KARACHI WATER & SEWERAGE BOARD

OFFICE OF THE PROJECT MANAGER (K-IV PROJECT)

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No. KW&SB/PM/K-IV/2019/1112/01
Dated: **December 11, 2019**

Mr. Asim I Osmani
Director / CEO
M/s Osmani & Company (Pvt.) Ltd.,
Karachi.

Project: Greater Karachi Bulk Water Supply Scheme, Phase-I, K-IV Project, (260 MGD)

Subject: <u>SUBMISSION OF FINAL DESIGN REVIEW REPORT ALONG WITH ANNEXURES BY M/S. NESPAK FOR THIRD PARTY DESIGN REVIEW OF K-IV PROJECT.</u>

Please refer to the captioned subject. It is stated that Final Design Review Report along with Annexures (14 nos.) of 3rd party design review of K-IV Project by M/s. NESPAK are enclosed for your information & record.

Thanks & Regards,

11.12.19

Project Manager
K-IV Project, KW&SB

Copy to:

1. Secretary Local Government Department, GoS.
2. Secretary Planning & Development, GoS.
3. Managing Director, KW&SB.
4. Project Director, K-IV Project.
5. Office Copy.

Deltares

Karachi WTS third party review

Hydraulic analysis & simulations

Deltares

Title
Karachi WTS third party review

Project	**Attribute**	**Pages**
11204220-002	11204220-002-HYE-0010	13

Keywords
Water transmission system, Wanda, water hammer

Summary
NESPAK is performing review works for Phase 1 of the Greater Karachi Bulk Water Transmission Scheme K-IV (K-IV) for Karachi Water & Sew Board (KWSB) and has contracted Deltares as a sub-contractor for third-party review.
Deltares has reviewed the pumping station design and NESPAK's hydraulic calculations of the canals and siphons. Deltares has performed multiple hydraulic calculations and simulations to check the pumping station design and verify the hydraulic calculations of NESPAK. This document is a brief description of the simulation models used by Deltares and the calculations performed by Deltares in order to perform the review of the design and hydraulic calculations of the Karachi WTS system.

The surge protection as specified in the original design report suffices to protect the pumping stations and rising mains during a full pump trip. However, the design allows for optimization of the surge protection because the current surge protection equipment (pneumatic vessels and pressure relief valves) are larger than what is necessary.

Although there are small (negligible) differences in the simulation results of NESPAK and Deltares for the hydraulic capacity of the canals and siphons, the conclusion is that the design flow rate of 260 MGD and 650 MGD can be transported by the canals and siphons.

References
Sub-Consultancy Services agreement between NESPAK and Deltares for Design Review/Vetting of the Greater Karachi Bulk Water Supply Scheme K-IV Project, Phase-I (260 / 650 MGD),

Version	Date	Author	Initials	Review	Initials	Approval	Initials
1.0	oct. 2019	M. Tukker		A. Heinsbroek		B. van Vossen	
2.0	Nov. 2019	M. Tukker	[signature]	A. Heinsbroek	[signature]	B. van Vossen	[signature]

Status
final

Contents

1 Introduction

NESPAK is carrying out review works for Phase 1 of the Greater Karachi Bulk Water Transmission Scheme K-IV (K-IV) for Karachi Water & Sew Board (KWSB). K-IV is a municipal infrastructure project being jointly developed by the provincial and federal governments in Karachi, Pakistan, to augment the city's daily water supply. The project is designed to provide 650 million gallons of water daily to Karachi in three phases. The new water supply will be extracted from Keenjhar Lake through three water canals. The total length of the Phase 1 of the project is approximately 120km, and consists of canal sections, intake structures, culverts, aqueducts and siphons.

NESPAK requires expert advice on hydraulic aspects of the K-IV project and has selected Deltares as a subcontractor to NESPAK for this third-party design review work. Deltares has reviewed the pumping station design and NESPAK's hydraulic calculations of the canals and siphons. Deltares has performed multiple hydraulic calculations and simulations to check the pumping station design and verify the hydraulic calculations of NESPAK. Deltares' conclusions were reported to NESPAK in separate memo's[1,2] and have been discussed with NESPAK during a visit to Lahore in August 2019.

This document is a brief description of the simulation models used by Deltares and the calculations performed by Deltares. The waterhammer analysis of pumping stations 1 and 2 is described in chapter 2, the hydraulic analysis of the canal bed profiles and hydraulic capacity is analyzed in chapter 3.

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[1] *Deltares memo 11204220-002-HYE-0003, "Review Design report Pumping station - K-IV phase 1 260 MGD".*

[2] *Deltares memo 11204220-002-HYE-0008, "Review L-profiles and hydraulic calculations Reach 2 & 3 canals and siphons".*

2 Pumping stations

The pumping stations PS1 and PS2 each consist of 6 pumps, of which 4 pumps will be in operation simultaneously. The pumping stations both are discharging into high reservoirs (forebays) by means of four parallel rising mains. The surge protection for the four rising mains is provided by eight pneumatic vessels (surge vessels), two surge vessels are connected to each pipeline.
Additionally, a pressure relief valve is connected to the pump header that discharges back into the pump sump. The pressure relief valve at PS-1 has a set pressure of 70 psi (4.83 barg) and a rated discharge of 7 m^3/s. The pressure relief valve at PS-2 has a set pressure of 130 psi (8.96 barg) and a rated discharge of 7 m^3/s.

