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HYDRAULIC STUDY FOR THE NEW CAIRO RAW WATER PIPELINE

EGYPT WATER AND WASTEWATER SECTOR SUPPORT PROGRAM

Funded by the United States Agency for International Development (USAID)

September 2010

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Draft Report

New Cairo Raw Water System Hydraulic Modeling Study

Prepared for

Chemonics

September 2010

Prepared by

CH2MHILL®

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Acronyms and Abbreviations

BPS	booster pump station, booster pump site
CAD	computer aided design
CAV	combination air admission/air release valve
EMWL	emergency maximum water level
EPS	extended period simulation
GRP	glass reinforced pipe
HGL	hydraulic grade line
HHWL	high-high water level
IPS	intake pump station
LLWL	low-low water level
m	meter
m/s	meters per second
m^3	cubic meters
m^3/sec	cubic meters per second
MG	million gallons
MGD	million gallons per day
mm	millimeter
MOC	method of characteristics
mwc	meters water column
NCRWS	New Cairo Raw Water System
SCADA	supervisory control and data acquisition
USEPA	United States Environmental Protection Agency
VSD	variable speed drive
WTP	water treatment plant

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Executive Summary

The New Cairo Raw Water System (NCRWS) is currently under construction and the first phase is expected to be completed by the end of 2011. The system consists of one raw water intake pump station (IPS), three booster pump stations (BPS 2, 3, and 4), and multiple parallel 2200-millimeter (mm) and 2600-mm diameter pipelines that run approximately 30 kilometers (km) from the Nile River to the newly constructed New Cairo Potable Water Treatment Plant (WTP). Construction will be completed in eight pump installation phases, with design flows ranging from 6 cubic meters per second (m^3/sec) at Phase 1 to an ultimate flow of 48 m^3/sec at Phase 8.

Because the pumping capacity required for Phases 5-8 is to be supplied by a parallel system of pump stations and pipelines that mirror Phases 1-4 (with identical hydraulics and capacities), the following report is based on analysis of Phases 1-4 only. The ultimate flow rate for Phase 4 is 24 m^3/sec (exactly half of Phase 8).

CH2M HILL was assigned the task of performing a hydraulic computer modeling analysis on the NCRWS beginning in June of 2010, which focused on two primary issues:

- Pump and forebay level operation
- Hydraulic transients otherwise known as “surge” or “water hammer”

The following report summarizes the background data supporting this analysis, the results of the hydraulic analysis, and Phase 1 and 4 recommendations. Four primary conclusions are presented based on the analysis described in this report:

- The NCRWS will supply the design flow rates, and the hydraulic components of the system (pumps, motors, and piping) are well matched to the basic hydraulic performance requirements.
- The system requires protection from surge conditions resulting from sudden pump failure and other anticipated hydraulic conditions. Both hydro-pneumatic tanks and surge tanks (standpipes) are required, which supports the finding of other engineering firms that have studied the NCRWS.
- Because each pump station pumps directly to the forebay of the next pump station downstream, the system is very sensitive to changes in flow rates. This sensitivity applies to both normal and emergency operation. The system requires protection from forebay overflow by incorporating additional control logic and additional forebay volume.
- It is possible to develop a solution that addresses both the surge and forebay level operation in one structure which consists of two concentric tanks located at the relative highpoints on each major pipeline segment just upstream of each BPS. The inner tank is a standpipe (or concrete structure) with weir that continuously overflows into an outer tank. The outer tank effectively increases the operating volume of the downstream booster pump station forebay.

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Detailed conclusions and recommendations on the pump operation/forebay analysis and surge analysis are described below:

Pump Operation and Forebay Volume Analysis

CH2M HILL conducted a detailed hydraulic analysis of the NCRWS including pump and forebay water level operation. Extended period simulations (EPS) were conducted using the steady state computer model developed for this study. The following conclusions and recommendations were developed based on an analysis of the existing and proposed design conditions:

- **Pump Cycling** - The results of the EPS hydraulic model analysis show that pumps starts and stops will not exceed the design requirements during hot weather of 2 starts per hour.
- **Forebay Overflow** - The EPS modeling of a power failure at a BPS shows that the forebays will overflow within minutes unless the upstream pump station is shut down immediately. Manual control may not provide adequate response time. CH2M HILL recommends that an Emergency Maximum Water Level (EMWL) elevation be used as a control set- point to shut down the upstream pump station. Also, additional forebay volume is recommended in conjunction with the proposed EMWL set-point. Three alternative locations for the additional storage are described in this report.
- **Phase 1 Normal Operation** - Multiple EPS model runs were conducted of the existing Phase 1 design, with all pipes in service and with various pipes out of service at each major pipeline segment (IPS 1 to BPS 2, BPS 2 to BPS 3, BPS 3 to BPS 4, and BPS 4 to the WTP). For the existing Phase 1 design, the system remains balanced and forebay level operation is not a problem even if a pipe is out of service.
- **Phase 4 Normal Operation** - Multiple EPS model runs were conducted of the existing Phase 4 design, with all pipes in service and with various pipes out of service at each major pipeline segment (IPS 1 to BPS 2, BPS 2 to BPS 3, BPS 3 to BPS 4, and BPS 4 to the WTP). For the existing Phase 4 design, system flows are well balanced and forebay level operation is not a problem when all pipes are in service. However, it is more challenging to balance flows if a pipe is out of service. Typically, if a pipe is taken out-of-service, the all 12 pumps immediately upstream of the off-line pipe should remain in service, and the remaining pumping stations should only operate 11 pumps.
- **Phase 1 Normal Operation with Proposed Standpipe/Weir** - Multiple EPS model runs were conducted with the proposed “standpipe with weir”structure at Phase 1 flows. Flow control would be beneficial at the IPS under this condition. (If the existing electric control valves at the IPS can be throttled as a temporary measure, system flows would be better balanced. However, if the control valves cannot be used in this way, variable speed pump drives (VSDs) could provide the same function.)
- **Phase 4 Normal Operation with Proposed Standpipe/Weir** - Multiple EPS model runs were conducted with the proposed “standpipe with weir”structure at Phase 4 flows. The system flows are well balanced with all pipes in service. However, if a pipe is taken out

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of service, the same strategy described above can be utilized to balance flows in the system.

- **Variable Speed Pump Drives** - VSDs were considered during this study but were not considered as an absolute necessity because the modeling showed that pump over cycling would not be an issue for the NCRWS. However, incorporating a small number of VSD pumps in future phases (2 at each pump station by Phase 4) would provide operational flexibility especially when pipes are taken out of service for maintenance.
- **Real-Time Energy and Emergency Control System** – Due to the operational complexity and potential power costs to operate the NCRWS, a real-time energy and emergency management system (EMS) such as the Derceto Aquadapt™ software can operate in parallel with the supervisory control and data acquisition (SCADA) system and be used to plan for future pump or pipeline maintenance activities, respond to emergency shut downs, and minimize energy costs through off-peak pumping strategies.

Surge Analysis

CH2M HILL conducted a comprehensive computer surge model analysis of the NCRWS and review of previous surge studies by three firms, Hitachi, Charlatte, and Dorsch Consult.

The following conclusions are based on CH2M HILL's review of the three previous surge studies:

- The three previous studies (taken together with the current study) provide the same general recommendations. Each study finds that surge protection is needed and recommends the installation of hydro-pneumatic surge vessels at the pump stations.
- Each of the three studies allowed negative transient pressures near the end of each major pipeline segment. Charlatte and Dorsch recommend standpipes, open chambers, and air inlet/outlet valves to mitigate this surge condition. (It should be noted that a discrepancy exists in the pipeline length used during the Hitachi study and the pipeline CAD drawings provided for this study from IPS 1 to BPS 2. If the CAD drawings are correct, the Hitachi study may have underestimated the negative pressures at the end of the pipelines.)

The following conclusions and recommendations are based on CH2M HILL's surge study:

- **Positive Pressure Design Criteria** - CH2M HILL understands that current design includes only "air release" valves at certain points along the pipelines. Allowing negative transient pressures may pose a risk to the pipeline including gasket failure due to the combined external load plus negative internal transient pressures in the pipeline. Replacing existing "air release" valves with "combination air admission/air release valves" (CAVs) along with constructing multiple new CAV vaults near the end of each major pipeline segment would result in additional capital expense and significant maintenance requirements. For this reason, CH2M HILL adopted a design criterion of maintaining positive pressures at all times during steady state and surge conditions.
- **Recommended Surge Control Strategy (Hydro-pneumatic Tanks Plus Standpipes)** - CH2M HILL recommends the installation of hydro-pneumatic tanks at the intake and

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booster pump stations and an open top "standpipe with weir" surge control structure at the relative high point at the end of each major pipeline segment upstream of BPS 2, BPS 3, and BPS 4 (a total of 3 structures). The "standpipe with weir" structure provides a dual purpose of surge control and additional forebay storage capacity.

- **Equalization Reservoir at WTP** – Either a "standpipe with weir" structure or larger reservoir is recommended upstream of the NCWTP at the pipeline high point to mitigate surge conditions, provide equalized flow to the WTP during pump station service interruptions, and to incorporate an off-peak pump strategy to reduce pumping power costs.

- **Intake Pump Station Hydro-pneumatic Tanks** - The maximum number of hydro-pneumatic tanks at the IPS is fixed at eight due to structural constraints. CH2M HILL found that the tank volumes recommended by Hitachi were adequately sized if the proposed "standpipe with weir" structure is constructed.

- **Booster Pump Station Hydro-pneumatic Tanks** - Because of the large volumes of air required to control surge at Phase 4 conditions, large spherical hydro-pneumatic tanks (two per BPS) represent a more economical solution than a large number of smaller tanks at BPS 2, 3, and 4. However, the Phase 1 hydro-pneumatic tank volume requirements are much smaller. Three hydro-pneumatic tank construction sequence options for BPS 2, 3, and 4 are described below:

    - Option A: Supply many hydro-pneumatic tanks of small volume for Phases 1 and 4 (likely not feasible due to site spatial constraints)

    - Option B: Supply hydro-pneumatic tank(s) of small volume for Phase 1 and supplement with a large single volume hydro-pneumatic tanks for Phase 4

    - Options C: Construct one of the large spherical hydro-pneumatic tanks by Phase 1 and a second sphere before Phase 4

- **Hydro-pneumatic Tank Piping Manifold** - The surge model analysis showed a critical sensitivity to the diameter and length of the hydro-pneumatic tank manifold in preventing negative pressures at the end of the pipelines. At Phase 4 conditions, two spherical tanks with 2.6-meter (m) diameter manifolds (12 m in length) prevent negative pressures when used in conjunction with the recommended "standpipe with weir" structure.

- **Isolation Valve Pressure Equalization** - It is not clear if bypass valves are proposed at large isolation valves on the transmission pipelines. Surge analysis showed the need for these valves in order to reduce unseating head and to control surge during opening of the isolation valve.

- **Isolation Valve Closure** - Recommended minimum closure time for the large isolation valves is 2 minutes. The valve and controls suppliers should be consulted on recommended closing times based on their standard practices.

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Summary of Recommendations

The following summary of recommendations is provided based on the pump operation/forebay volume analysis and the surge analysis conducted during this study:

- **Recommendation 1 (Pump Controls)** - CH2M HILL recommends the control strategy described in Section 2.4. An EMWL control set-point that shuts down the upstream pumping station is critical to prevent forebay overflow.
- **Recommendation 2 (Emergency Storage)** - CH2M HILL has proposed several emergency storage options for consideration (Alternatives 1A, 1B, and/or 1C). Storage alternative 1A and 1B would provide storage local to the booster pump station. Alternative 1C (standpipe with weir structure) would be located upstream of the booster pump station. Refer to Section 3.3.
- **Recommendation 3 (Temporary Control Valve Throttling)** – If Alternative 1C (standpipe with weir structure) is constructed by Phase 1, utilize the IPS electric control valves to throttle flow until Phase 4 (designer to confirm feasibility with valve manufacturer). Refer to Section 3.5.3.3.
- **Recommendation 4 (Pipe Maintenance Strategy)** – Pipe maintenance activities can affect pump operation at Phase 4 conditions. A real-time hydraulic model linked with the SCADA system (i.e., Derceto Aquadapt software) can be used to plan maintenance and emergency strategies as well as to optimize pumping costs.
- **Optional Recommendation 5 (Variable Speed Drives)** – Incorporate VSDs at 2 of the 16 pumps to provide additional flexibility in operation during pipeline maintenance or emergency conditions.
- **Recommendation 6 (Hydro-pneumatic Tanks)** – Incorporate hydro-pneumatic tanks with sufficient volumes as recommended in Section 4. Either Option B or C, described above, is recommended. Special attention should be made regarding the diameter and length of the hydro-pneumatic tank manifold piping. Refer to Section 4.5.
- **Recommendation 7 (Back-up Pipe between BPS 2 and BPS 3) –** Two 2.6 meter diameter pipelines convey flow from BPS 2 to BPS 3. If one pipe is out of service at Phase 4 design flows, velocities are extremely high and providing adequate surge protection is difficult. For this reason, it is recommended that third pipe be constructed that can be shared with the parallel Phase 5-8 system during maintenance or emergencies.
- **Recommendation 8 (Standpipe/Weir Structure**) – Incorporate a single "standpipe with weir" structure at the relative high point of each pipeline segment (one upstream of each BPS and WTP) to provides protection against surge as well as provide additional forebay storage volume. Refer to Section 3.3.1.3. Alternatively, a large reservoir could be constructed upstream of the WTP at the pipeline high point.
- **Recommendation 9 (Bypass Valves**) - Bypass valves should be installed at all large isolation valves to reduce unseating heads during valve opening.

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1.0 Introduction

In early 2010, CH2M HILL was asked by the Egyptian Water and Wastewater Holding Company to evaluate design aspects of the New Cairo Raw Water System (NCRWS). Specific design and operational concerns were raised by CH2M HILL and the Holding company at that time. In June of 2010, CH2M HILL was contracted through Chemonics to perform a hydraulic and surge modeling evaluation of the entire NCRWS. This section describes the background on the NCRWS project, the study scope of work, and the data collection and review performed at the beginning of this study.

1.1 Background

The NCRWS is currently under construction, and the first phase is expected to be completed by 2011. The system will consist of one raw water intake pump station (IPS), three booster pump station sites (BPS 2, 3, and 4), and multiple parallel 2200-millimeter (mm) and 2600-mm diameter pipelines that run approximately 30 kilometers (km) from the Nile River to the newly constructed New Cairo Potable Water Treatment Plant (WTP). The total elevation change from the Nile River to the WTP is approximately 400 m.

The IPS will receive run-of-river flow from the Nile River and pump it to the BPS 2 site, which pumps to the BPS 3 site, which pumps to the BPS 4 site, which pumps to the NCWTP as shown in Figure 1-1. Each BPS receives flow into a forebay reservoir with an approximate volume of 6,000 cubic meters (m^3).

A total of eight pump installation phases are planned for the NCRWS. IPS 1 is currently being constructed to accommodate all eight phases. At each booster pump station site, two identical stations are being constructed, one for Phase 1-4 and the other for Phase 5-8. While both stations are currently being constructed, the Phase 5-8 stations will not house pumps until Phase 1-4 stations are completed.

It is understood that the Phase 1 pumps and motors have been approved and ordered for delivery to the job site. It is also understood that subsequent phases are expected to be implemented every 6 to 12 months with ultimate build-out to Phase 8 expected about 5 to 6 years after completion of Phase 1.

Previous surge studies have been conducted on different segments of the system, but no comprehensive study had been conducted prior to the preparation of this report by CH2M HILL. The three prior studies include:

- Hitachi Plant Technologies completed a surge study in 2009 for IPS 1 at Phases 1 and 4 conditions.
- Charlatte (Fayat Group) has completed a surge study in 2010 for BPS 2, BPS 3, and BPS 4 for Phase 1 conditions.
- Dorsch Consult surge study in 2010 for BPS 2, BPS 3, and BPS 4 at Phases 1 and 4 conditions.

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FIGURE 1-1
Plan View of NCRWS
New Cairo Raw Water System Hydraulic Modeling Study

1.2 Scope of Work

CH2M HILL has been contracted by Chemonics to conduct a hydraulic computer modeling analysis of the proposed NCRWS, from IPS to the WTP, in order to evaluate the adequacy of the current design from an operational and surge protection standpoint. The study includes developing an extended period simulation (EPS) model and surge model of the system for the Phase 1 and Phase 4 design flows.

The scope of work was divided into the following tasks:

- Task 1 – Data Collection
- Task 2 – Model Development
- Task 3 – Operational Modeling Analysis
- Task 4 – Surge Modeling Analysis

1.3 Document Review and Data Gaps

The reports, letters, and drawings that were provided to CH2M HILL at the beginning of this study primarily address design of the IPS at Phase 1 through Phase 4 design flows. Very little information was available for the BPSs other than the design drawings. A pump control strategy and level set-points for Phase 1 was provided, but not for Phase 2 through Phase 4 conditions.

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At the beginning of this study, the client provided CH2M HILL with the information shown in Table 1-1 below.

TABLE 1-1
Documents Provided by Designers and Contractors
New Cairo Raw Water System Hydraulic Modeling Study

Document No.	Description	Data Gap
1	General Arrangement of IPS Drawing, April 21, 2008	Sufficient to perform study
2	Required Head Range of Pumps (IPS), Hitachi, June 19, 2008	Sufficient to perform study
3	Design Performance Curves in Parallel Operation (IPS), Hitachi, June 19, 2008	Sufficient to perform study
4	Pump Design Performance Curves (IPS#1), Hitachi, December 27, 2007	Sufficient to perform study
5	Water Hammer Analysis (IPS#1), Hitachi, June 19, 2008	Sufficient to perform study with exceptions: • The pipeline length does not match the contractor CAD drawings (Document #8). • The pipeline length used for Hitachi's surge analysis is 10,000 meters (m). The length of the pipelines in the contractor CAD drawings is 11,600 m. • The discrepancy occurs at the most critical portion of the pipeline at the top of the hill where negative pressures can occur during surge events.
6	"Reply to the Letter of the New Consultant (Enviro Civec) for the New Cairo Transmission Mains" (response letter from Siemens on various questions regarding IPS), February 13, 2010	Sufficient to perform study
7	Hydraulic Pump Operations Report for Overall System Including IPS and BPS 2, 3, & 4 to the WTP. (Phase 1 operation including pump start/stop set-points), Undated Document	Sufficient to perform study with exceptions: • Pump control set-points for Phase 2, 3, and 4 conditions were not included in this document • For this study, CH2M HILL utilized similar forebay level strategy and developed start/stop set-points for pumps 5 through 12
8	`Booster Pump Station Pump House Plan and Section Drawings, January 15, 2008	Sufficient to perform study with exceptions: • Drawing lacked general arrangement information on the proposed hydro-pneumatic surge tanks recommended by Charlatte. • Drawing did not indicate the type of check valve being specified for BPS 2, 3, and 4. • Correspondence with the Torishima pump representative indicated that the check valves were simple swing type and no electric control valves were included in design

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The information shown in the Table 1-2 includes data and reports provided to CH2M HILL during this study by the Charlatte Reservoirs (Fayat Group) and Dorsch Consult. Charlatte had previously performed a surge analysis and submitted a hydro-pneumatic bladder tank design to the Arab Contractors for BPS 2, 3, and 4 for Phase 1 conditions only. The report of Dorsch Consult to the Arab Contractors was forwarded to CH2M HILL in August, 2010 near the end of the CH2M HILL study.

