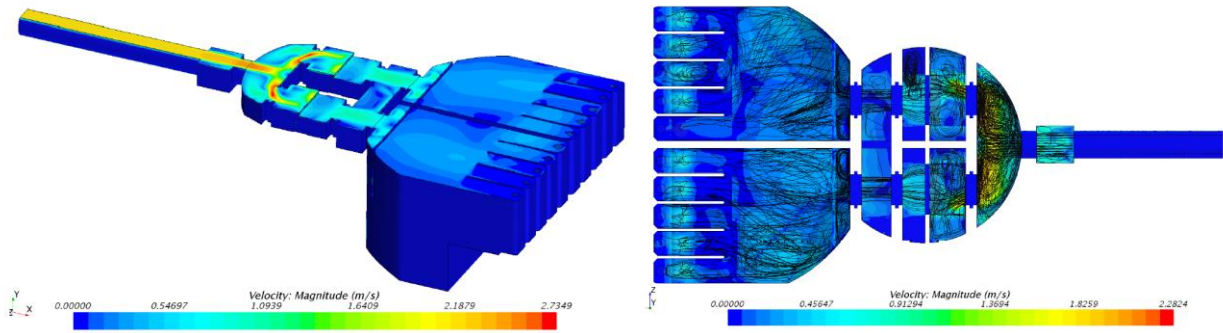


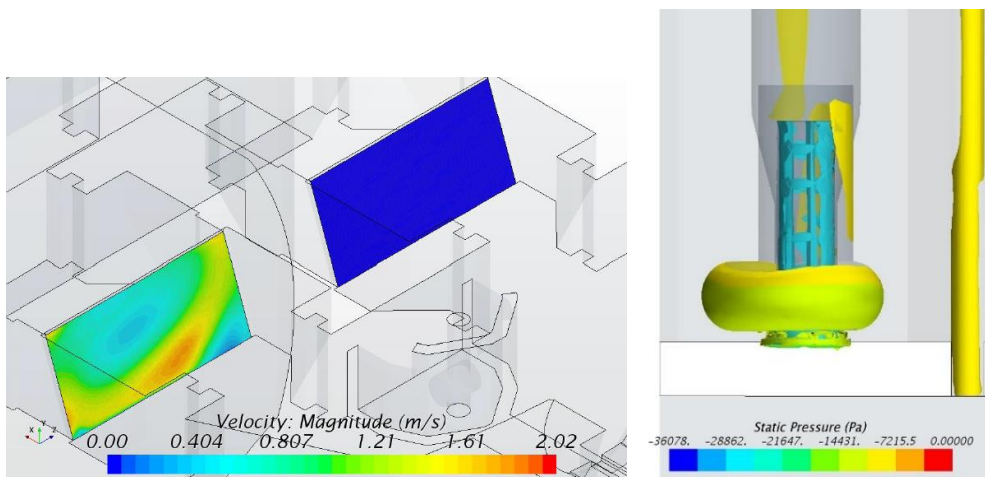
Fig. 5: Diffuser Field Pipe Section and Duckbill Arrangement

## 5 CFD Modelling

Computational Fluid Dynamics (CFD) analysis for MPSO project was conducted from COWI and BHR Group as approved vendors from client's (Ashghal) vendor list. CFD objective is to assess the overall flow patterns through the Pumping Station intake and predict if physical modelling will demonstrate the conformance with ANSI/HI 9.8 standards as per contractual requirements (1). The analysis focused on presenting the flow characteristics such as contours and vectors of the velocity at various sections of the structures, presence of dead zones (low velocity zones) and recirculation zones, identification of potential separation and flow instabilities, detection of high vorticity regions, determination of pump-pre-swirl angles and illustration of zones with highest tendency for sedimentation. The model was presented with colour coded graphics showing insight into a detailed flow pattern and velocities which helped to visualise the flow patterns through the structure and into the pumps.



**Fig. 6:** Velocity magnitude contours and velocity streamlines



**Fig. 7:** Velocity distribution across bar screens and pump intake hydraulics

Scenarios studied under CFD analysis are a subset of the set of operating conditions, and the results obtained, regarding flow patterns, vorticity, swirl, etc., may differ for other conditions. Therefore, a broader range of operations was tested on the physical model of the pumping station to confirm its performance.

## 6 Physical Modelling

MPSO Physical Model Study was conducted by the Ashghal approved specialist BHR Group, UK. Each of the scenarios, have been analyzed based on the worst hydraulic conditions specified under table 2. Major observations and measurements made during the final testing on the Musaimeer Pumping Station physical model are presented herewith. The sufficient length of the inlet pipe was modelled to ensure representative flow conditions. The model extended to a level of -11.00mQNHD, with the overflow chamber walls rising to this height. This allowed for testing up to the normal maximum operating level.



**Fig. 8:** Model overview and angled jet impinging on the screen

Upstream water levels were not observed to be backed up, with the tunnel remaining un-surcharged under all test conditions and below the maximum available level even with a single screen operating partially clogged at the maximum station design flowrate. Minor settlement was observed at several locations under low flow conditions. This material was largely swept clear under higher test conditions. Settlement at the maximum flow was limited to one side of the forebay area around the vortex plunge pool and the edges of the screen distribution chamber. The distribution chamber was swept clear at lower flowrates due to reduced water levels. No coarse material was carried past the grit traps. Conditions in the forebay area were highly energetic. At flowrates below half the station maximum baffle blocks in the forebay area conditioned flow to the screen chambers; at higher flows, flow to the screens retained a significant angle. Approach flow to the screens had a center bias, but average velocity was below industry maximum for bar screens. The change in flow patterns local to the screens and pumps that were shown in the CFD study, were found to be minimal. Changeable conditions in the pump bays were resolved by modifications local to the pumps. All pump swirl angles were measured well below the maximum of 5 degrees and no detrimental surface or submerged vortices were observed.

As a result of the combined studies from Hydraulic design calculations, CFD analysis and physical modelling several adjustments to the original design have been implemented such as peripheral benching along the walls of the distribution chamber feeding the settling basins and corner fillet downstream of the screens to minimize solid settlement. Installation of baffle wall within the settling basin for the purpose of minimizing flow velocities and solids carryover as well as installation of benching and cone arrangement in pump intake. Adjustments in the diffuser field arrangement such as varying diameter of HDPE pipework also ensured homogenous flow distribution through duckbills.

## **7 Conclusions**

Musameer pumping station Hydraulic Design considered various challenging aspects such as full operational capability with only one bar screen in operation partially clogged, minimization of grit accumulation throughout the inlet and outlet works, avoidance of grit conveyance through the piping system and adequately sized pipework system for 19.7m<sup>3</sup>/s for 32m approximately available head. Finally, gravity system shall ensure full flow conveyance of dry weather and storm weather flow through the 10km tunnel ensuring homogenous flow through the diffuser field-duckbill valves to the marine environment. All the design values, parameters and results have been cross verified and confirmed during the first 5-month operational period of the pumping station and outfall.

The above-mentioned studies and tests ensure the uninterrupted operational efficiency of this unique project for Qatar as well as increased redundancy against current and future extreme rainfalls events.

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