The design report states that the air vessels have been designed using a general design rule. No justification for the pressure relief valve specifications is given in the report. This chapter discusses the simulations and analysis performed by Deltares to verify that the surge protection suffices to protect the pumping stations and rising mains in case of a full pump trip.

2.1 Input data

The design of the pumping stations is detailed in the report “Pumping station design report, K-IV phase 1 – 260 MGD”, submitted by Osmani Consultancy. Deltares has used an assumed value for data that was not specified in the report, these assumptions will be discussed in the following paragraphs.

2.1.1 Pipeline properties

The report does not state the exact wall thickness of the pipelines used in the pumping stations and rising mains. However, the wall thickness has been calculated from the inner- and outer diameters of the pipes specified in the report. The pipeline properties used in the model are shown in Table 2.1. The report also doesn’t state the maximum allowable pressure in the rising mains or pumping station piping. Based on the stated diameter and wall thickness, a maximum allowable pressure of 10 barg is assumed for all pipes.

Table 2.1 Pipeline properties

Property	**DN1800**	**DN2500**
Outer diameter (mm)	1829	2590
Inner diameter (mm)	1800	2546
Wall thickness (mm)	14.5	22
Young’s modulus (N/m^2)	2.1×10^{11}	2.1×10^{11}
Wave speed (m/s)	962	987
Maximum allowable pressure (barg)	10	10

2.1.2 Pump characteristics

The characteristics for the pumps are not clearly specified in the report, but the rated discharge and head is stated. Based on the rated discharge and pump head, an ideal pump is selected using standard design rules. The polar moment of inertia of the pumps is also estimated via standard design rules.
Due to the static head of the system, the check valves will close almost immediately after a pump trip. Therefore, the influence of these pump properties on the pressures in the pipeline

during a full pump trip is negligible. The pump characteristics used in the model are shown in Figure 2.1 and Figure 2.2.

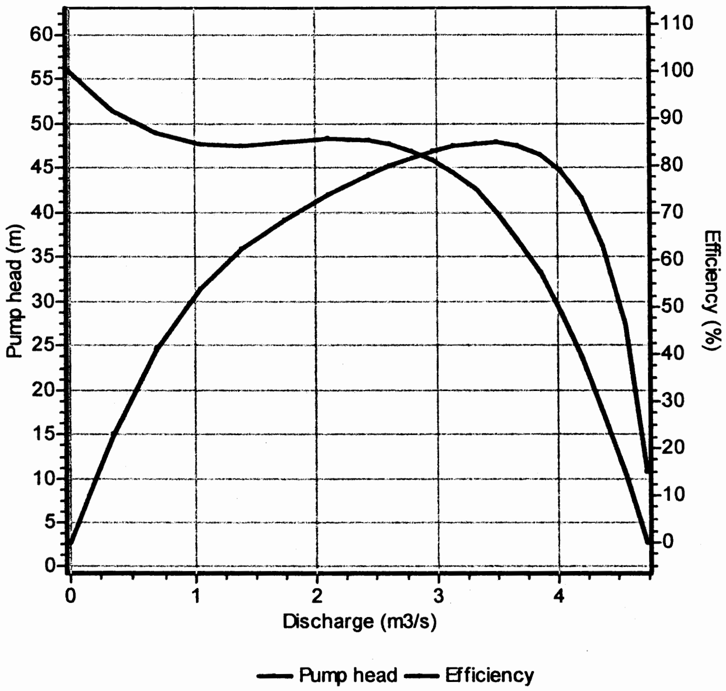


Figure 2.1 Pump characteristic (QHE) of the pumps in PS-1. The polar moment of inertia of the pump is 616 kgm²

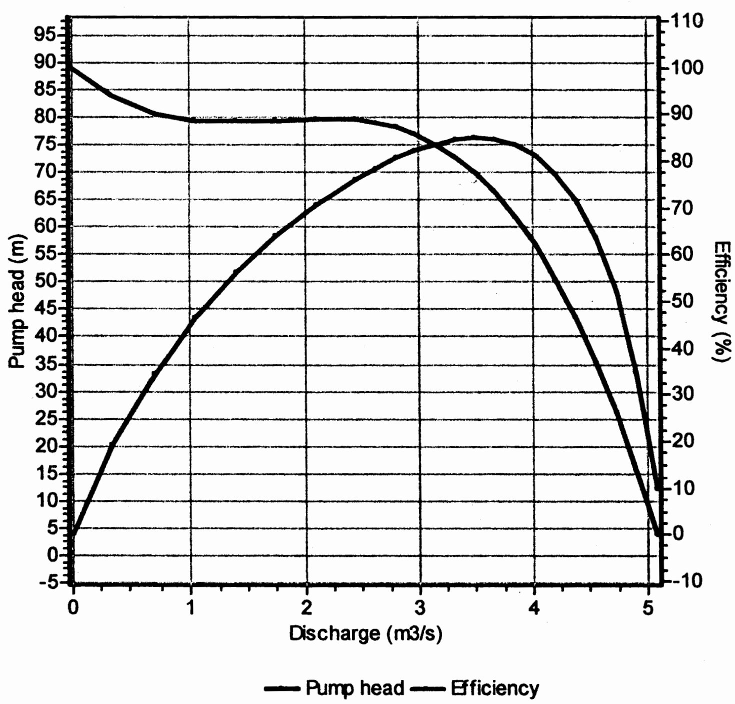


Figure 2.2 Pump characteristic (QHE) of the pumps in PS-2. The polar moment of inertia of the pump is 1200 kgm²