TABLE 1-2
Documents Provided by Charlatte and Dorsch Consult
New Cairo Raw Water System Hydraulic Modeling Study

Document No.	Information	Data Gap
9	Detailed CAD plan view drawing of raw water transmission mains and pumping stations from IPS 1 to Cairo Potable Water Treatment Plant, Charlatte Reservoirs-Fayat Group, received June 7, 2010	Sufficient to perform study
10	Detailed CAD pipeline profile drawing of raw water transmission mains and pumping stations from BPS 2 to the Cairo Potable Water Treatment Plant, Charlatte Reservoirs-Fayat Group, received June 7, 2010	Sufficient to perform study with exceptions: • However, this drawing lacked a profile of the pipelines from IPS to BPS 2. • CH2M HILL used the profile data from Hitachi's water hammer analysis study (Document #5). The last 1,600 m which is missing from Hitachi's profile was estimated for the CH2M HILL study
11	"Design Calculations for the protection from water hammer for the Raw Water Boosters number (2, 3, & 4) to New Cairo Water Treatment" (surge analysis report), Charlatte Reservoirs-Fayat Group, March 31, 2010	Sufficient to perform study
12	BPS 2, 3, and 4 Pump and System Curves (Phase 1 Flows), Torishima, May 28, 2009	Sufficient to perform study
13	"Surge Analysis Draft Report – PS2 to PS3, PS3 to PS4, PS4 to WTP." Prepared by The Arab Contractors; Osman Ahmad Osman & Co., August 2010 ("Dorsch Consult" Report)	Sufficient to perform study

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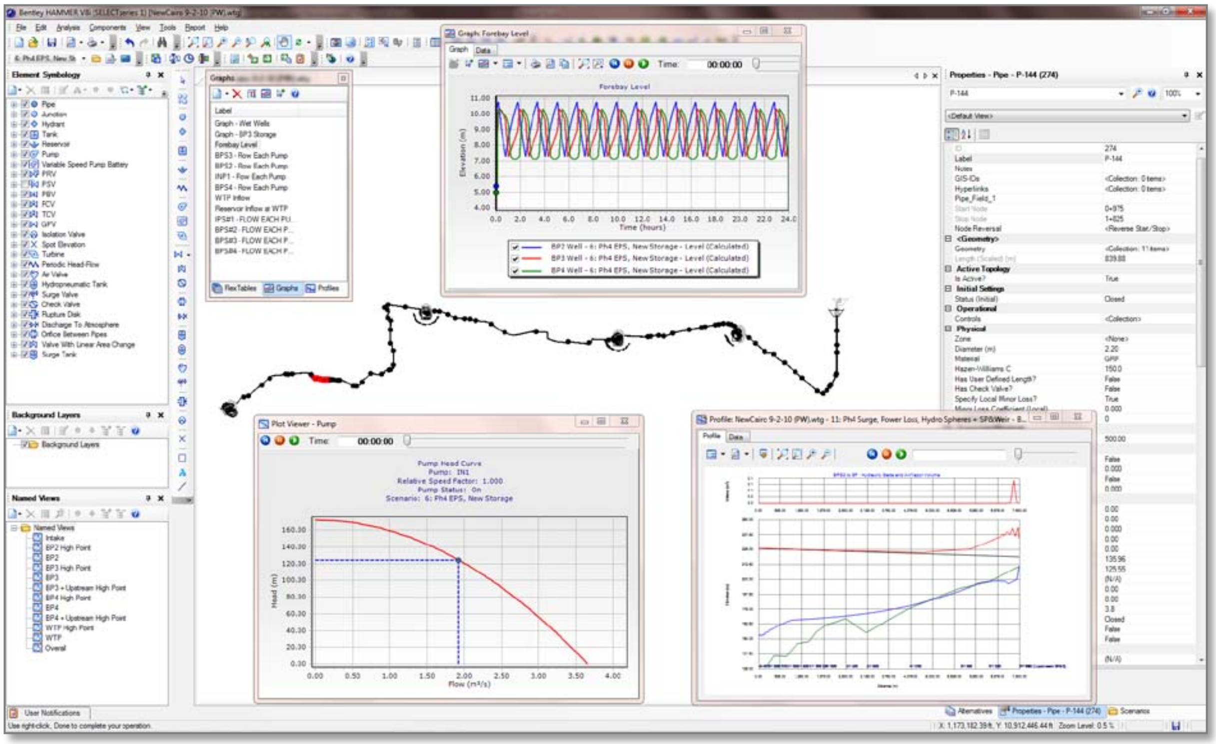
2.0 Computer Model Development

A fully dynamic hydraulic computer model was developed for this study to perform steady state, EPS, and surge analyses. The model was developed from the documents and information described in Section 1.3.

2.1 Modeling Software

The hydraulic computer model was developed in the WaterGEMS Hammer v8i software by Bentley Haestad Methods. The model platform consists of a graphical user interface with extensive functionality. The WaterGEMS hydraulic engine is based on EPA Net, which is a free and open source code software developed by the United States Environmental Protection Agency (USEPA). The Hammer surge engine utilizes the Method of Characteristics (MOC) and works within the WaterGEMS platform. A screen shot of the New Cairo model is shown in Figure 2-1.

FIGURE 2-1
WaterGEMS-Hammer Hydraulic Modeling Software
New Cairo Raw Water System Hydraulic Modeling Study



2.2 Pipeline Profile

Using the provided CAD drawings (Documents #9 and #10, Section 1.3), the transmission mains were digitized, and elevation data was incorporated at key points along the pipeline profile as shown in Figure 2-2. Specific attention was paid to the elevations along the flat

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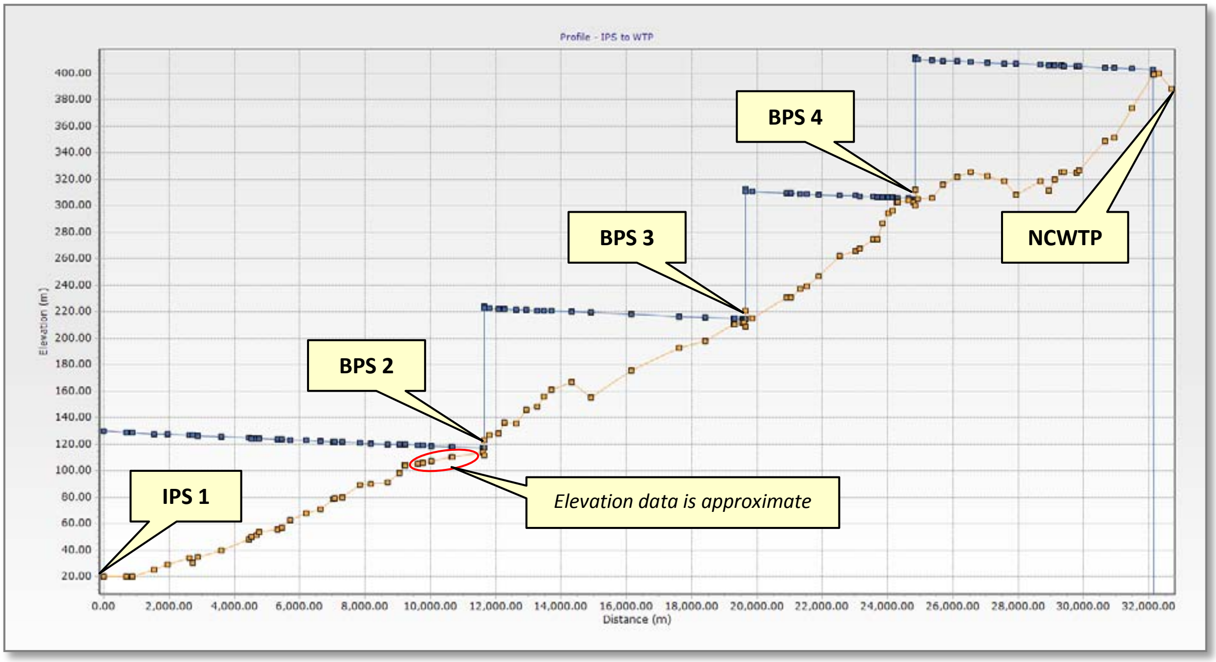
portion of the pipeline just upstream of each BPS, where negative and vacuum pressures can sometimes occur during surge conditions. Pipeline profile information from IPS 1 to BPS 2 was taken from the Hitachi study (Document #5, Section 1.3) since elevation data was not provided in the CAD drawings. Also, the total pipeline length in the Hitachi study is about 1,500 m shorter than the CAD drawing, and for this reason the elevations along the last 1,500 m of pipe are approximate as indicated in Figure 2-2. The hydraulic grade line from IPS 1 to the NCWTP is also shown in Figure 2-2 at Phase 4 flows, which indicates the very low static pressure just upstream of each BPS.

FIGURE 2-2
Transmission Main Profile and Phase 4 Hydraulic Grade Line
New Cairo Raw Water System Hydraulic Modeling Study



2.3 System Configuration and Phases

The NCRWS consists of multiple parallel pipelines and pumping stations as shown in Figure 2-3. Two primary pipeline trains will convey raw water from the Nile River to the NCWTP (train A and train B). Train A consists of half of IPS 1 and three BPSs (BPSs 2, 3, and 4), which are being constructed in four phases (Phase 1-4). Train B will be an identical system and is also being constructed in four phases (Phase 5-8). All six BPS structures have been constructed. The Phase 1 mechanical components, including pumps and piping, are currently being constructed for Train A. In addition, the single IPS structure has been constructed, and the mechanical components for Phase 1 are currently being constructed.

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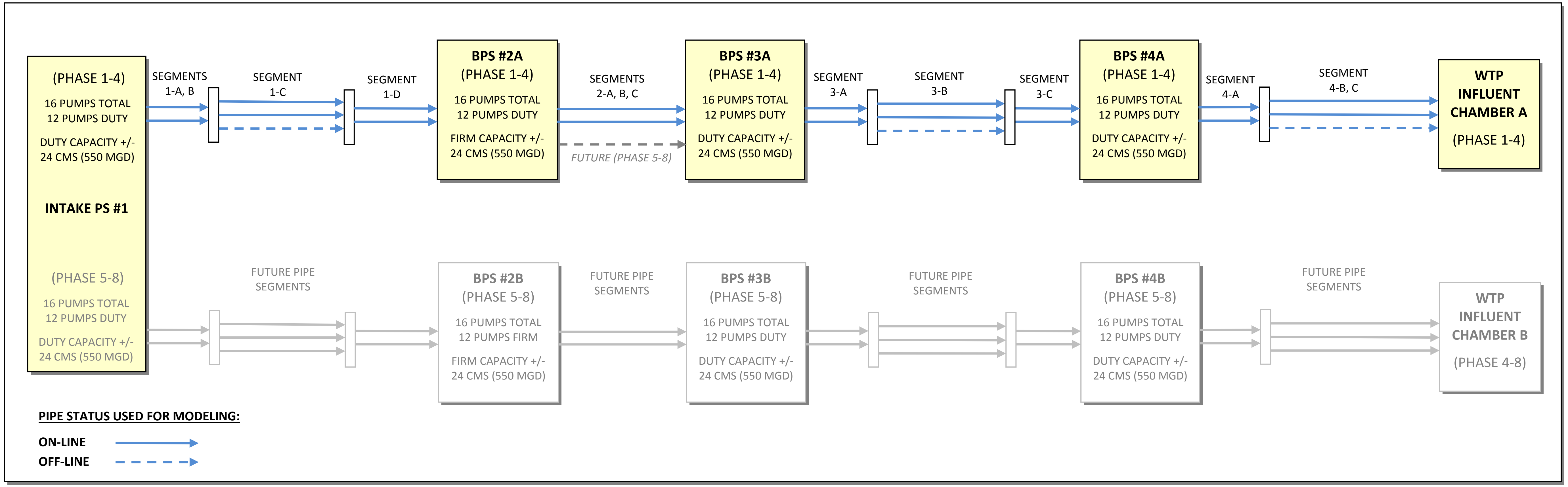
FIGURE 2-3
Raw Water System Schematic
New Cairo Raw Water System Hydraulic Modeling Study



INTAKE PS #1 TO BPS #2

PIPE SEGMENT	STATION START	STATION STOP	LENGTH (meters)	LENGTH SOURCE	NUMBER OF PIPES	PIPE DIA. (meters)	PIPE MATERIAL	MATERIAL SOURCE
1-A	0	850	850	(1)	2	2.6	PCCP	(1)
1-B	850	2650	1,800	(3)	2	2.6	GRP	(1)
1-C	0	5250	5,250	(3)	3	2.2	GRP	(1)
1-D	5250	8950	3,700	(3)	2	2.6	GRP	(1)
TOTAL PIPE ALIGNMENT LENGTH			11,600					

Source: (1) Hitachi Surge Study; (2) Charlatte Surge Study; (3) Contractor CAD Drawings

BPS #2 TO BPS #3

PIPE SEGMENT	STATION START	STATION STOP	LENGTH (meters)	LENGTH SOURCE	NUMBER OF PIPES	PIPE DIA. (meters)	PIPE MATERIAL	MATERIAL SOURCE
2-A	-400	-250	150	(3)	2	2.6	STL	(2)
2-B	-250	0	250	(3)	2	2.6	GRP	(2)
2-C	0	7460	7,460	(3)	2	2.6	GRP	(2)
TOTAL PIPE ALIGNMENT LENGTH			7,860					

Source: (1) Hitachi Surge Study; (2) Charlatte Surge Study; (3) Contractor CAD Drawings

BPS #3 TO BPS #4

PIPE SEGMENT	STATION START	STATION STOP	LENGTH (meters)	LENGTH SOURCE	NUMBER OF PIPES	PIPE DIA. (meters)	PIPE MATERIAL	MATERIAL SOURCE
3-A	-400	-200	200	(3)	2	2.6	STL	(2)
3-B	-200	4550	4,750	(3)	3	2.2	GRP	(2)
3-C	0	50	50	(3)	2	2.6	STL	(2)
TOTAL PIPE ALIGNMENT LENGTH			5,000					

Source: (1) Hitachi Surge Study; (2) Charlatte Surge Study; (3) Contractor CAD Drawings

BPS #4 TO WTP

PIPE SEGMENT	STATION START	STATION STOP	LENGTH (meters)	LENGTH SOURCE	NUMBER OF PIPES	PIPE DIA. (meters)	PIPE MATERIAL	MATERIAL SOURCE
4-A	-400	-325	75	(3)	2	2.6	STL	(2)
4-B	-325	0	325	(3)	3	2.2	GRP	(2)
4-C	0	7525	7,525	(3)	3	2.2	GRP	(2)
TOTAL PIPE ALIGNMENT LENGTH			7,925					

Source: (1) Hitachi Surge Study; (2) Charlatte Surge Study; (3) Contractor CAD Drawings

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Due to the fact that train A is an independent system from train B, the computer model was set up to only model the Phase 4 system which consist of 12 duty pumps at each pumping station (IPS 1, BPS 2, BPS 3, and BPS 4). Table 2-1 provides the total number of duty and standby pumps and approximate design flow at each phase of construction. For this study, only Phase 1 and Phase 4 conditions were evaluated using the computer model.

Figure 2-3 also identifies which pipes were assumed closed during the modeling analyses described in Sections 3 and 4 of this report. This figure also shows the source of for the pipeline material, diameter, length, and configuration.

TABLE 2-1
Number of Pumps and Design Flows at Intake and Booster Pumping Stations
New Cairo Raw Water System Hydraulic Modeling Study

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Total No. of Pumps	4	8	12	16	20	24	28	32
Total No. of Duty Pumps	3	6	9	12	15	18	21	24
Total No. of Stand-by Pumps	1	2	3	4	5	6	7	8
Total Duty Flow Rate (m^3/sec)	6	12	18	24	30	36	42	48
Total Duty Flow Rate (MGD)	137	274	411	548	685	822	959	1096

Note: flow rate will vary depending on number of pipelines on-line; MGD = million gallons per day; m^3/sec = cubic meters per second

2.4 Pumping Station Configuration

2.4.1 Booster Pumping Stations

The three Phase 4 booster pumping stations are identical in design with vertical turbine pumps, each rated ±2 m^3/sec, which pump from a forebay with a normal operation volume of 4,472 m^3 (1.18 million gallons [MG]) and emergency volume of 5,835 m^3 (1.54 MG) as shown in Table 2-2. A total of 12 duty and 16 total pumps will be located in each booster pumping station. Each booster pump station has similar but slightly different pump curves in what appears to be an effort to convey a constant flow from the IPS 1 to the NCWTP.

Per the Torishima pump manufacturer, the booster pump stations do not have electric control valves and have only hydraulic swing type check valves to prevent pump back spin. A pump discharge pipe diameter of 1 m was estimated from the design drawings. At the beginning of this study, the booster pumping station design drawings did not include a surge tank design.