2.2 Analysis and simulation results

The Hydraulic behavior of the pumping stations is identical due to the similarities in their layout and design, therefore, only the behavior of PS-1 is discussed in detail. The figures for the surge analysis of PS-1 and Rising main 1 are shown in Figure 2.3 through Figure 2.5. The results for PS-2 and rising main 2 are shown in Figure 2.6 through Figure 2.8.

After the pumps trip, a negative pressure surge propagates from the pumps into the rising main and pneumatic vessels. The pneumatic vessels react to this by discharging into the manifold, which causes the check valves to close. When the check valves are closed, the discharge from the pneumatic vessels propagates into the rising main, preventing negative pressures. When the pressure surge reaches the forebay it is reflected and travels back to the pneumatic vessels. The water level in the pneumatic vessels decreases due to the discharge into the rising mains, causing the pressure in the pneumatic vessel to decrease. The low pressure in the pneumatic vessels causes the liquid column in the rising main to decelerate and reverse flow direction. The reverse flow causes the water level in the pneumatic vessels to rise (refilling), increasing the pressure. When the pressure reaches the set point of the pressure relief valve, it briefly opens and discharges into the pump sump. The pressures in the rising main and pump manifold remain well within acceptable limits.

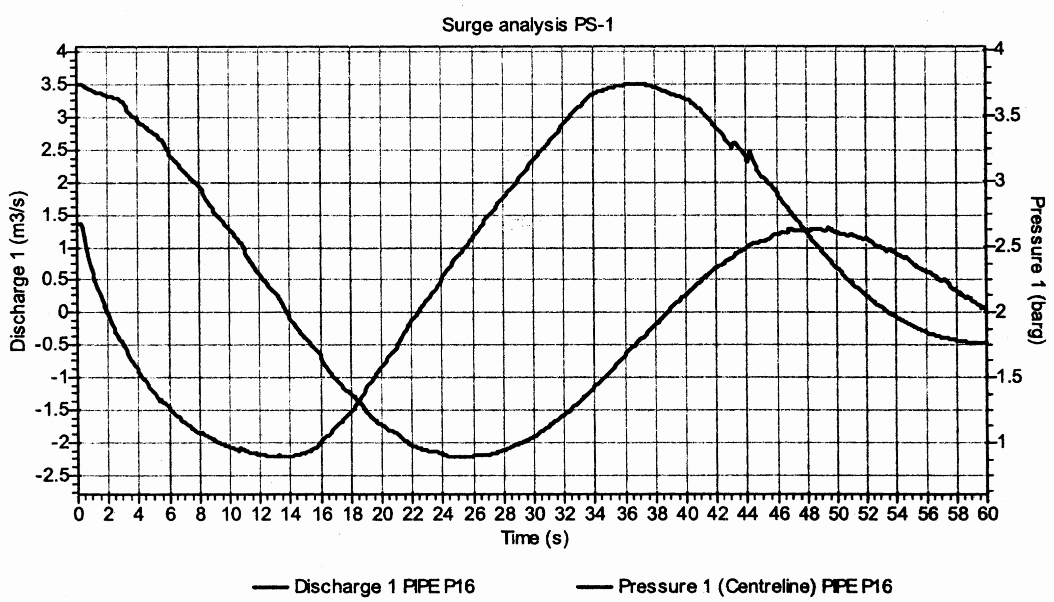


Figure 2.3 Discharge and pressure at the start of the rising main for PS-1.

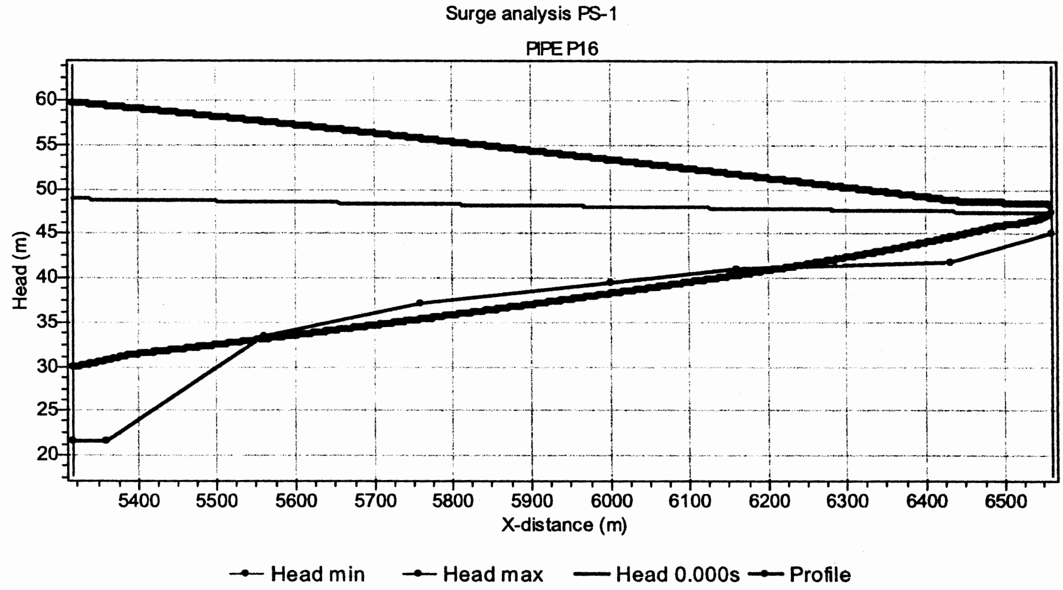


Figure 2.4 Steady-state (maximum design discharge) and minimum/maximum head envelope for the rising main 1 during a full pump trip.

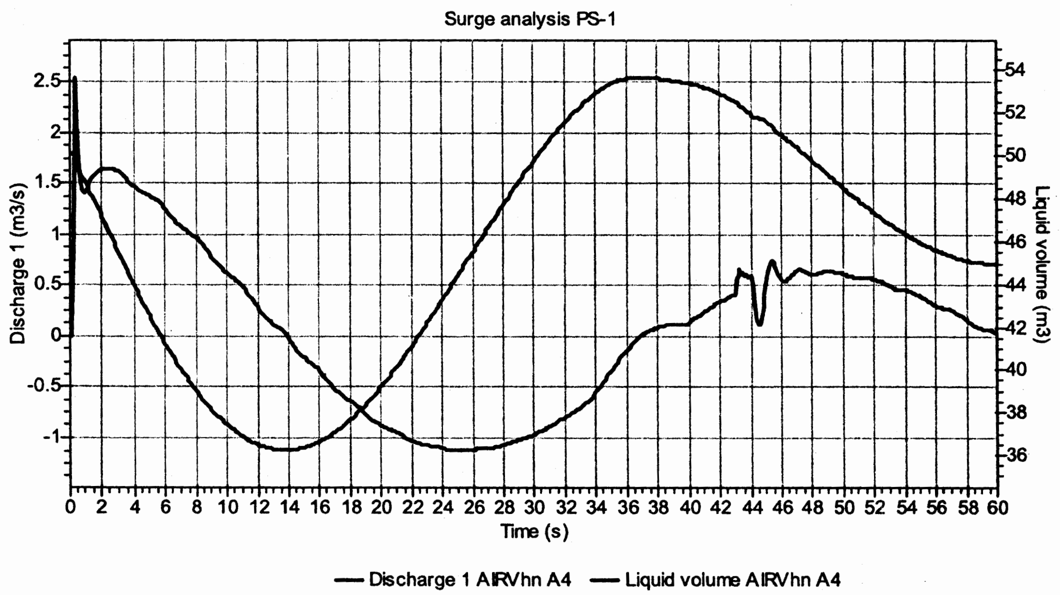


Figure 2.5 Discharge and liquid volume from one of the pneumatic vessels for PS-1.

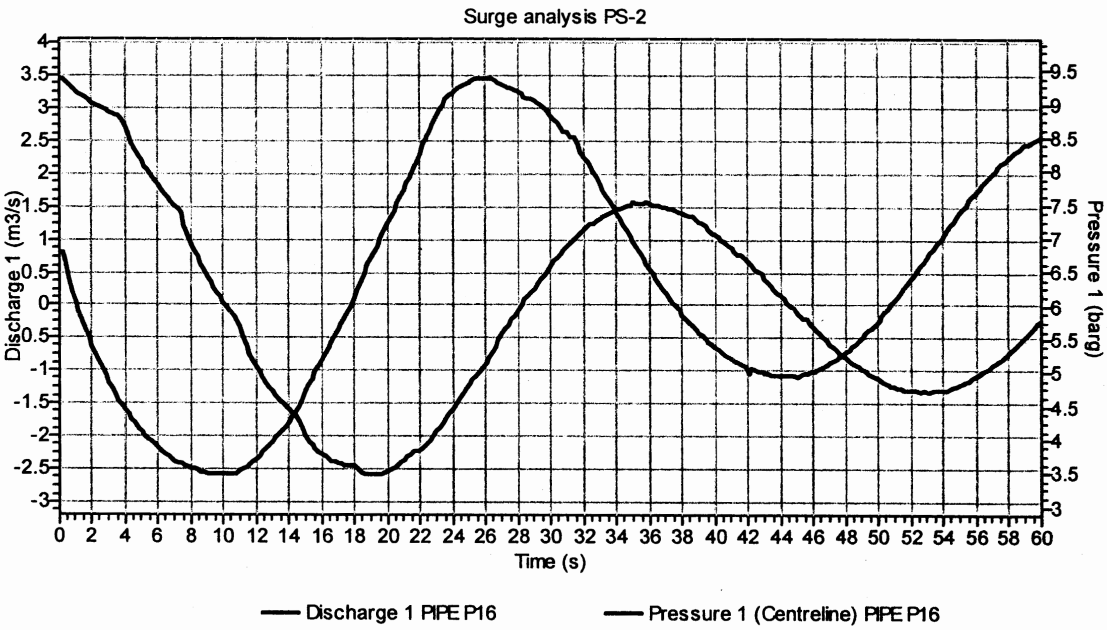


Figure 2.6 Discharge and pressure at the start of the rising main for PS-2.