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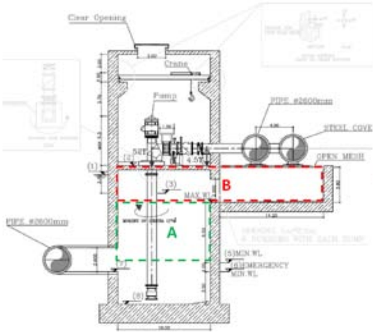
TABLE 2-2
Booster Pumping Station Normal Operation and Emergency Volumes
New Cairo Raw Water System Hydraulic Modeling Study

Forebay Dimensions	**Normal (A)**	**Emergency (B)**	**Units**
Width	10	22	m
Length	68.8	69.8	m
Area	688	1,536	m^2
Height (a)	6.5	3.8	m
Volume	4,472	5,835	m^3
	1.18	1.54	MG

(a) Normal operation volume "A" is from high-high water level (HHWL) to low-low water level (LLWL). Emergency volume "B" is from HHWL to the pump floor.



2.4.2 Intake Pumping Station

As shown in Figure 2-4, the IPS 1 is a single structure that will house all of the intake pumps through Phase 8. The pumps are horizontal end suction centrifugal design with extended shaft motors, each rated at ±2 m^3/sec. Each pump will have an electric control valve that throttles during start-up and shut-down of the pumps. As well, the design drawings seem to indicate that each pump has a hydraulic check valve to prevent pump back spin. A pump discharge pipe diameter of 1-m was estimated from the design drawings. The IPS 1 drawings show a total of sixteen 200-m^3 hydro-pneumatic surge tanks (four on each of four 2.6-m headers) for the Phase 8 design, each connected by a 0.8-m pipe with non-return valve.

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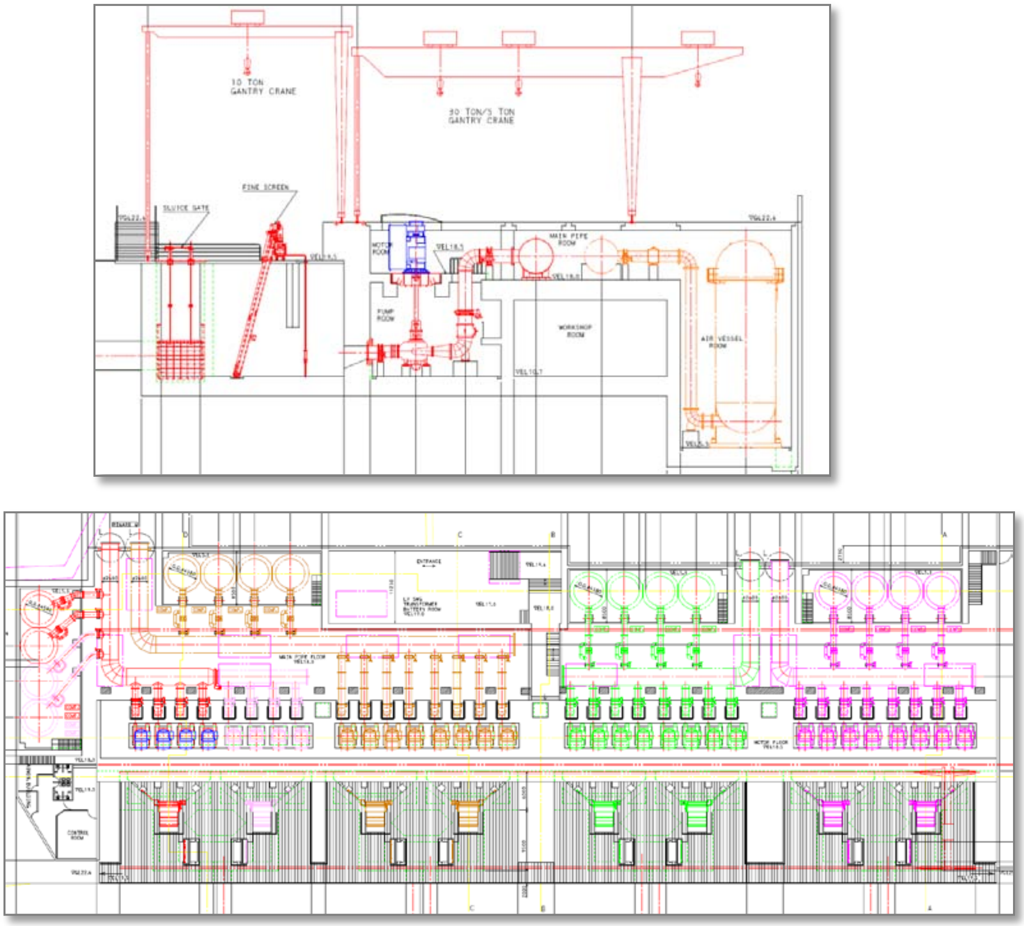
FIGURE 2-4
Intake Pumping Station Plan and Section Drawing
New Cairo Raw Water System Hydraulic Modeling Study



2.5 Pump Controls

2.5.1 Normal Operation

Document #7 (Section 1.3) describes the general control strategy for the NCRWS for Phase 1. The booster pump stations will be automatically controlled based on forebay level set-points, and it appears that the IPS 1 will be manually operated. However, specific pump start/stop elevations for Phase 1 were not provided. A control strategy was not provided for Phases 2-4 as well. To perform the modeling analysis, CH2M HILL estimated the pump start/stop elevations from Document #7 for Phase 1 as shown in Table 2-3. CH2M HILL also developed pump start/stop elevations for Phase 4 assuming the same control methodology as Phase 1 of pump start levels at the upper portion of the sump and pump stop levels at the lower portion of the sump.

2.5.2 Emergency Operation

Based on the modeling analysis described in Section 3, CH2M HILL recommends that the “emergency maximum water level” (EMWL) identified on the booster pump station

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drawings be utilized as a control set-point that shuts down the upstream pumping station. As described in Section 3.4, there is a significant risk of overflowing a booster pumping station forebay after a power loss if the upstream pumping station continues to operate. Based on the modeling analysis, it is recommended that the EMWL control set-point shut down the lead upstream pump with 0 second time delay, followed by the first lag pump with 30 second time delay, second lag pump with 60 second time delay, and so on. This control strategy should greatly reduce the risk of overflow during emergency situations. EMWL set-point elevations are provided in Table 2-3 for each BPS.

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TABLE 2-3
Pump Control Set-Points Used For Modeling Analysis
New Cairo Raw Water System Hydraulic Modeling Study

Booster Pumping Station 2				**Booster Pumping Station 3**				**Booster Pumping Station 4**			
Level (m)	**Elevation** (m-msl)	**PH 1 Set-Points (a)**	**PH 4 Set-Point (b)**	**Level** (m)	**Elevation** (m-msl)	**PH 1 Set-Points (a)**	**PH 4 Set-Point (b)**	**Level** (m)	**Elevation** (m-msl)	**PH 1 Set-Points (a)**	**PH 4 Set-Point (b)**
12.00	121.60	EMWL (c)	EMWL (c)	12.00	219.00	EMWL (c)	EMWL (c)	12.00	310.00	EMWL (c)	EMWL (c)
11.00	**120.60**	**HHWL**	**H.H.W.L.**	**11.00**	**218.00**	**H.H.W.L.**	**H.H.W.L.**	**11.00**	**309.00**	**H.H.W.L.**	**H.H.W.L.**
10.30	119.90		START P#12	10.30	217.30		START P#12	10.30	308.30		START P#12
10.07	119.67		START P#11	10.07	217.07		START P#11	10.07	308.07		START P#11
9.84	119.44		START P#10	9.84	216.84		START P#10	9.84	307.84		START P#10
9.61	**119.21**	**START P#3**	**START P#9**	**9.61**	**216.61**	**START P#3**	**START P#9**	**9.61**	**307.61**	**START P#3**	**START P#9**
9.38	118.98		START P#8	9.38	216.38		START P#8	9.38	307.38		START P#8
9.14	118.74		START P#7	9.14	216.14		START P#7	9.14	307.14		START P#7
8.91	118.51		START P#6	8.91	215.91		START P#6	8.91	306.91		START P#6
8.68	**118.28**	**START P#2**	**START P#5**	**8.68**	**215.68**	**START P#2**	**START P#5**	**8.68**	**306.68**	**START P#2**	**START P#5**
8.45	118.05		START P#4	8.45	215.45		START P#4	8.45	306.45		START P#4
8.21	117.81		START P#3	8.21	215.21		START P#3	8.21	306.21		START P#3
7.98	117.58		START P#2	7.98	214.98		START P#2	7.98	305.98		START P#2
7.75	**117.35**	**START P#1**	**START P#1**	**7.75**	**214.75**	**START P#1**	**START P#1**	**7.75**	**305.75**	**START P#1**	**START P#1**
7.29	**116.89**	**STOP P#3**	**STOP P#12**	**7.29**	**214.29**	**STOP P#3**	**STOP P#12**	**7.29**	**305.29**	**STOP P#3**	**STOP P#12**
7.05	116.65		STOP P#11	7.05	214.05		STOP P#11	7.05	305.05		STOP P#11
6.82	116.42		STOP P#10	6.82	213.82		STOP P#10	6.82	304.82		STOP P#10
6.59	116.19		STOP P#9	6.59	213.59		STOP P#9	6.59	304.59		STOP P#9
6.36	**115.96**	**STOP P#2**	**STOP P#8**	**6.36**	**213.36**	**STOP P#2**	**STOP P#8**	**6.36**	**304.36**	**STOP P#2**	**STOP P#8**
6.13	115.73		STOP P#7	6.13	213.13		STOP P#7	6.13	304.13		STOP P#7
5.89	115.49		STOP P#6	5.89	212.89		STOP P#6	5.89	303.89		STOP P#6
5.66	115.26		STOP P#5	5.66	212.66		STOP P#5	5.66	303.66		STOP P#5
5.43	**115.03**	**STOP P#1**	**STOP P#4**	**5.43**	**212.43**	**STOP P#1**	**STOP P#4**	**5.43**	**303.43**	**STOP P#1**	**STOP P#4**
5.20	114.80		STOP P#3	5.20	212.20		STOP P#3	5.20	303.20		STOP P#3
4.96	114.56		STOP P#2	4.96	211.96		STOP P#2	4.96	302.96		STOP P#2
4.73	114.33		STOP P#1	4.73	211.73		STOP P#1	4.73	302.73		STOP P#1
4.50	**114.10**	**LLWL**	**L.L.W.L.**	**4.50**	**211.50**	**L.L.W.L.**	**L.L.W.L.**	**4.50**	**302.50**	**L.L.W.L.**	**L.L.W.L.**
0	109.60	Base of Sump	Base of Sump	0	207.00	Base of Sump	Base of Sump	0	298.00	Base of Sump	Base of Sump

Note:

(a) - Phase 1 pump start/stop strategy shown is based on designers proposed operating scheme. CH2M HILL estimated specific start/stop elevations based on control logic graphic provided by designer

(b) - Phase 4 pump start/stop strategy was not provided by designer. CH2M HILL utilized similar operation scheme as Phase 1 and estimated specific start/stop elevations for the 12 pumps

(c) - The EMWL set-point is proposed by CH2M HILL to prevent forebay overflow. EMWL set-point sends SCADA signal back to upstream pumping station to shut down the lead pump with 0 second stop time delay, lag pump 1 with30 second stop time delay, lag pump 2 with 60 second stop time delay, lag pump 3 with 90 second stop time delay, etc.

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3.0 Pump Operation and Forebay Volume Analysis

An EPS modeling analysis was conducted to evaluate pump operation and forebay water levels. This analysis was conducted to determine if the forebays were sized appropriately to prevent overflows and to prevent excessive pump cycling which can overheat pump motors. This section is presented as follows:

- Section 3.1 – Design Criteria
- Section 3.2 – Design Conditions
- Section 3.3 – Alternatives
- Section 3.4 – Power Failure Event EPS
- Section 3.5 – Normal Operation EPS
- Section 3.6 – EPS Modeling Analysis Conclusions and Recommendations

The EPS analysis consists of a series of steady state model simulations to determine flow and volume changes over time. Unsteady "surge" conditions are described in Section 4 of this report.

3.1 Design Criteria

Table 3-1 summarizes the design criteria used for the EPS analysis. The booster pumping stations forebays must be sized appropriately to prevent the pumps from cycling on and off too frequently and to prevent overflows. Per the booster pumping station pump manufacturer, Torishima, the minimum allowable pump cycle time during hot weather is 2 starts per hour.

TABLE 3-1
Pump Operation and Forebay Volume - Design Criteria
New Cairo Raw Water System Hydraulic Modeling Study

Criteria	Description	Source
1	Pump cycling (maximum of 2 pump starts per hour during hot weather)	Torishima
2	Prevent forebay from overflowing or emptying during normal operation or power failure event	CH2M HILL

3.2 Design Conditions

The existing and proposed Phase 1 and Phase 4 designs were evaluated under the following conditions as part of the pump operation and forebay volume analysis:

- Emergency power failure at upstream pumping station
- Emergency power failure at downstream pumping station
- Normal operation with all pipes in service

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- Normal operation with one pipe out of service

3.3 Alternatives

The following alternatives were considered as part of the pump operation and forebay volume modeling analysis described in Section 3.4 and Section 3.5:

- Alternative 1 - new storage tanks
- Alternative 2 - new pump controls
- Alternative 3 - control valve throttling
- Alternative 4 - new variable speed drive pumps

Recommendations regarding these alternatives are described in Section 3.6.

3.3.1 Alternative 1 - New Storage Tanks

Alternative 1 consists of adding new storage tanks to increase the available volume of the forebays at each booster pumping station. Alternative 1A, 1B, and 1C were developed as part of this study:

- Storage Alternative 1A – Additional volume between Phase 4 and Phase 8 booster pumping stations with gravity return to sump

- Storage Alternative 1B – Additional volume between Phase 4 and Phase 8 booster pumping stations with pumped return to sump

- Storage Alternative 1C – Additional volume upstream of the booster pumping station at relative high point on the transmission main in conjunction with surge control structure

3.3.1.1 Storage Alternative 1A – Local Storage with Gravity Flow Return to Sump

Storage Alternative 1A consist of constructing new underground concrete storage tanks each with an approximate volume of 8,630 m^3 (2.3 MG) in the space between the existing Phase 4 and Phase 8 booster pumping station forebays as shown in Figure 3-1. The structures would be located under the 2.6-m diameter discharge headers as shown in Figure 3-2, which demonstrates the new tanks being used as emergency storage with overflow weir and bottom sluice gate that can be opened to drain water back to the sump after lowering the sump to the low-low water level (LLWL). (Alternatively, the sluice gate could be left open at all times under normal operation.) As shown in Figure 3-2, the existing emergency volume of 5,750 m^3 (1.5 MG) plus the Alternative 1A volume would provide a total approximate emergency volume of 14,380 m^3 (3.8 MG).

3.3.1.2 Storage Alternative 1B – Local Storage with Pumped Flow Return to Sump

Storage Alternative 1B is the same as Alternative 1A except that the volume of the new tank is 2.3 times larger (approximately 20,130 m^3 or 5.3 MG). A low head, high flow dewatering pump would be required to pump water back to the sump after an overflow as shown in Figure 3-3. (Alternately, sluice gates could be constructed and left open during normal operation and closed as needed in order to pump the additional storage content back to the sump.) As shown in Figure 3-3, the existing emergency volume of 5,750 m^3 (1.5 MG) plus the Alternative 1B volume would provide a total approximate emergency volume of 25,880 m^3 (6.8 MG).

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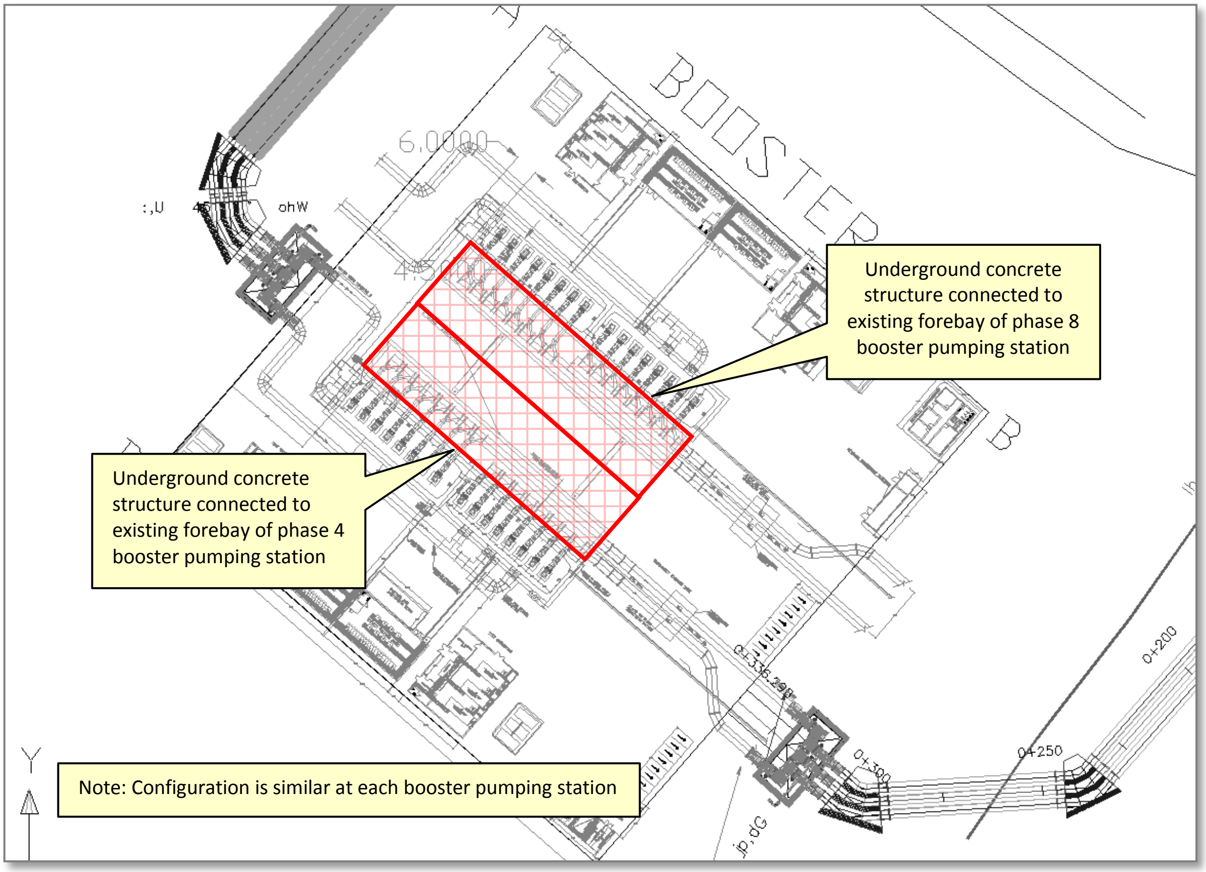
FIGURE 3-1
Storage Alternative 1A and 1B – Plan View of Additional Volume Between Phase 4 and Phase 8 Booster Pumping Stations
New Cairo Raw Water System Hydraulic Modeling Study