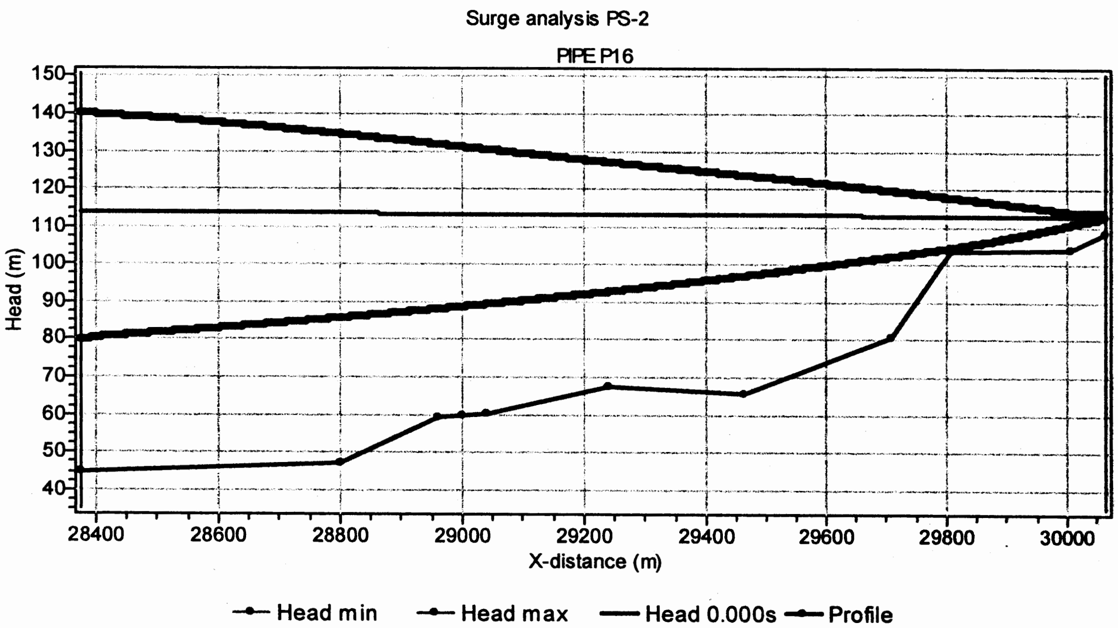


Figure 2.7 Steady-state (maximum design discharge) and minimum/maximum head envelope for the rising main 2 during a full pump trip.

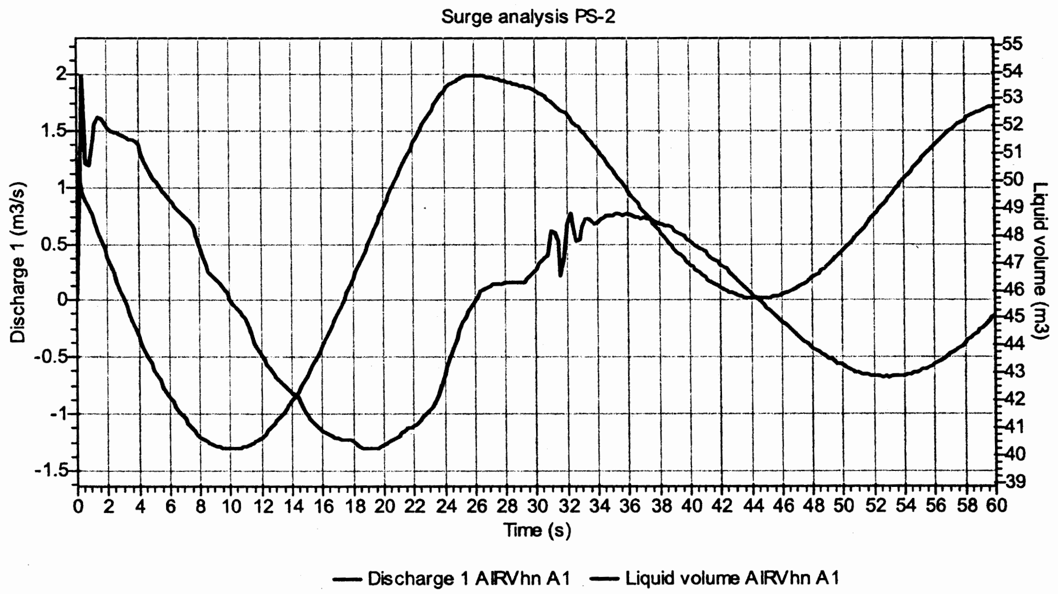


Figure 2.8 Discharge and liquid volume from one of the pneumatic vessels for PS-2.

2.3 Conclusions

From the simulation results discussed in the previous chapter, it is concluded that the surge protection as specified in the pumping station design report suffices to protect the pumping stations and rising mains during a full pump trip.

However, the design allows for optimization of the surge protection because the current surge protection equipment (pneumatic vessels and pressure relief valves) are larger than what is necessary.

3 Canals

There are two long canals in the system, Reach 2 and Reach 3. Reach 2 connects Forebay-1 to the Pumping station 2 and Reach 3 connects Forebay-2 to the end-basin near Karachi. Multiple siphons are located in both canals to provide crossings for rivers and roads. Deltares has performed hydraulic calculations of the canals and siphons using the software Wanda to verify the calculations performed by NESPAK and to verify the hydraulic capacity of the canals.

3.1 Input data

All input data for these calculations is provided by NESPAK, via the hydraulic calculation sheets that were provided to Deltares.
The energy losses in the Wanda simulations performed by Deltares are calculated from the wall roughness using the Colebrook-White and Darcy-Weisbach equations. For both the 260 MGD and the 650 MGD scenario the Darcy-Weisbach friction factor is specified directly, a value of 0.02 is used for the friction factor in the 650 MGD scenarios. The MS siphons have an assumed wall roughness of 1 mm and the RCC siphons have a wall roughness of 2 mm. Note that the wall roughness in this model also includes all hydraulic losses, such as bends and section-transitions.

The hydraulic calculations do not take into account the degradation of the hydraulic capacity over time due to sedimentation, fouling, biological growth on the canal/siphon walls or other causes. One of the major risks in the system is settling of sediment in the siphons, causing a reduction of the hydraulic capacity.
The risk of sediment settling can be estimated using simple design equations such as the Shields criterium and the Rouse number. However, an important parameter in these equations is the particle size of the sediment. At this time there is only very limited information available on the expected sediment particle sizes, sediment load or any other properties of the sediment that may be transported through the canals and siphons. As such, additional studies regarding sediment properties should be performed and any assessment regarding sediment transport should be verified at a later design stage when this information is available. In order to do a preliminary assessment of the risk of sedimentation in the siphons, the particle size classification of ISO 14688 has been used as input for a preliminary assessment.

3.2 Simulation results

The Free-surface-flow (FSF-)conduit (which solves the Saint-Venant equations) is used to simulate open channel flow in the canals. The siphons are modelled using the pipe component in Wanda. Both rectangular and circular pipes are modelled in these calculations. Please note that in the Wanda software, the elevation profile of the FSF-conduits is specified as the bed-level (bottom), but for the pipes the profile is specified as centre-line. This has no effect on the hydraulic calculations, but it results in a difference in displayed elevation at the transitions from canal to siphon and vice versa when plotting the elevation profile for both the canal and siphons in a single figure.

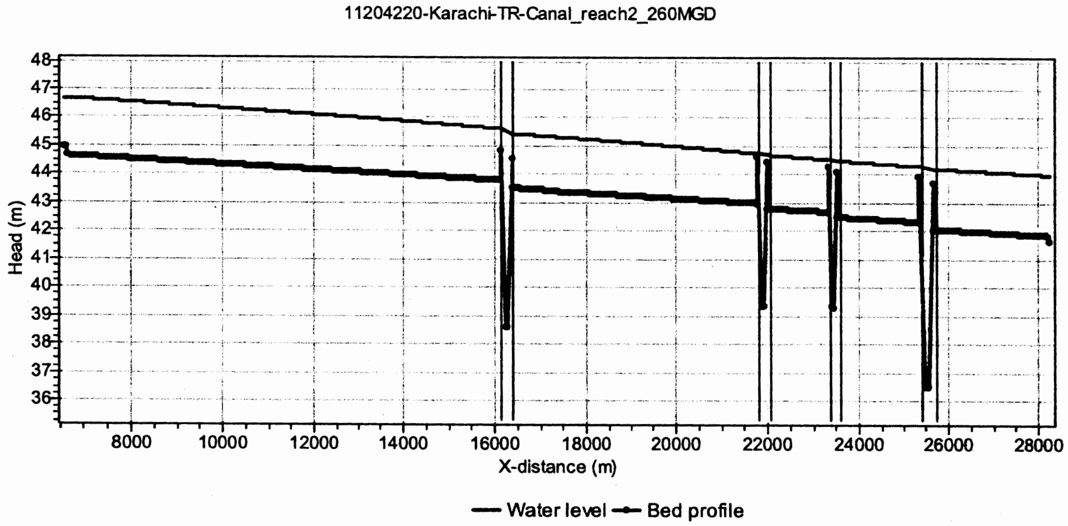


Figure 3.1 Head envelope of Canal Reach 2 and siphons for a discharge of 260 MGD (13.4 m³/s)