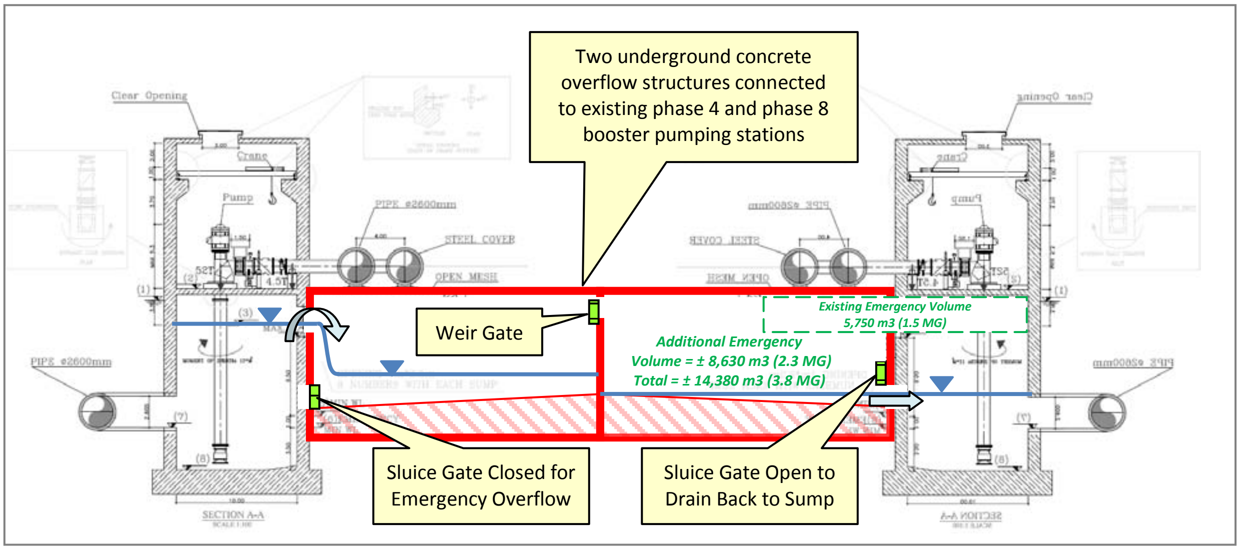


Underground concrete structure connected to existing forebay of phase 8 booster pumping station

Underground concrete structure connected to existing forebay of phase 4 booster pumping station

Note: Configuration is similar at each booster pumping station

FIGURE 3-2
Storage Alternative 1A – Section View Showing Additional Emergency Storage at Booster Pumping Stations (Gravity Return)
New Cairo Raw Water System Hydraulic Modeling Study



Two underground concrete overflow structures connected to existing phase 4 and phase 8 booster pumping stations

Weir Gate

Existing Emergency Volume 5,750 m3 (1.5 MG)

Additional Emergency Volume = ± 8,630 m3 (2.3 MG)
Total = ± 14,380 m3 (3.8 MG)

Sluice Gate Closed for Emergency Overflow

Sluice Gate Open to Drain Back to Sump

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FIGURE 3-3
Storage Alternative 1B – Section View Showing Additional Emergency Storage at Booster Pumping Stations (Pumped Return)
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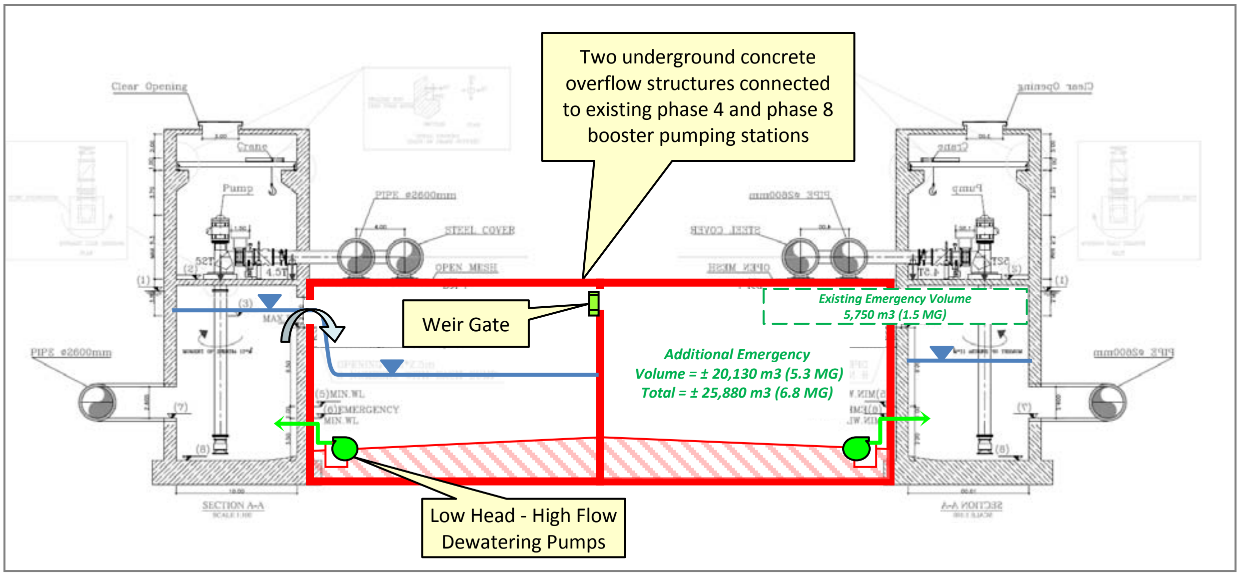

TABLE 3-2
Emergency Forebay Storage for Alternative 1A and 1B
New Cairo Raw Water System Hydraulic Modeling Study

Volumes	Formula	Cubic Meters	Million Gallons
Existing Emergency Forebay Volume	A	5,750	1,5
Additional Volume (Alternative 1A)	B	8,630	2.3
Total Volume (Alternative 1A)	C = A + B	14,380	3.8
Additional Volume (Alternative 1B)	D	20,130	5.3
Total Volume (Alternative 1B)	E = A + D	25,880	6.8

Notes:
Additional volumes that can be achieved between Ph 4 and Ph 8 booster pumping stations is estimated based on contractor drawings

3.3.1.3 Storage Alternative 1C – Standpipe/Weir Concentric Tanks

Storage Alternative 1C considers a novel approach to providing additional storage and additional surge control in one structure as shown in Figure 3-4. As identified in this report in Section 4, a standpipe (surge tank) is recommended along the flat portion of the pipeline just upstream of each booster pumping station to mitigate surge conditions (negative pressures). Under Storage Alternative 1C, this internal surge tank could be designed as an overflow structure with weir and spillway which flows into an outer, larger tank that effectively increases the available forebay volume of the downstream booster pumping station. Due to the fact that this tank is relatively close to each booster pumping station the head loss between the two is relatively low, and for this reason the level in the outer storage tank would cycle with the forebay water level. The approximate location for the "standpipe/weir concentric tanks" is shown in Figures 3-5, 3-6, and 3-7.

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In addition, Figure 3-8 shows the high point location upstream of the New Cairo Potable Water Treatment Plant (NCPWTP) which requires a vent pipe, storage tank, or large storage reservoir to prevent negative pressures during steady state operation. CH2M HILL recommends constructing a large reservoir upstream of the NCPWTP for the following reasons:

- Increased surge protection
- To provide steady flow to NCPWTP for treatment process
- To gravity flow to NCWTP during periods of high pumping costs (off-peak pumping strategy)

FIGURE 3-4
Storage Alternative 1C – Additional Volume Using Concentric Tanks Upstream of Booster Pumping Stations
New Cairo Raw Water System Hydraulic Modeling Study

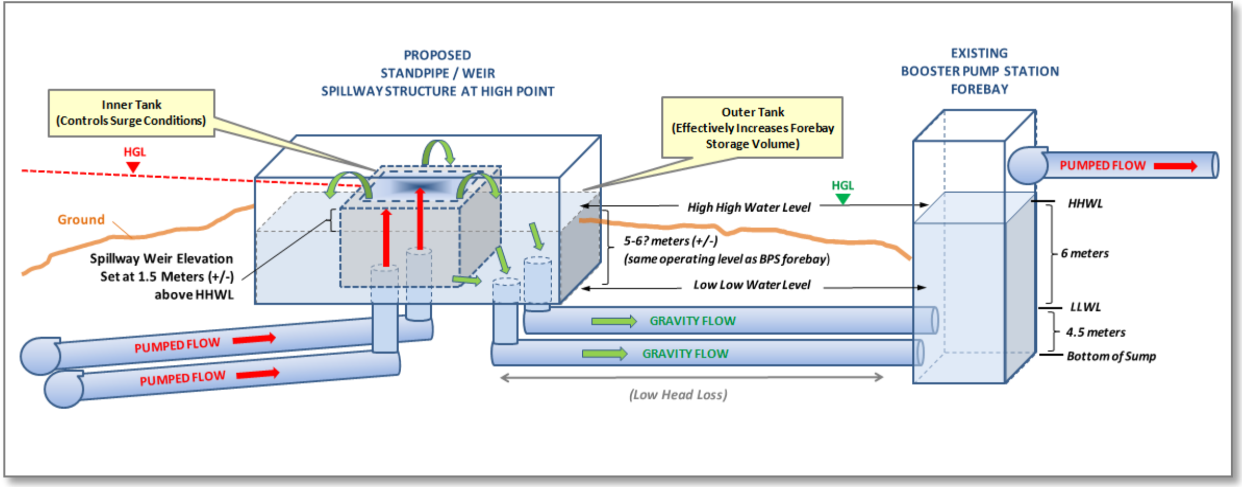

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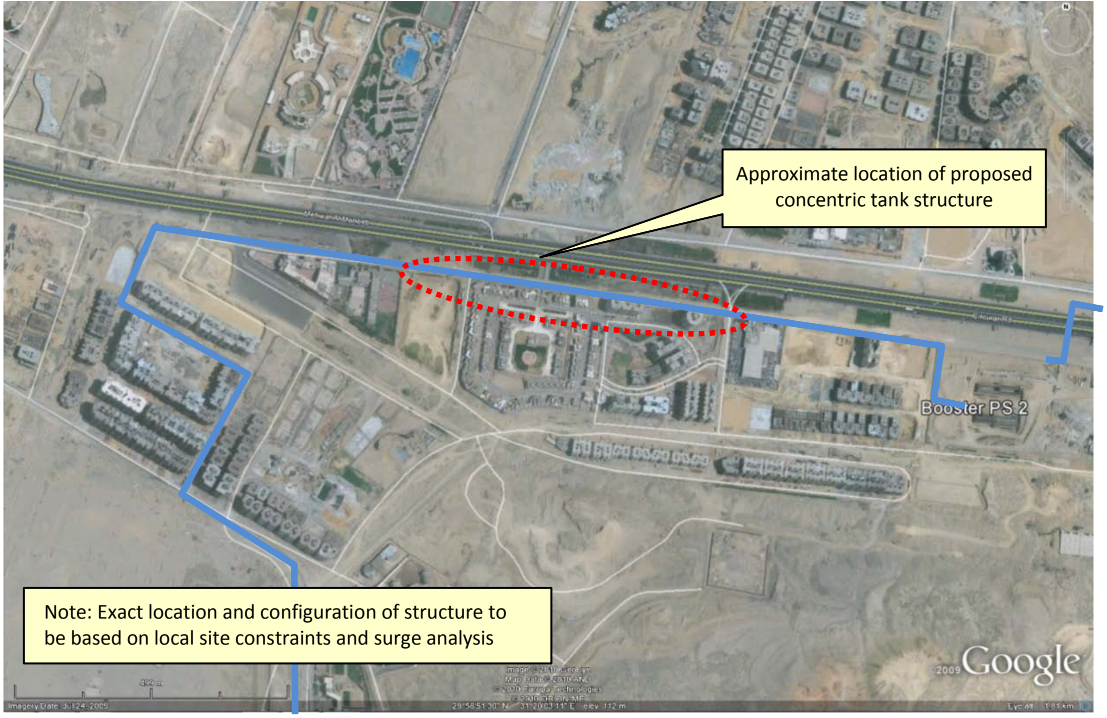
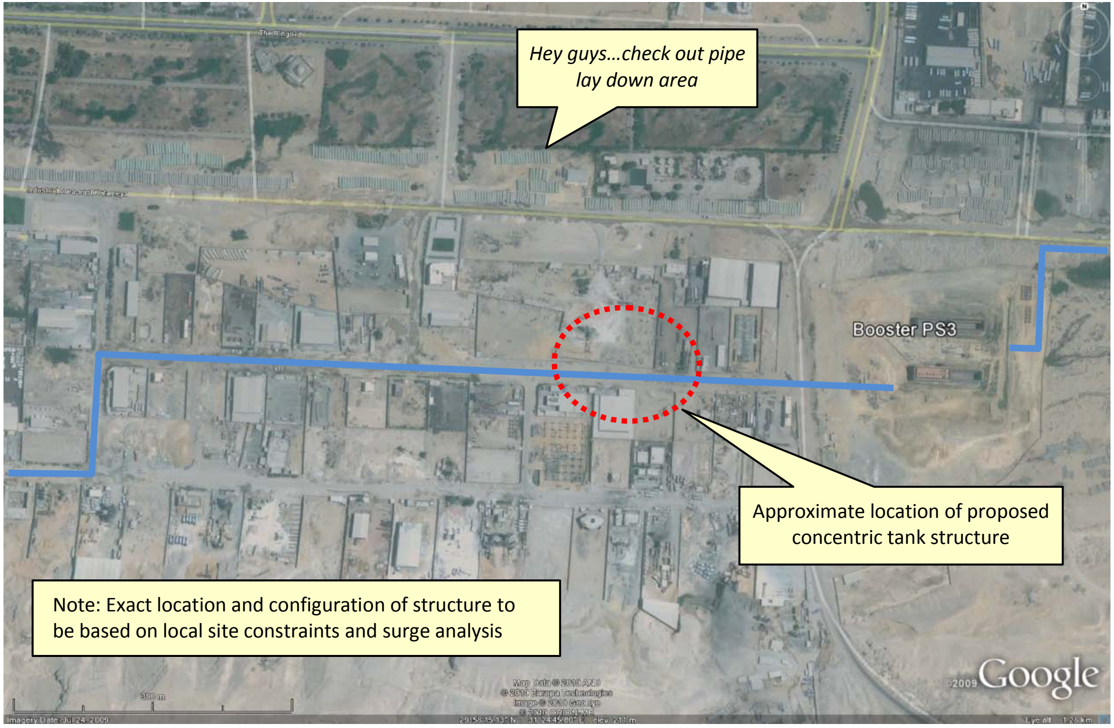
FIGURE 3-5
Storage Alternative 1C - Approximate Location of Concentric Tanks Upstream of BPS 2
New Cairo Raw Water System Hydraulic Modeling Study



Approximate location of proposed concentric tank structure

Note: Exact location and configuration of structure to be based on local site constraints and surge analysis

FIGURE 3-6
Storage Alternative 1C - Approximate Location of Concentric Tanks Upstream of BPS 3
New Cairo Raw Water System Hydraulic Modeling Study



Hey guys…check out pipe lay down area

Approximate location of proposed concentric tank structure

Note: Exact location and configuration of structure to be based on local site constraints and surge analysis

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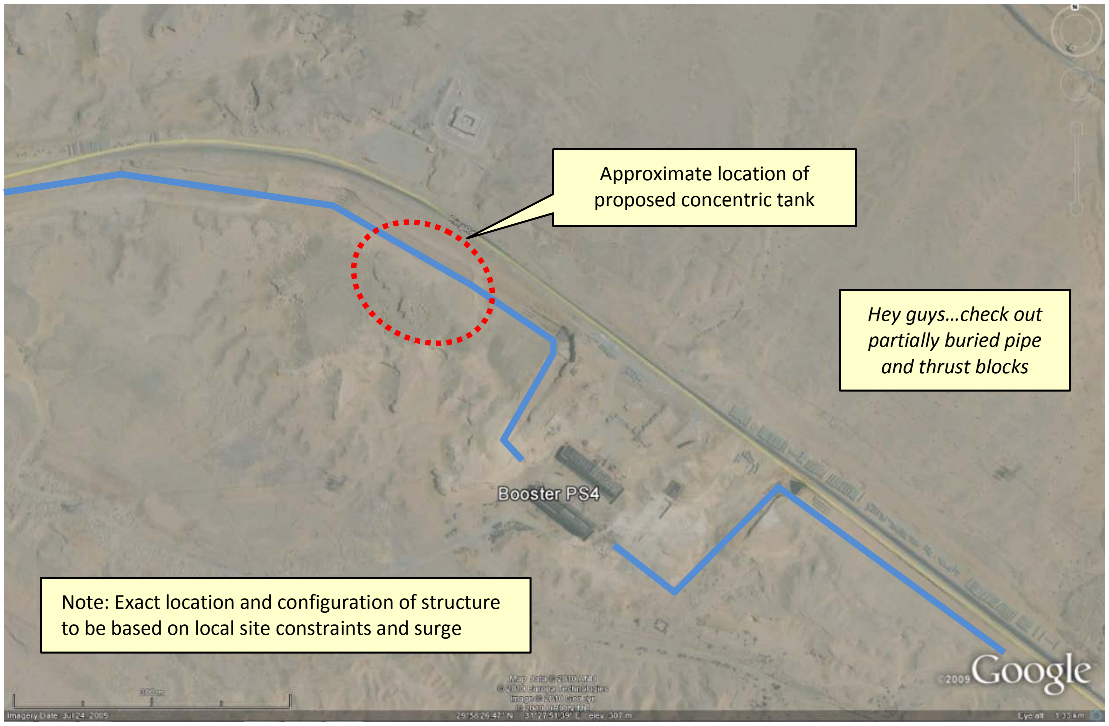
FIGURE 3-7
Storage Alternative 1C - Approximate Location of Concentric Tanks Upstream of BPS 4
New Cairo Raw Water System Hydraulic Modeling Study