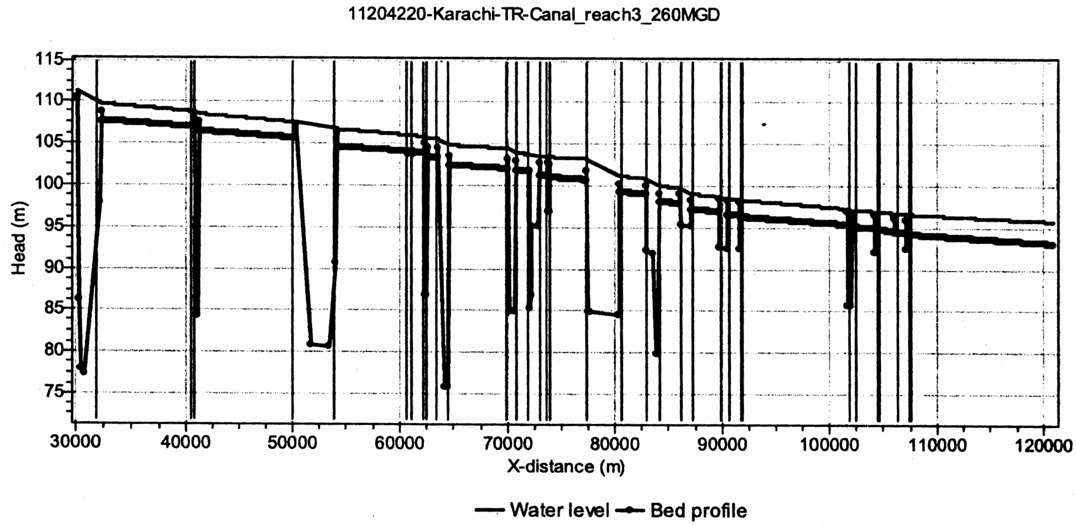


Figure 3.2 Head envelope of Canal Reach 3 and siphons for a discharge of 260 MGD (13.4 m³/s)

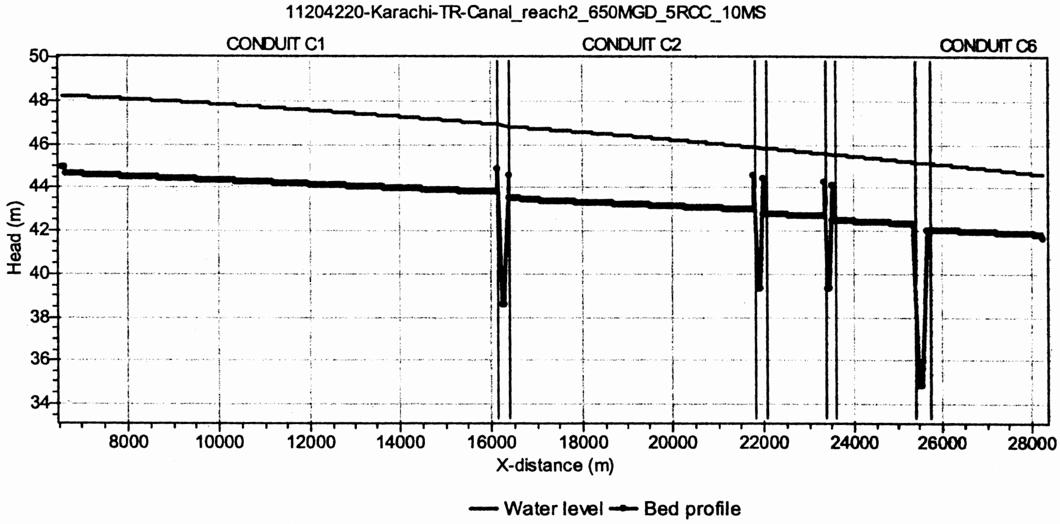


Figure 3.3 Head envelope of Canal Reach 2 and siphons for a discharge of 650 MGD (34.2 m³/s)

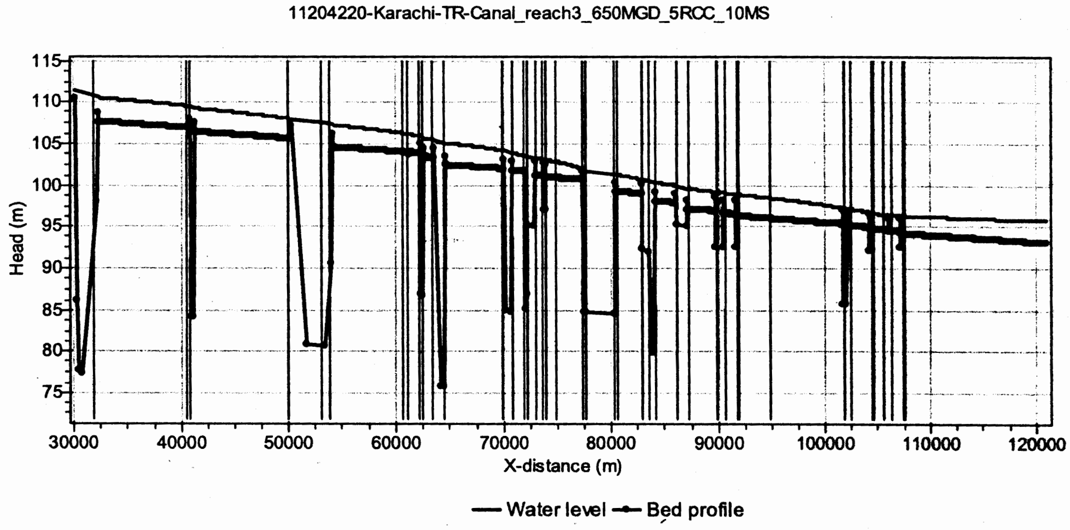


Figure 3.4 Head envelope of Canal Reach 3 and siphons for a discharge of 650 MGD (34.2 m³/s)

3.3 Conclusions

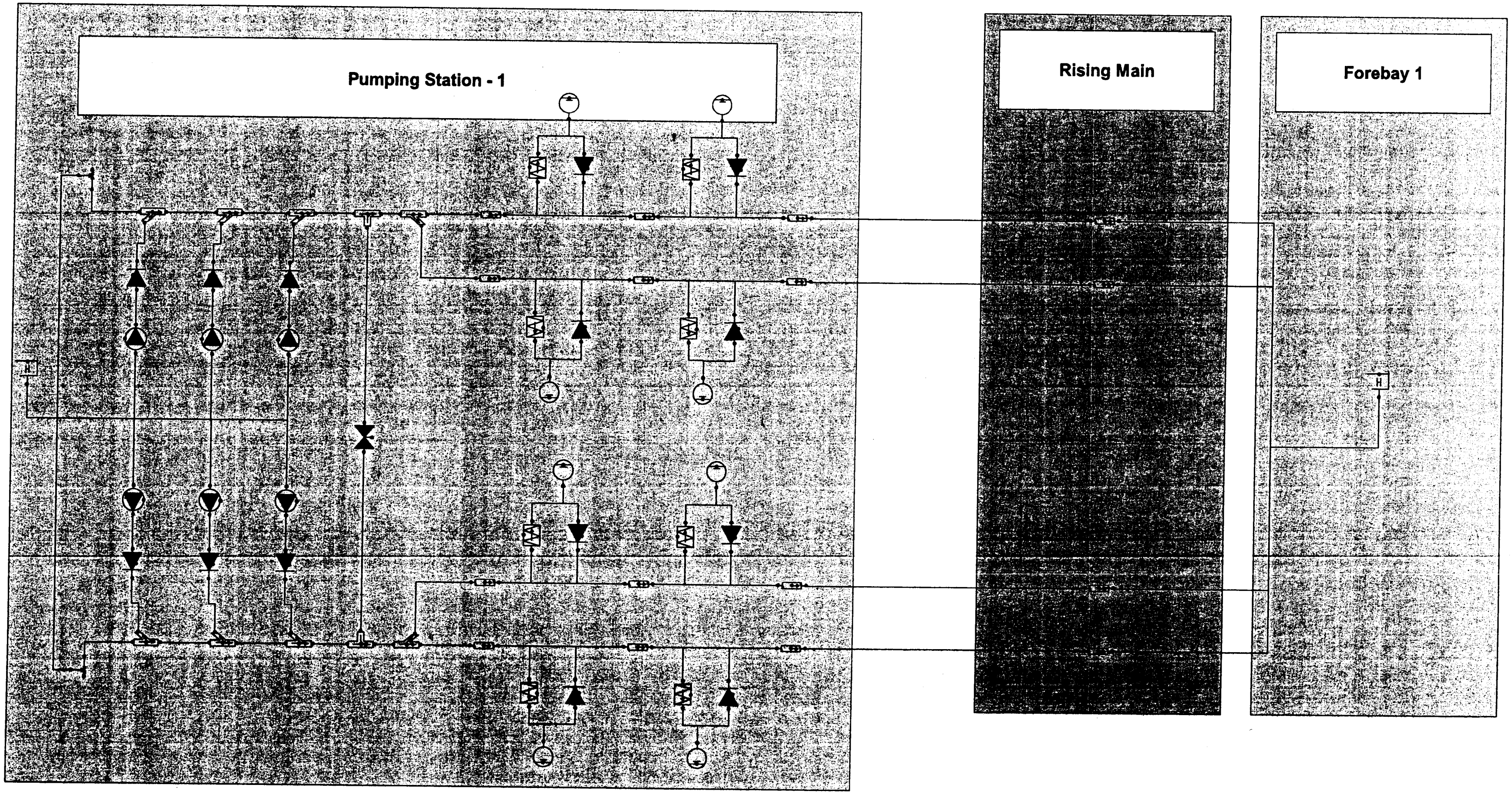
The results from these simulations have been used to verify and confirm the hydraulic calculations performed by NESPAK. There are small differences in the calculation results from Deltares and NESPAK. These differences have been analysed and discussed with NESPAK' engineers and our mutual conclusion is that these differences are negligible and are caused by the differences in the numerical modelling methods that were used.

The conclusion is that the design flow rate of 260 MGD and 650 MGD can be transported by the canals and siphons. The water levels in the canal are within acceptable limits.
A preliminary assessment of the risk of sedimentation in the siphons indicates that the flow velocity in the siphons is not sufficient to transport medium and coarse sediments. Fine

sediments may be transported through the siphons, depending on the exact sediment properties and sediment load. It should be noted that this assessment only considers the particle size and density of the sediment. For large amounts of sediment or sediment with cohesive particles other physical phenomena can influence the sediment transport.
This analysis should have been performed during the initial design phase of the project and mitigating measures could have been incorporated into the original design. It is highly recommended to perform additional analysis and studies regarding sediment transport through the canals and siphons and design mitigating measures where required, as these aspects directly affect the reliability and the hydraulic capacity of the system.

A Simulation models

11204220-Karachi-TR-PS-1.wdx



11204220-Karachi-TR-PS-2.wdx