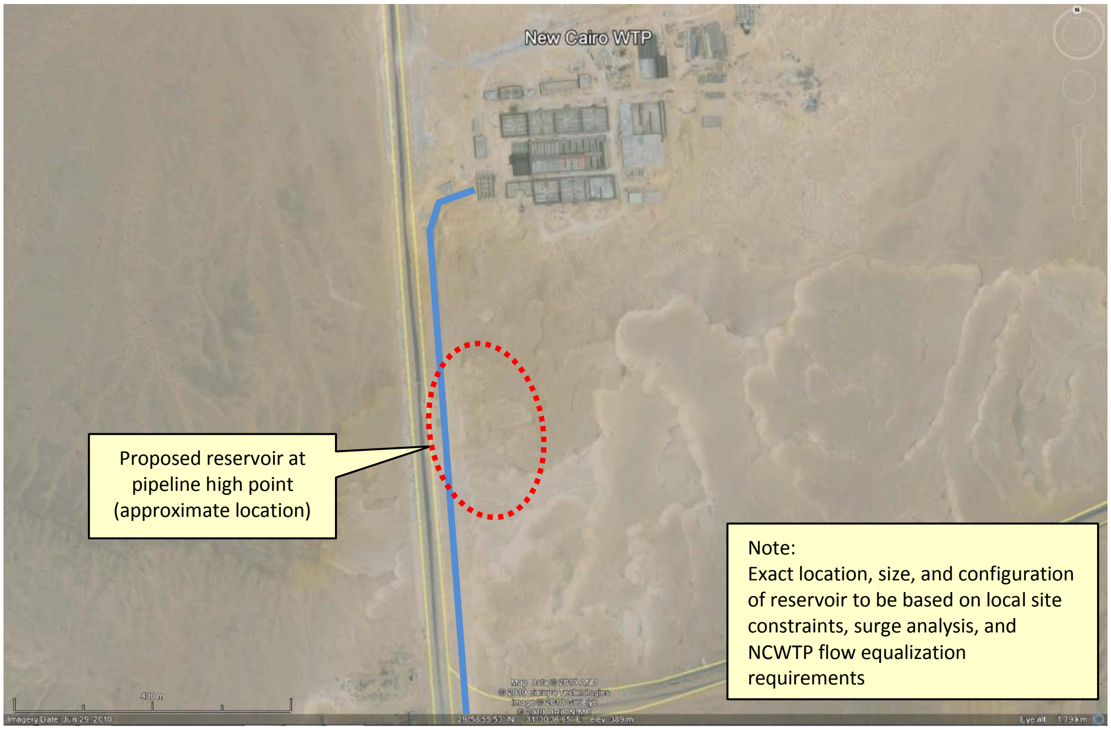


Approximate location of proposed concentric tank

Hey guys…check out partially buried pipe and thrust blocks

Note: Exact location and configuration of structure to be based on local site constraints and surge

FIGURE 3-8
High Point at New Cairo Potable Water Treatment Plant - Approximate Location of Proposed Reservoir
New Cairo Raw Water System Hydraulic Modeling Study



Proposed reservoir at pipeline high point (approximate location)

Note:
Exact location, size, and configuration of reservoir to be based on local site constraints, surge analysis, and NCWTP flow equalization requirements

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3.3.2 Alternative 2 - New Pump Controls

Pump controls set-points for Phase 1 and Phase 4 are described in Section 2.4 and shown in Table 2-3. The pumps will be normally controlled by local forebay water levels. At each phase, the level set-points will require adjustment to accommodate the new pumps. Phase 1 and 4 set-points are verified using the hydraulic model as described in Section 3.5.

In Section 3.4, the new EMWL set-point that shuts down the pumps at the upstream pumping station is analyzed using the EPS model.

3.3.3 Alternative 3 – Throttle Existing Control Valves

Based on correspondence with the Torishima pump representative, the booster pumping stations are designed with swinging disc check valves and no not have automatic control valves. Document #6, described in Section 1.3, indicates that IPS 1 has automated electric control valves at each pump that throttles during pump start-up and shut-down. Potentially, this control valve could be used to throttle flow at IPS 1 if an unbalance resulted between IPS 1 and BPS 2 as described in Section 3.5.1.

3.3.4 Alternative 4 - New Variable Speed Drive Pumps

Variable speed drives (VSDs) adjust the pump motor voltage which reduces or increases the pump rotational speed and resulting flow. VSDs can provide flexibility in pump operation utilizing either flow or pressure set-points or a simple constant speed reduction. Based on the modeling analysis described below in Section 3.5, the constant speed pump design is satisfactory based on the described assumptions. However, as described in Section 3.6, the owner and operator may chose to incorporate a small number of VSD pumps in a future design phase for operational flexibility.

3.4 Power Failure Event Extended Period Simulations

The following EPS were conducted to evaluate the effects of power loss on forebay water levels. Each scenario was evaluated against the design criteria described in Section 3.1:

- Scenario 1: Power Failure at Upstream Pumping Station (Existing Phase 4 Design)
- Scenario 2: Power Failure at Downstream BPS (Existing Phase 1 Design)
- Scenario 3: Power Failure at Downstream BPS (Existing Phase 4 Design)
- Scenario 4: Power Failure at Downstream BPS (Phase 1-4, Additional Storage)
- Scenario 5: Power Failure at Downstream BPS (Phase 4 Design, New Controls)

It should be noted that these model runs to not account for surge conditions. Refer to Section 4 for surge analysis results.

3.4.1 Scenario 1: Power Failure at Upstream Pumping Station (Existing Phase 4 Design)

Scenario 1 evaluates the effects of a power loss at an upstream pumping station on the downstream booster pumping station forebay water level at Phase 4 flow conditions. Figure 3-9 shows the forebay water level response at BPS 2 when IPS 1 power is lost. The 12 pumps at BPS 2 shut down in a controlled manner over 8 minutes, indicating that the pump

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controls shown in Table 2-3 are adequate and the forebay volume is adequate under this scenario.

3.4.2 Scenario 2: Power Failure at Downstream BPS (Existing Phase 1 Design)

Scenario 2 evaluates the effects of a power loss at a booster pumping station while an upstream station continues to operate at Phase 1 flows. Figure 3-10 shows the forebay water level response at BPS 2 after a power loss while the three pumps at IPS 1 continue to operate. The BPS 2 forebay overflows in approximately 15 minutes.

3.4.3 Scenario 3: Power Failure at Downstream BPS (Existing Phase 4 Design)

Scenario 3 evaluates the same condition as Scenario 2 but at Phase 4 flows. Figure 3-11 shows the forebay water level response at BPS 2 after losing power while 12 pumps at IPS 1 continue to operate. In this scenario, the BPS 2 forebay overflows in approximately 4 minutes.

3.4.4 Scenario 4: Power Failure at Downstream BPS (Phase 1-4 Flows; Additional Storage)

Scenario 4 evaluates the same condition as Scenario 3 but with additional storage at or near the booster pumping station (Storage Alternatives 1A, 1B, or 1C). Figure 3-12 shows the estimated time for the forebay to overflow for each design phase using different emergency storage volumes. If the emergency forebay volume is increased from 5,750 m^3 (1.5 MG) to 25,880 m^3 (6.8 MG), the time prior to an overflow increases from 15 minutes to 72 minutes at Phase 1 flows, but only 4 minutes to 18 minutes at Phase 4 flows.

3.4.5 Scenario 5: Power Failure at Downstream BPS (Phase 4 Design; New Controls)

To reduce the risk of overflow and minimize the required volume of emergency storage, Scenario 5 evaluates the same conditions as Scenario 3 except with new controls that shut down the upstream pumps after the downstream pump station loses power. This control set-point is called the EMWL as described in Section 2.4 and shown in Table 2-3. As shown in Figure 3-13, upon reaching the EMWL set-point at BPS 2, the IPS 1 pumps are shut down at 30 second intervals, which limit the water level rise to approximately 123.8 m, just below the overflow elevation of 124.6 m.

This control strategy requires constant communication throughout the supervisory control and data acquisition (SCADA) system which must send a signal to the upstream pump station to shut down the pumps. If the SCADA signal fails and a human operator does not intervene within a few minutes, the forebay would overflow onto the ground at a rate of approximately 25 m^3/sec.

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FIGURE 3-9
Scenario 1: BPS 2 Forebay Water Level After Power Failure at IPS 1 (Existing Phase 4 Design)
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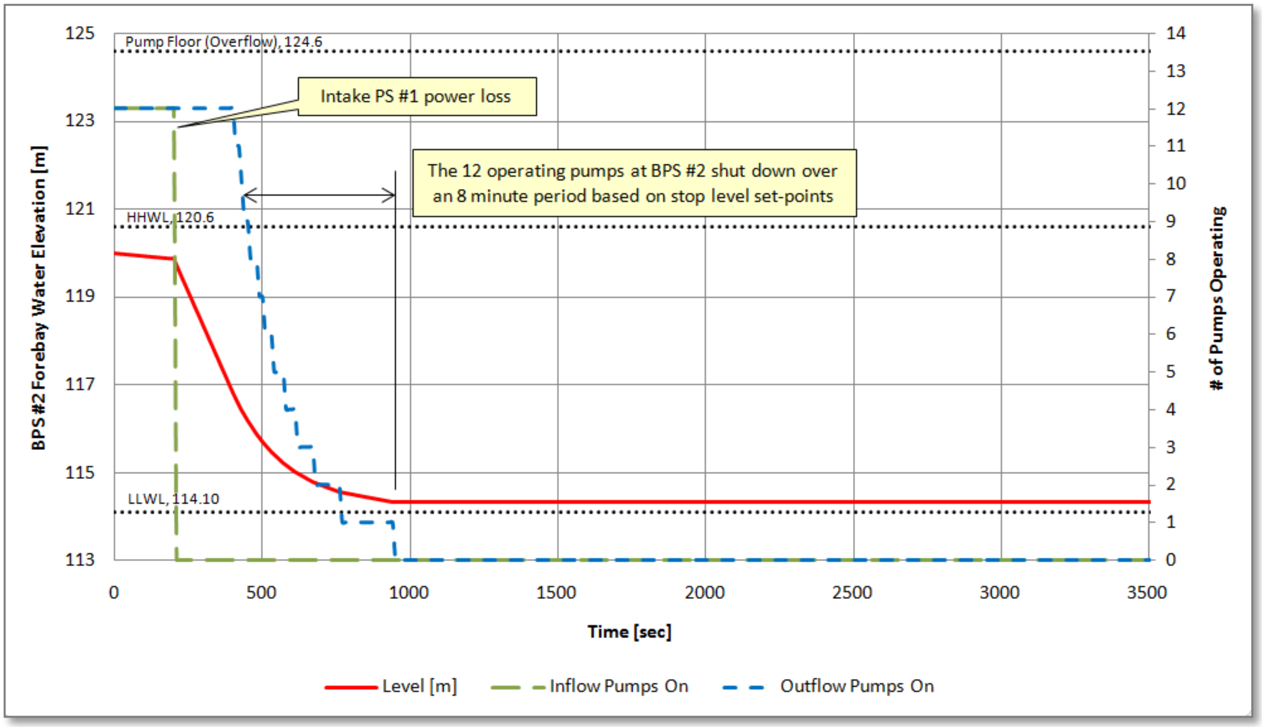

FIGURE 3-10
Scenario 2: BPS 2 Forebay Water Level After Power Failure at BPS 2 (Existing Phase 1 Design)
New Cairo Raw Water System Hydraulic Modeling Study

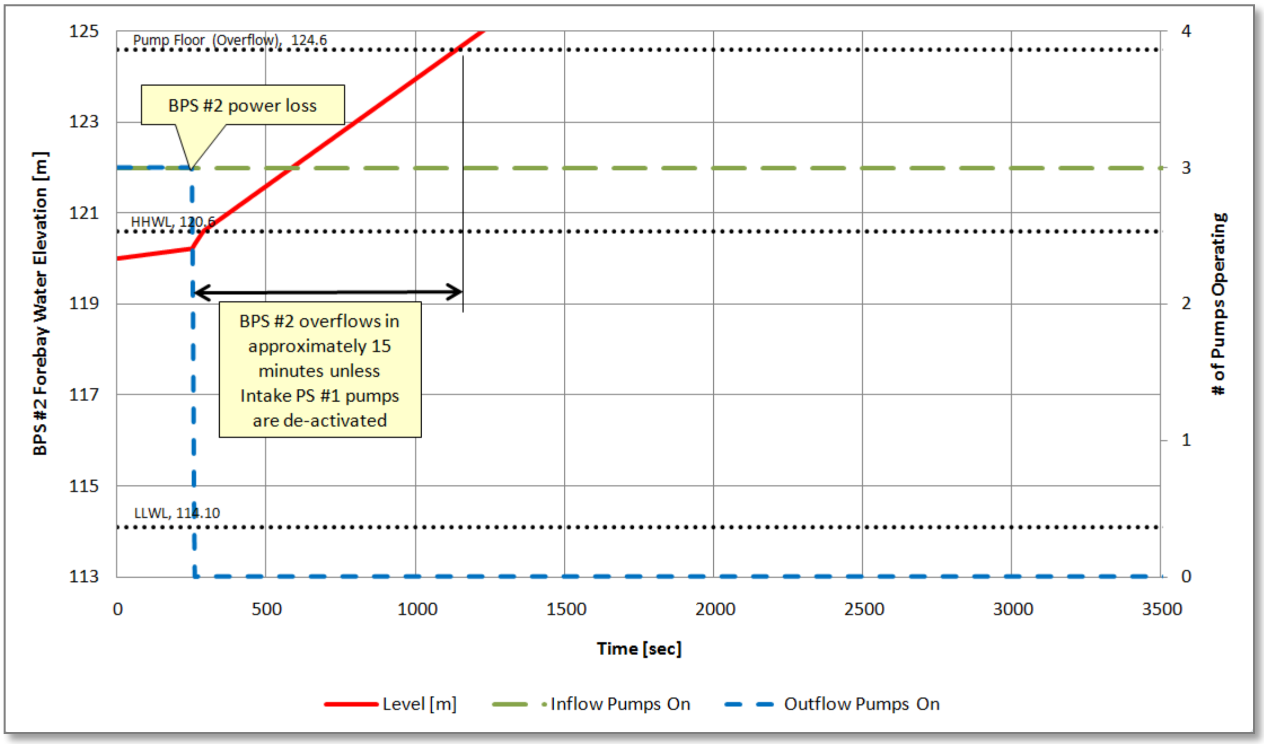

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FIGURE 3-11

Scenario 3: BPS 2 Forebay Water Level After Power Failure at BPS 2 (Existing Phase 4 Design)

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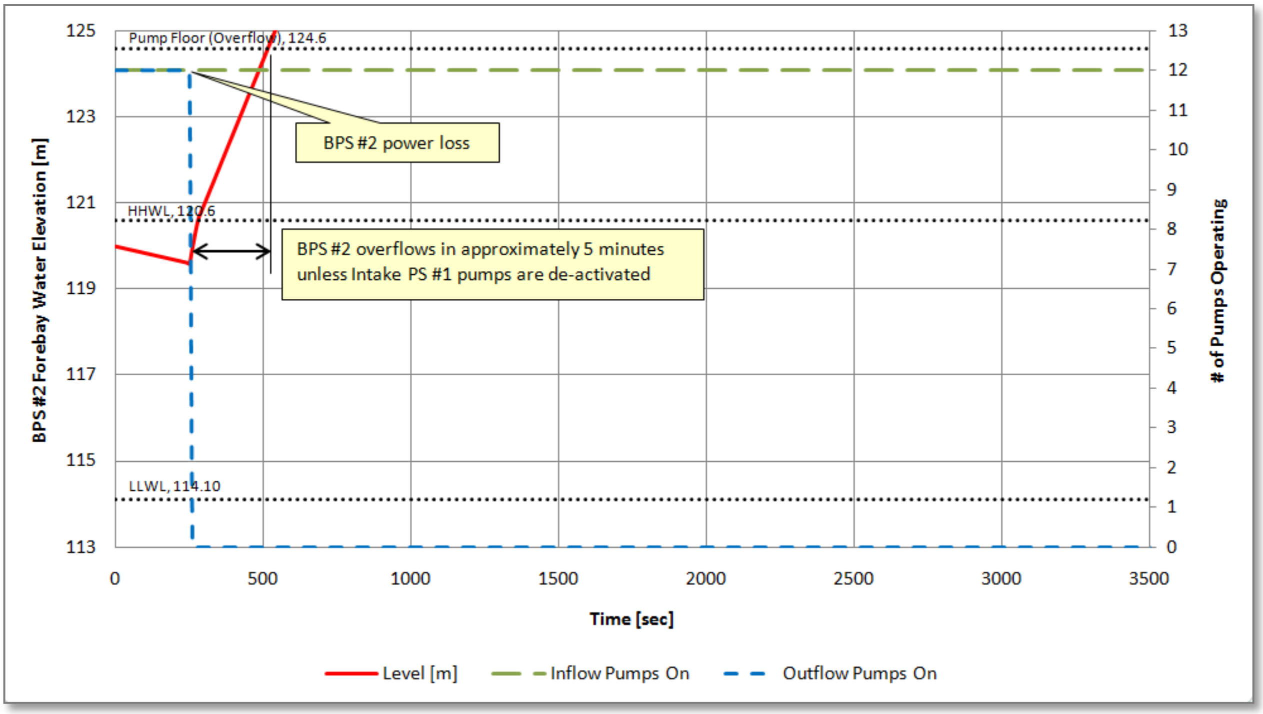

FIGURE 3-12

Forebay Overflow Time vs. Design Flow For Existing and Alternative Storage Volumes

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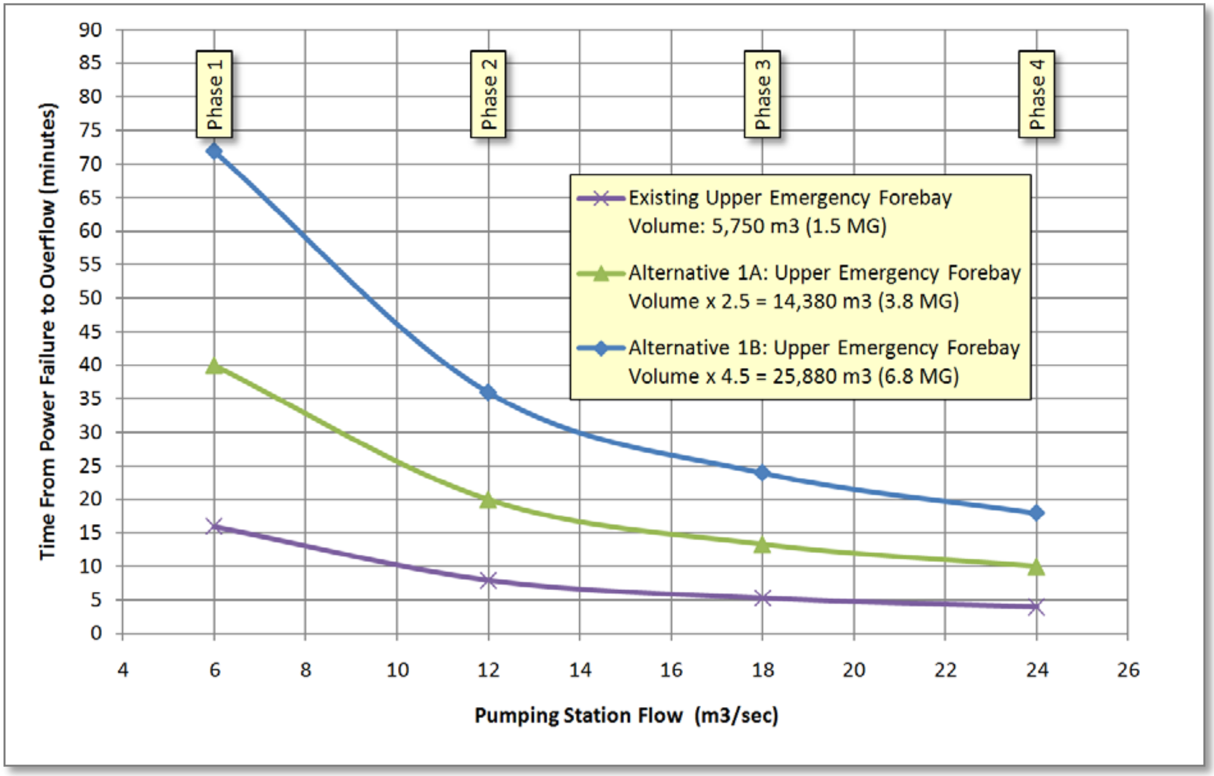

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FIGURE 3-13
Scenario 5: BPS 2 Forebay Water Level After Power Failure at Phase 4 Flows (New EMWL Control Set-Point)
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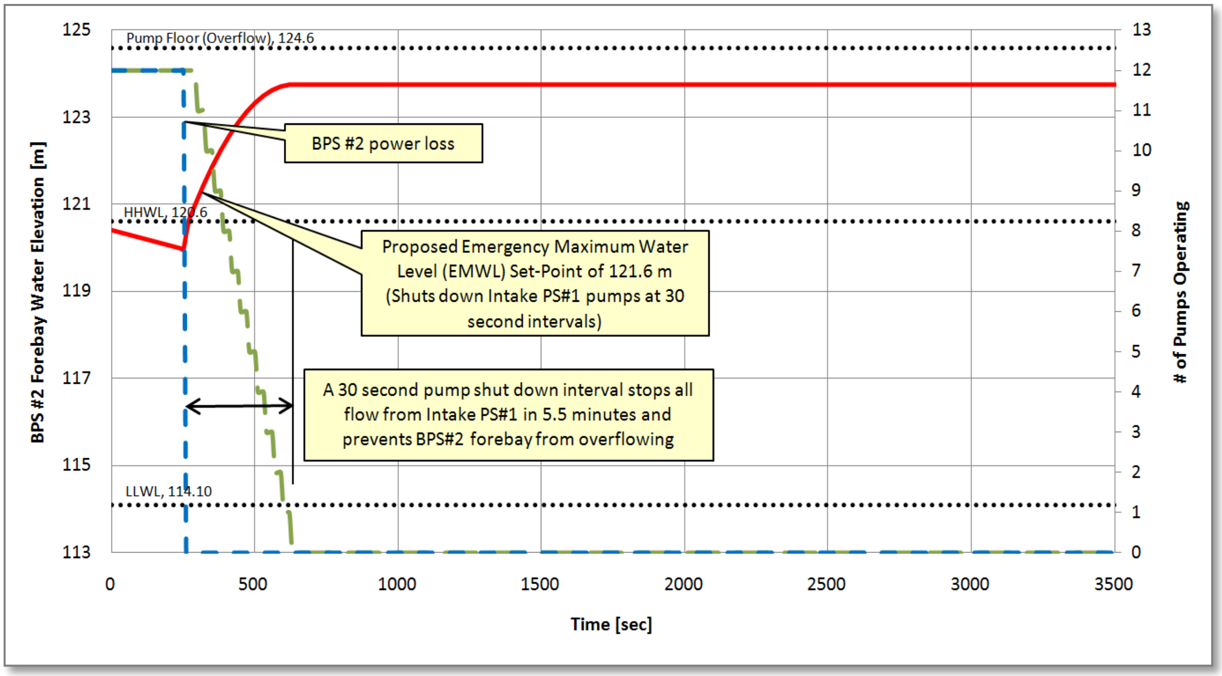

3.5 Normal Operation Extended Period Simulations

The following EPS were conducted to evaluate the effects of normal operation on forebay water levels when all pipes are on-line and one pipe is off-line. Each scenario was evaluated against the design criteria described in Section 3.1:

- Scenario 6: Normal Operation (Existing Phase 1 Design With All Pipes Open)
- Scenario 7: Normal Operation (Existing Phase 1 Design With One Pipe Closed)
- Scenario 8: Normal Operation (Proposed Phase 1 Design With New Standpipes)
- Scenario 9: Normal Operation (Existing Phase 4 Design With All Pipes Open)
- Scenario 10: Normal Operation (Existing Phase 4 Design With Some Pipes Closed)
- Scenario 11: Normal Operation (Proposed Phase 4 Design With New Standpipes)
- Scenario 12: Normal Operation (Proposed Phase 4 Design, With New Standpipe, One Pipe Closed

3.5.1 Scenario 6: Normal Operation (Existing Phase 1 Design; All Pipes Open)

Scenario 6 evaluates three pumps operating at each pumping station with all pipes open under Phase 1 design conditions without the EMWL control set-point described in Section 2.4 (Table 2-3). The results of Scenario 6 are shown in Figure 3-14. The model indicates that the wet well levels will stabilize between 9 and 12 m without any pump cycling. However, it should be noted that very small changes to model assumptions such as

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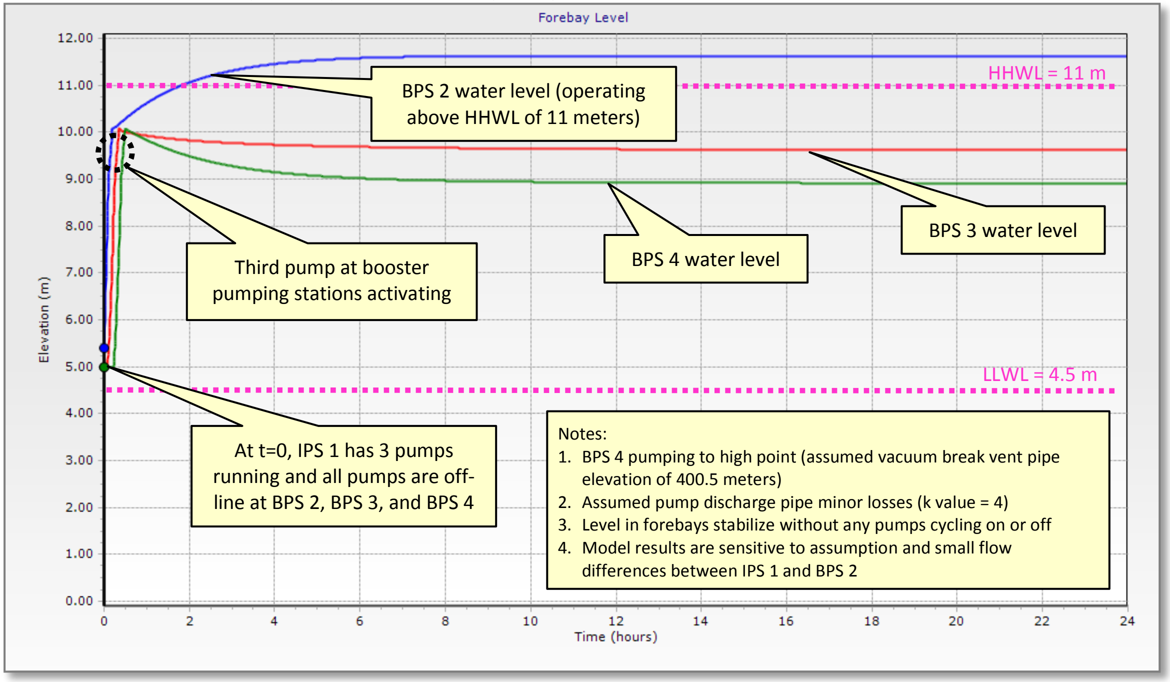
elevations and minor losses can significantly affect simulation results. It is apparent that IPS 1 is pumping more flow than BPS 2 resulting in the forebay water level at BPS 2 to exceed the HHWL of 11 m. If the electric control valves at IPS 1 can be used to throttle flow, the water level at BPS 2 could be kept below the HHWL. Refer to Section 3.5.3 (Scenario 8) for additional model runs with the IPS 1 control valves throttled.

FIGURE 3-14
Scenario 6: Booster Pumping Station Forebay Levels (Existing Phase 1 Conditions, All Pipes Open)
New Cairo Raw Water System Hydraulic Modeling Study



Notes:
1. BPS 4 pumping to high point (assumed vacuum break vent pipe elevation of 400.5 meters)
2. Assumed pump discharge pipe minor losses (k value = 4)
3. Level in forebays stabilize without any pumps cycling on or off
4. Model results are sensitive to assumption and small flow differences between IPS 1 and BPS 2

3.5.2 Scenario 7: Normal Operation (Existing Phase 1 Design; One Pipes Closed)

Scenario 7 is the same as Scenario 6 except that a single pipe was closed in the model to attempt to create an unbalanced flow between two pumping stations. Four model runs were performed, each one with a pipe closed between two different pumping stations. Due to the fact that the pipeline head losses are low at Phase 1 flows, the Scenario 7 simulations provided very similar results as Scenario 6.

3.5.3 Scenario 8: Normal Operation (Phase 1 Design Plus Standpipe/Weir Concentric Tanks)

Based on the Phase 1 surge analysis described in Section 4 of this report, the standpipe/weir surge control structure is recommended at Phase 1 (elevations shown in Table 3-3). Scenario 8 evaluates the operational effects of this recommendation by performing three model runs (Scenario 8A, 8B, and 8C):

- Scenario 8A – Normal Operation With Standpipe and Without EMWL Control Set-point
- Scenario 8B - Normal Operation With Standpipe and EMWL Control Set-point
- Scenario 8C - Normal Operation With Standpipe and Control Valves Throttling at IPS 1

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3.5.3.1 Scenario 8A - Normal Operation with Standpipe and Without EMWL Control Set-point

The additional volume of the standpipe/weir structure does not significantly improve forebay levels during normal operation. Rather, the weir establishes a slightly different hydraulic grade line (HGL) and affects the flow at each pumping station which negatively impacts forebay level operations as opposed to Scenario 6. The results of Scenario 8A are shown in Figure 3-15. Forebay water levels at each booster pumping station operate above the HHWL of 11 m. BPS 2 and 3 are operating near the overflow of 15 m.

3.5.3.2 Scenario 8B - Normal Operation with Standpipe and EMWL Control Set-point

To prevent the forebay water levels from operating above the HHWL, the EMWL control set-point was evaluated, and the results are shown in Figure 3-16. While the EMWL control set-point prevents high water levels in the booster pumping station forebays, it results in only two pumps operating at IPS 1 and the levels shown in Figure 3-16. The resulting flow delivered to the proposed reservoir upstream of the NCWTP would be less than the design flow as shown in Figure 3-17. However, a human operator could manually activate a third pump at IPS 1 as needed which would result in a more stable flow delivered to the NCWTP (not shown in Figure 3-16). Due to the potential complexity of this operation, Scenario 8C was evaluated to determine if the system could be better balanced so that the pumps would not cycle over a 24 hour period.

3.5.3.3 Scenario 8C - Normal Operation with Standpipe and Control Valves Throttling at IPS 1

To prevent the EMWL control set-point from being triggered every couple hours as described above, Figure 3-18 shows the effects of throttling the IPS 1 electric control valves. Assuming a minor loss (k-value of 16) to represent the combined head loss of the discharge check valve and throttling control valves at each pump discharge header, a total minor loss of 6 m brings the system into balance such that no pumps cycle during the simulation and the forebay water levels stay below the HHWL. The results of this analysis show that the proposed standpipe structures could be built for Phase 1 without negatively affecting Phase 1 operation as long as the IPS 1 control valves can be throttled as described above.

It should be noted that throttling would be a temporary measure until more pumps are brought on-line.

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FIGURE 3-15

Scenario 8A: BPS Forebay Levels at Phase 1 Flows (With Standpipe/Weir Surge Control Structure, With All Pipes Open, and Without EMWL Control Set-Point)

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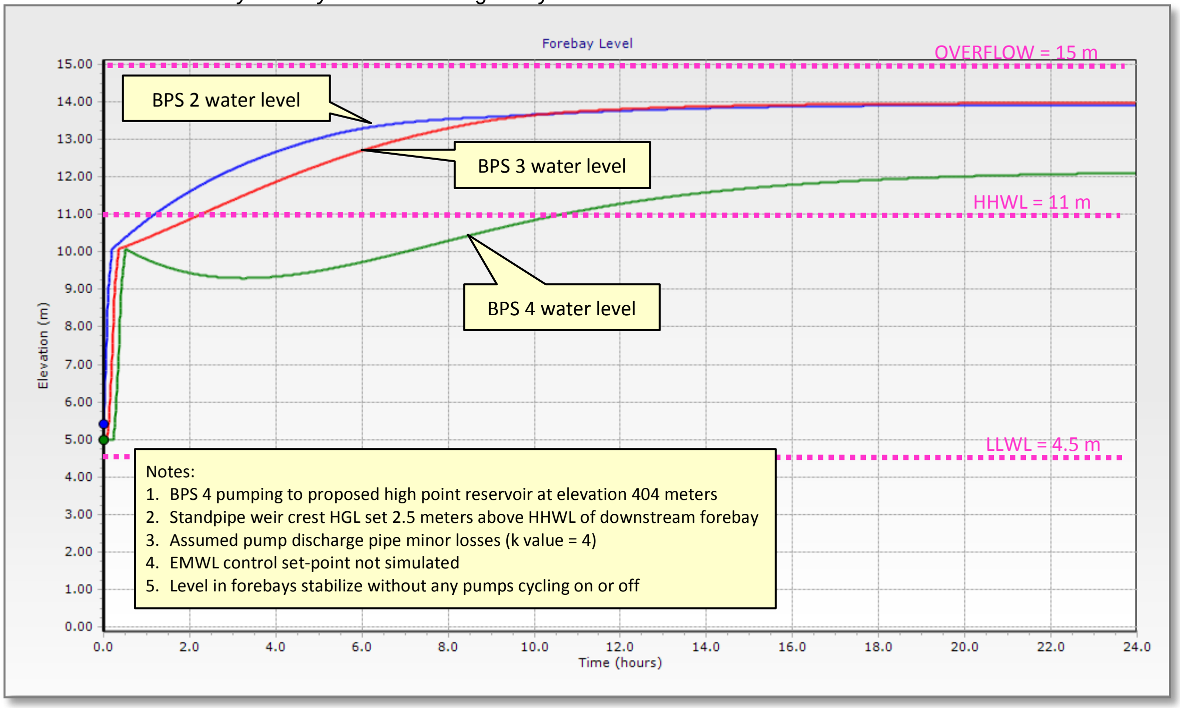
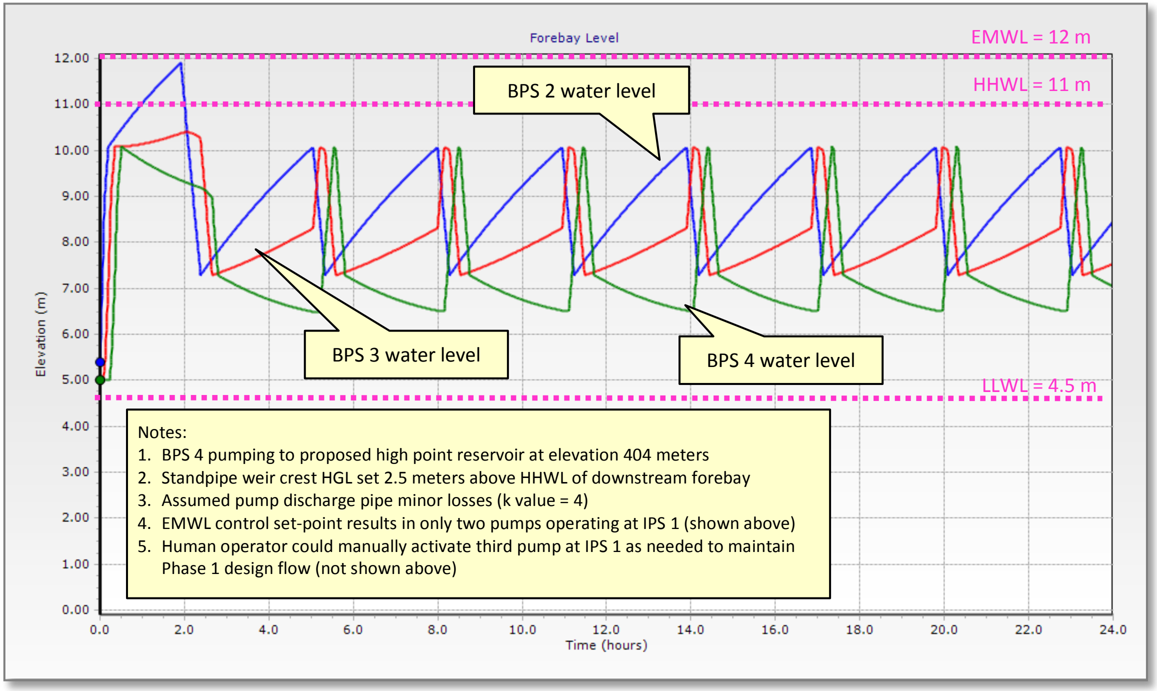


Notes:
1. BPS 4 pumping to proposed high point reservoir at elevation 404 meters
2. Standpipe weir crest HGL set 2.5 meters above HHWL of downstream forebay
3. Assumed pump discharge pipe minor losses (k value = 4)
4. EMWL control set-point not simulated
5. Level in forebays stabilize without any pumps cycling on or off

FIGURE 3-16

Scenario 8B: BPS Forebay Levels at Phase 1 Flows (With Standpipe/Weir Surge Control Structures, With All Pipes Open, and With EMWL Control Set-Point)

New Cairo Raw Water System Hydraulic Modeling Study



Notes:
1. BPS 4 pumping to proposed high point reservoir at elevation 404 meters
2. Standpipe weir crest HGL set 2.5 meters above HHWL of downstream forebay
3. Assumed pump discharge pipe minor losses (k value = 4)
4. EMWL control set-point results in only two pumps operating at IPS 1 (shown above)
5. Human operator could manually activate third pump at IPS 1 as needed to maintain Phase 1 design flow (not shown above)

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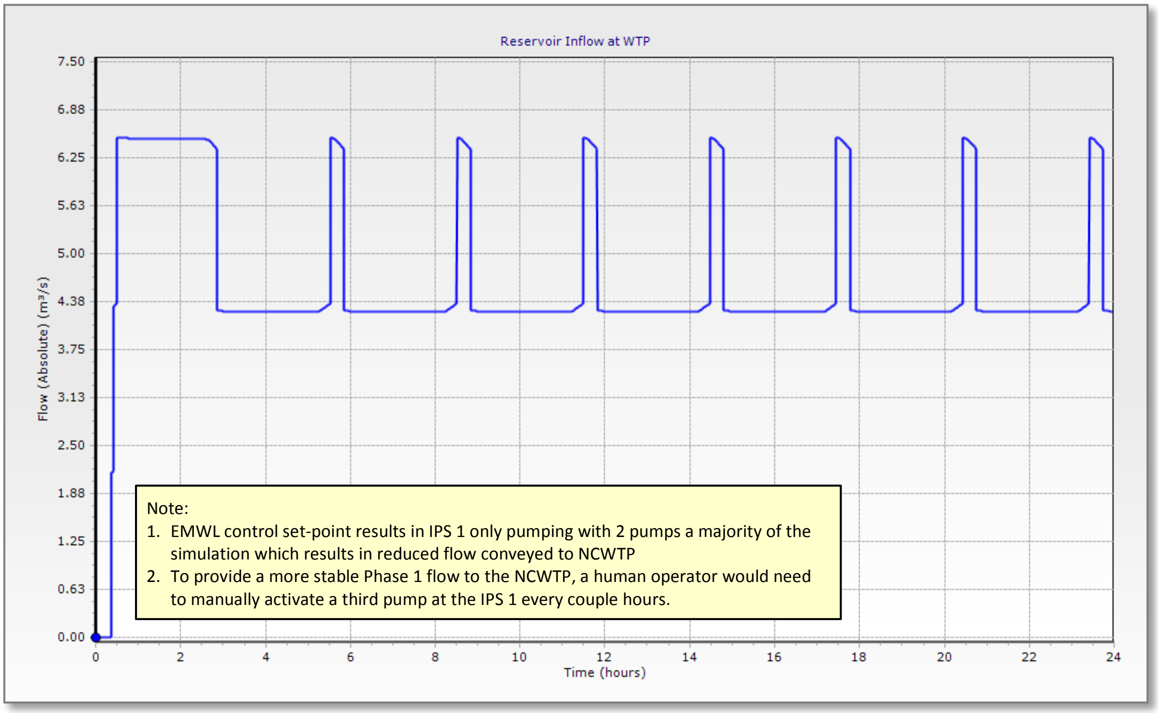
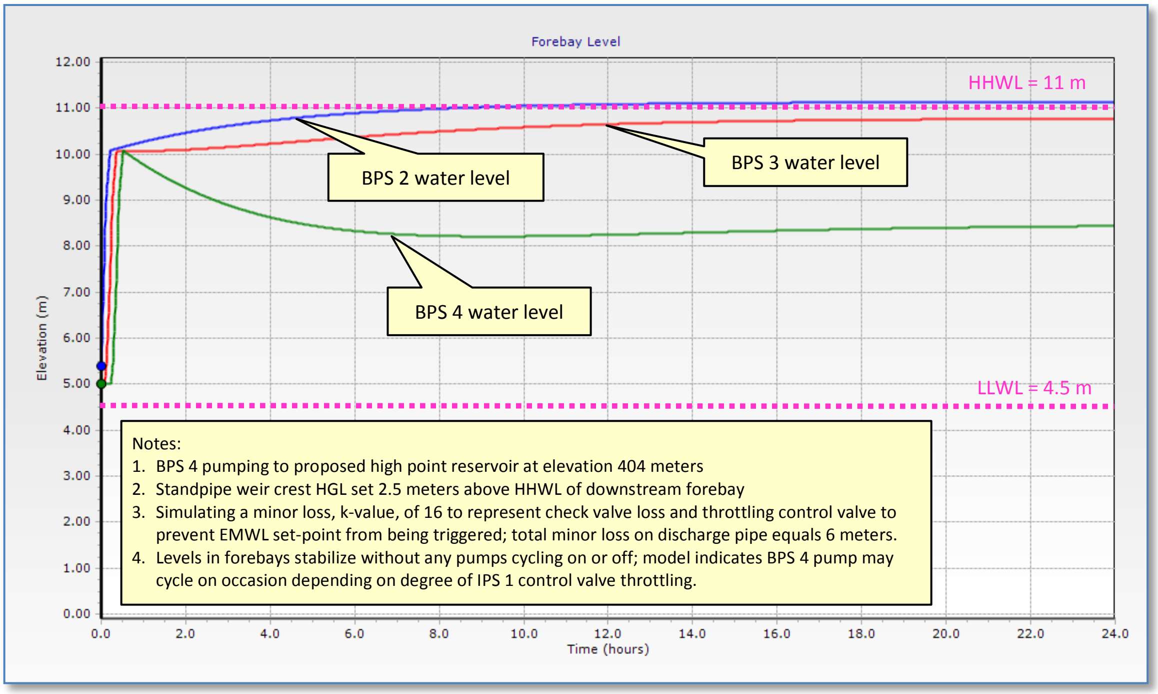
FIGURE 3-17
Scenario 8B: Flow to Proposed Reservoir at NCWTP (With Standpipe/Weir Surge Control Structures, With All Pipes Open, and With EMWL Control Set-Point)
New Cairo Raw Water System Hydraulic Modeling Study



Note:
1. EMWL control set-point results in IPS 1 only pumping with 2 pumps a majority of the simulation which results in reduced flow conveyed to NCWTP
2. To provide a more stable Phase 1 flow to the NCWTP, a human operator would need to manually activate a third pump at the IPS 1 every couple hours.

FIGURE 3-18
Scenario 8C: BPS Forebay Levels at Phase 1 Flows (With Standpipe/Weir Surge Control Structures, With All Pipes Open, and Throttling Control Valve at IPS 1 so that EMWL Control Set-Point is Not Triggered)
New Cairo Raw Water System Hydraulic Modeling Study



Notes:
1. BPS 4 pumping to proposed high point reservoir at elevation 404 meters
2. Standpipe weir crest HGL set 2.5 meters above HHWL of downstream forebay
3. Simulating a minor loss, k-value, of 16 to represent check valve loss and throttling control valve to prevent EMWL set-point from being triggered; total minor loss on discharge pipe equals 6 meters.
4. Levels in forebays stabilize without any pumps cycling on or off; model indicates BPS 4 pump may cycle on occasion depending on degree of IPS 1 control valve throttling.

TABLE 3-3
Standpipe Weir and Crest Elevations and Downstream Forebay HHWL Elevations (Scenario 8 and 11)
New Cairo Raw Water System Hydraulic Modeling Study

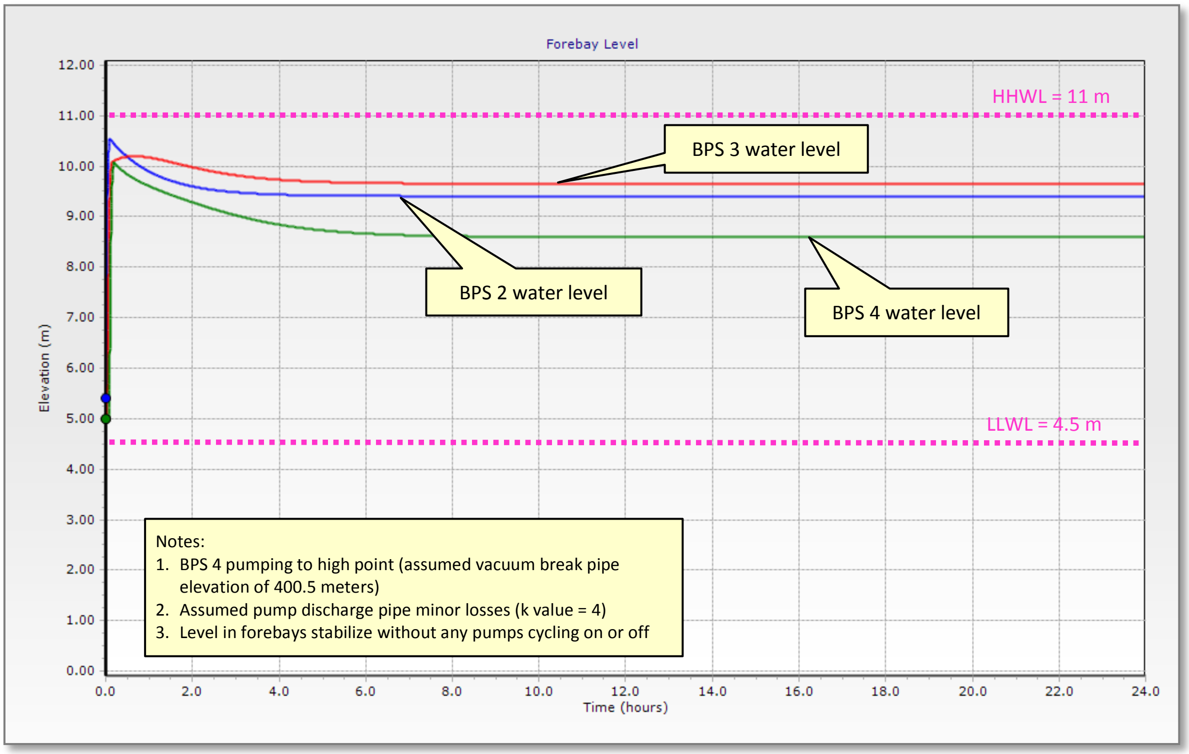
Standpipe #	**Weir / Crest Elevations (m)**	**Downstream Forebay / WTP**	**Forebay HHWL (m)**
SP#1-2	122.1 / 123.1	BPS 2	120.6
SP#2-3	219.5 / 220.5	BPS 3	218.0
SP#3-4	310.5 / 311.5	BPS 4	309.0
WTP Reservoir	404	WTP	N/A

Notes:
1. Weir elevation set at 1.5 m above downstream forebay HHWL.
2. Weir crest elevation will vary based on flows
3. WTP reservoir maximum elevation set 5 m above centerline of pipe at high point (399 m)

3.5.4 Scenario 9: Normal Operation (Existing Phase 4 Design; All Pipes Open)

Scenario 9 evaluates 12 pumps operating at each pumping station with all pipes open under existing Phase 4 design conditions using the control set-points described in Section 2.4 (Table 2-3). The results of Scenario 9 are shown in Figure 3-19. The model indicates the forebay water levels will stabilize in a tight range between 8 and 9 m without any pump cycling.

FIGURE 3-19
Scenario 9: Booster Pumping Station Forebay Levels (Existing Phase 4 Design, All Pipes Open)
New Cairo Raw Water System Hydraulic Modeling Study



Notes:
1. BPS 4 pumping to high point (assumed vacuum break pipe elevation of 400.5 meters)
2. Assumed pump discharge pipe minor losses (k value = 4)
3. Level in forebays stabilize without any pumps cycling on or off

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3.5.5 Scenario 10: Normal Operation (Existing Phase 4 Design; One Pipe Closed)

Scenario 10 evaluates the same conditions as Scenario 9 but with one pipe closed in the system. Three model runs were conducted with a 2.2-m pipe closed between different booster pumping stations:

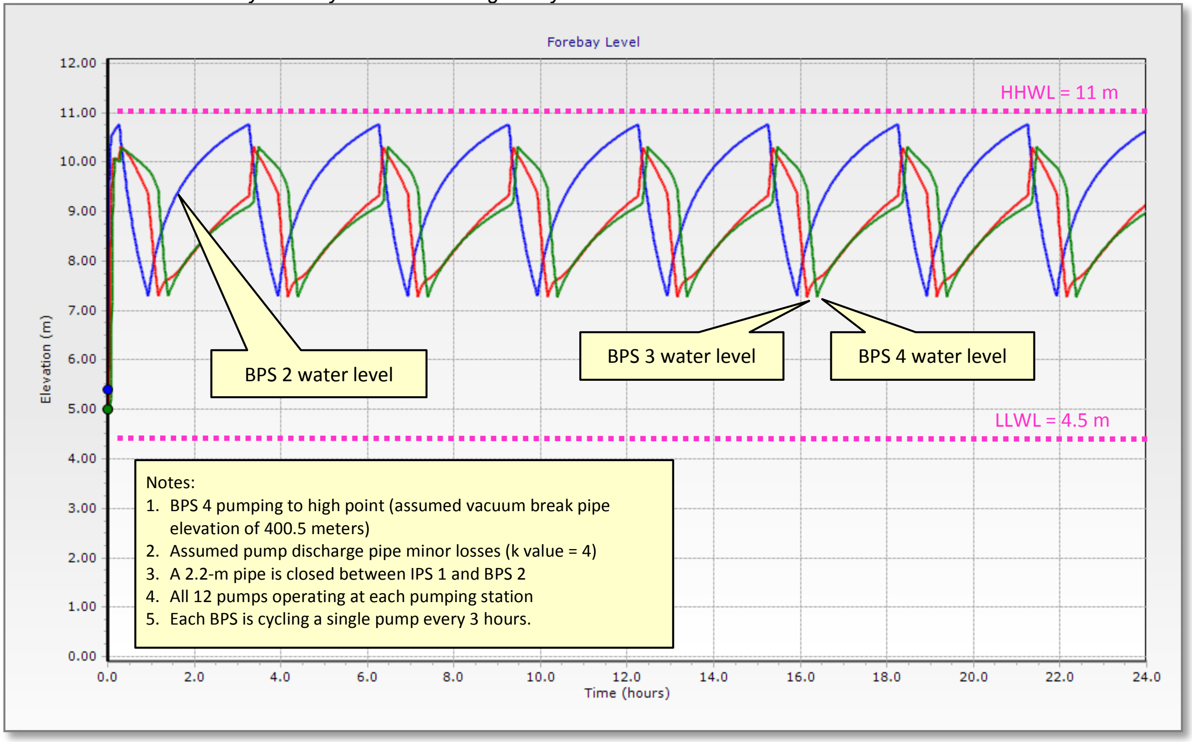
- Scenario 10A – Pipe Closed Between IPS 1 and BPS 2
- Scenario 10B – Pipe Closed Between BPS 3 and BPS 4
- Scenario 10C – Pipe Closed Between BPS 4 and NCWTP

A scenario was not conducted with one of the two 2.6-m pipes closed between BPS 2 and BPS 3 because the velocity in a single 2.6-m pipeline at Phase 4 flows is excessively high (4 meters per second [m/sec]). As described in Section 4, it is difficult to provide adequate surge control under this condition. For this reason, it is recommended that during the construction of the Phase 5-8 pipelines between BPS 2 and BPS 3, an additional pipe be constructed as a redundant pipe to provide service while other pipes are out-of-service.

3.5.6 Scenario 10A – Normal Operation, Phase 4, Pipe Closed Between IPS 1 and BPS 2

The results of Scenario 10A are shown in Figure 3-20 and are considered to be acceptable. When a single 2.2-m pipe is off-line between IPS 1 and BPS 2, 12 pumps can operate and forebay water levels will remain within 7.5 and 11 m at each booster pumping station. One of the 12 pumps shuts off every 3 hours, and 1 of the 4 standby pumps activates about 1 hour later.

FIGURE 3-20
Scenario 10A: BPS Forebay Levels (Existing Phase 4 Design, Pipe Closed Between IPS 1 and BPS 2)
New Cairo Raw Water System Hydraulic Modeling Study



Notes:
1. BPS 4 pumping to high point (assumed vacuum break pipe elevation of 400.5 meters)
2. Assumed pump discharge pipe minor losses (k value = 4)
3. A 2.2-m pipe is closed between IPS 1 and BPS 2
4. All 12 pumps operating at each pumping station
5. Each BPS is cycling a single pump every 3 hours.

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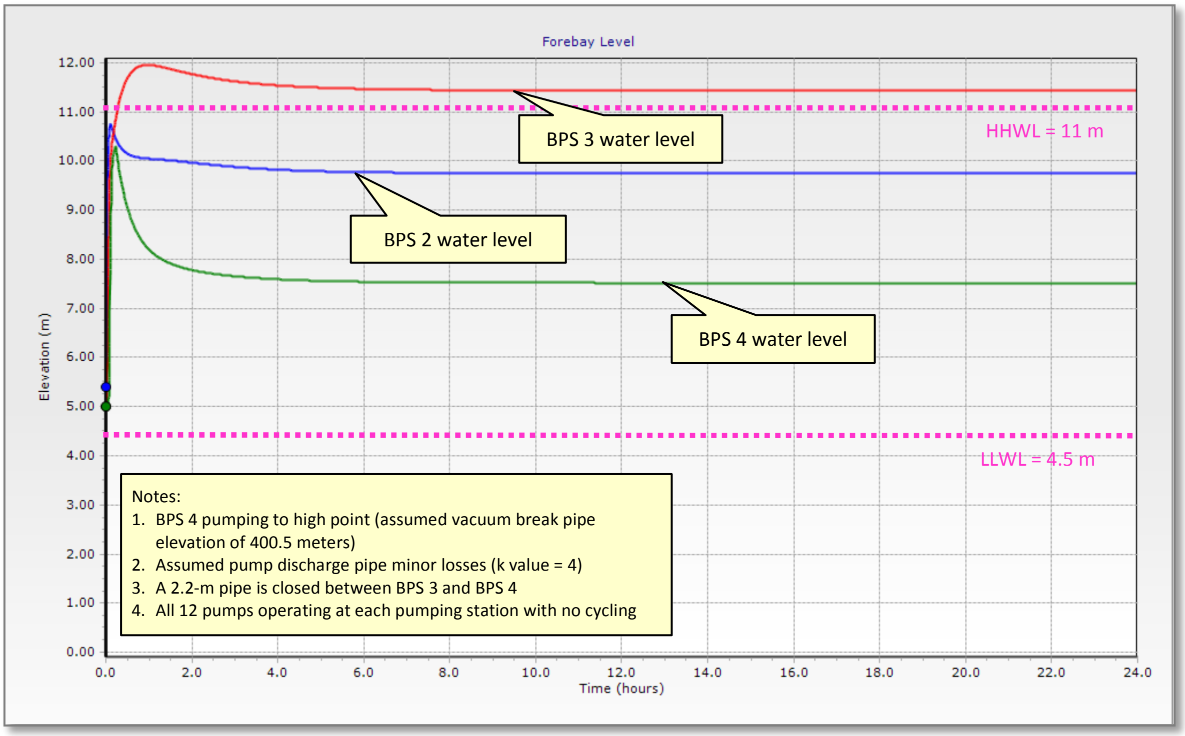
3.5.6.1 Scenario 10B – Normal Operation, Phase 4, Pipe Closed Between BPS 3 and BPS 4

The results of Scenario 10B are shown in Figure 3-21 and are considered to be acceptable. When a single 2.2-m pipe is off-line between BPS 3 and BPS 4, 12 pumps can operate without any cycling and forebay water levels remain within 7.5 and 11.5 m at each booster pumping station. BPS 3 is close to the EMWL control set-point but was not triggered.

FIGURE 3-21
Scenario 10B: BPS Forebay Levels (Existing Phase 4 Design, Pipe Closed Between BPS 3 and BPS 4)
New Cairo Raw Water System Hydraulic Modeling Study



Notes:
1. BPS 4 pumping to high point (assumed vacuum break pipe elevation of 400.5 meters)
2. Assumed pump discharge pipe minor losses (k value = 4)
3. A 2.2-m pipe is closed between BPS 3 and BPS 4
4. All 12 pumps operating at each pumping station with no cycling

3.5.6.2 Scenario 10C – Normal Operation, Phase 4, Pipe Closed Between BPS 4 and NCWTP

For Scenario 10C, the model shows that if 12 pumps are operated at each pumping station, the forebay at BPS 4 will trigger the EMWL control set-point which will shut down an upstream pump at BPS 3 which will cause the forebay water level at BPS 3 to rise and trigger the EMWL control set-point, etc. The results of this sequence is that eleven pumps will run at IPS 1, BPS 2, and BPS 3 and will stabilize forebay water levels as shown in Figure 3-22 while BPS 4 continues to have 12 pumps running. Water levels under this configuration stabilize at 8.0 to 8.5 m at each forebay.

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FIGURE 3-22
Scenario 10C: BPS Forebay Levels (Existing Phase 4 Design, Pipe Closed Between BPS 4 and NCWTP)
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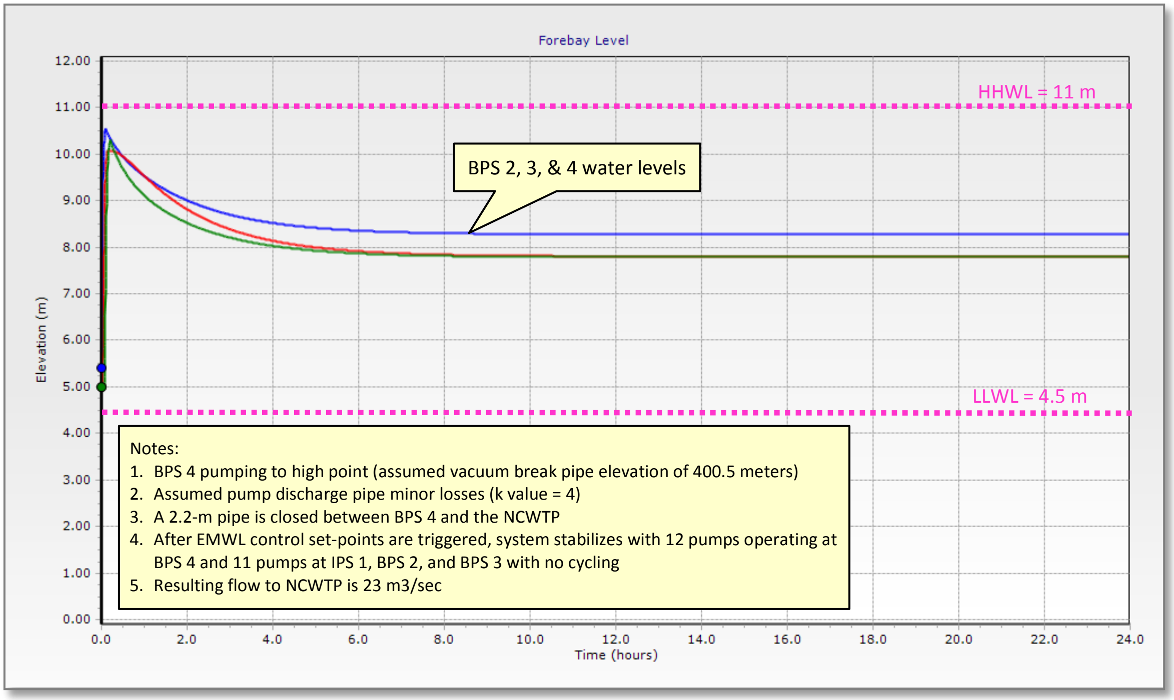

Notes:

1. BPS 4 pumping to high point (assumed vacuum break pipe elevation of 400.5 meters)
2. Assumed pump discharge pipe minor losses (k value = 4)
3. A 2.2-m pipe is closed between BPS 4 and the NCWTP
4. After EMWL control set-points are triggered, system stabilizes with 12 pumps operating at BPS 4 and 11 pumps at IPS 1, BPS 2, and BPS 3 with no cycling
5. Resulting flow to NCWTP is 23 m3/sec

3.5.7 Scenario 11: Normal Operation (Phase 4 Design Plus Standpipe/Weir Concentric Tanks)

Scenario 11 evaluates the same conditions as Scenario 9 but with the proposed standpipe/weir surge control structure. Scenario 11 considers that all pipes are open at Phase 4 conditions using the control set-point strategy described in Section 2.4 (Table 2-3). The results of Scenario 11 are shown in Figure 3-23. The model indicates the forebay water levels will stabilize in a tight range between 8 and 9 m without any pump cycling. However, if a pipe is closed somewhere in the system, pump operation may require some attention as described in Scenario 12.

3.5.8 Scenario 12: Normal Operation (Proposed Phase 4 Design; With New Standpipes; One Pipe Closed)

Scenario 12 evaluates the same conditions as Scenario 11 but with a pipe closed in the system. Three runs were conducted with a pipe closed between different pumping stations:

- Scenario 12A – Pipe Closed Between IPS 1 and BPS 2
- Scenario 12B – Pipe Closed Between BPS 3 and BPS 4
- Scenario 12C – Pipe Closed Between BPS 4 and NCWTP

3.5.8.1 Scenario 12A – Normal Operation, Phase 4, New Standpipe, Pipe Closed Between IPS 1 and BPS 2

The results of Scenario 12A are shown in Figure 3-24 and are considered to be acceptable. When a single 2.2-m pipe is off-line between IPS 1 and BPS 2, 12 pumps can operate and

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forebay water levels will remain within 7 and 11 m at each booster pumping station. One of the 12 pumps shuts off every 2 hours, and one of the four standby pumps activates about an hour later.

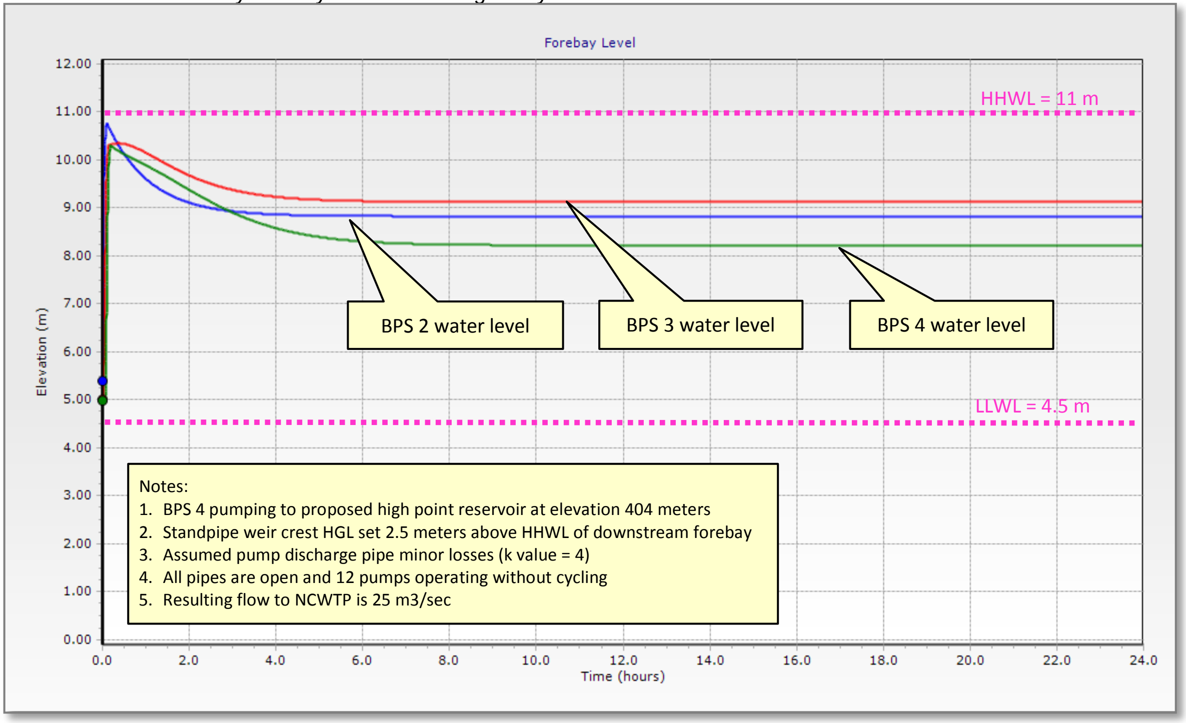
3.5.8.2 Scenario 12B – Normal Operation, Phase 4, New Standpipe, Pipe Closed Between BPS 3 and BPS 4

The results of Scenario 12B are shown in Figure 3-25 and are considered to be acceptable. When a single 2.2-m pipe is off-line between BPS 3 and BPS 4, eleven pumps can be operated at IPS 1, BPS 2, and BPS 4, and 12 pumps can be operated at BPS 3 which will keep forebay water levels within 7 and 11 m. At BPS 3, one of the 12 pumps shuts off every 2 hours, and one of the four standby pumps activates about an hour later. At BPS 4, one of the 12 pumps shuts off every 4 hours, and one of the four standby pumps activates about an hour later.

3.5.8.3 Scenario 12C – Normal Operation, Phase 4, New Standpipe, Pipe Closed Between IPS 4 and the NCWTP

The results of Scenario 12C are shown in Figure 3-26 and are considered to be acceptable. When a single 2.2-m pipe is off-line between BPS 4 and the NCWTP, eleven pumps can be operated at IPS 1, BPS 2, and BPS 3, and 12 pumps can be operated at BPS 4 which will keep forebay water levels stable for BPS 2 and 3. At BPS 4, one of the 12 pumps shuts off every 4 hours, and one of the four standby pumps activates about an hour later.

FIGURE 3-23
Scenario 11: BPS Forebay Levels (Proposed Phase 4 Design, New Standpipes, All Pipes Open)
New Cairo Raw Water System Hydraulic Modeling Study



Notes:
1. BPS 4 pumping to proposed high point reservoir at elevation 404 meters
2. Standpipe weir crest HGL set 2.5 meters above HHWL of downstream forebay
3. Assumed pump discharge pipe minor losses (k value = 4)
4. All pipes are open and 12 pumps operating without cycling
5. Resulting flow to NCWTP is 25 m3/sec

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FIGURE 3-24
Scenario 12A: BPS Forebay Levels (Phase 4 Design, New Standpipes, Pipe Closed Between IPS 1 and BPS 2)
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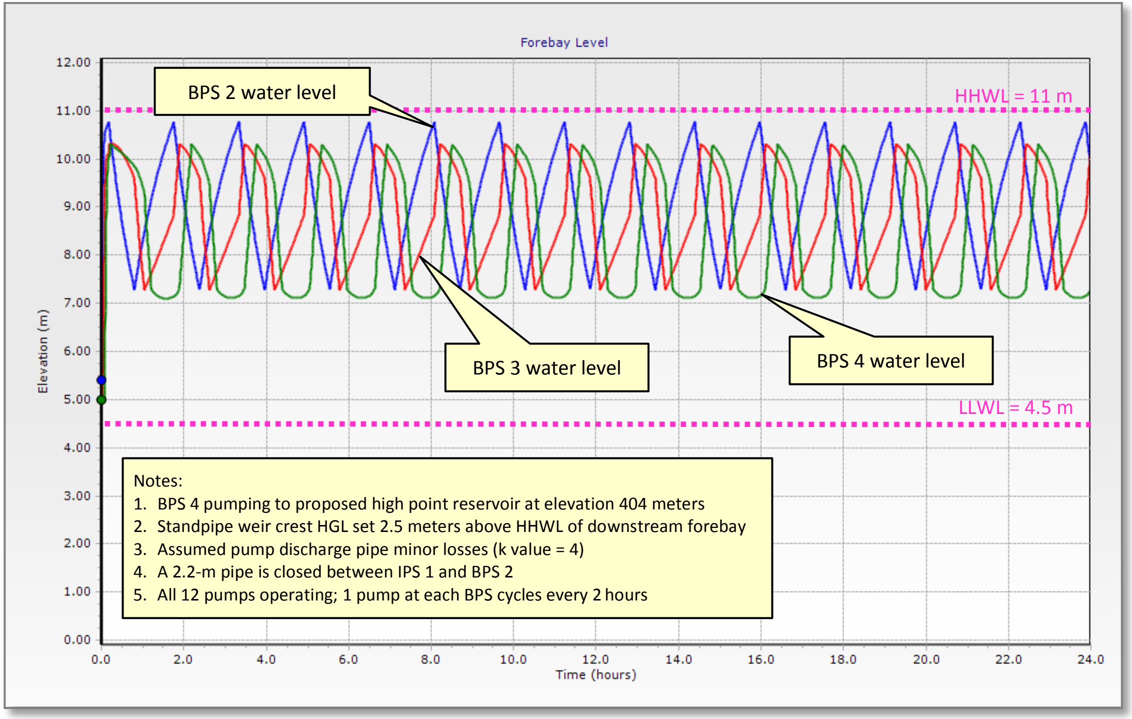
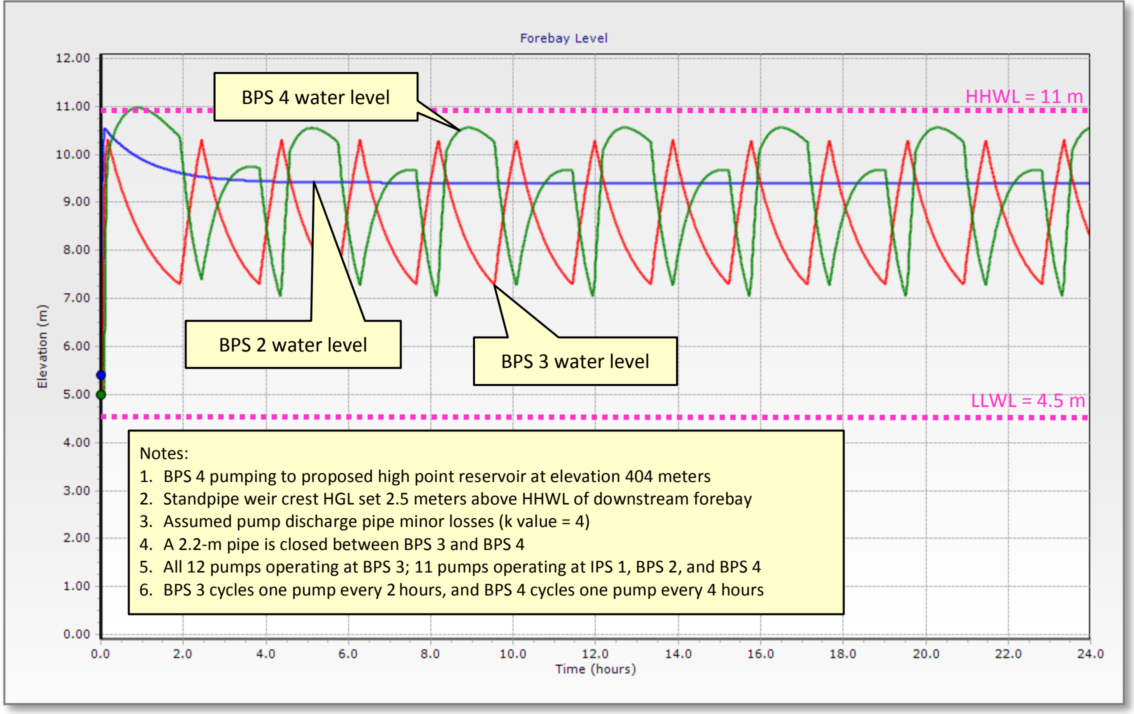


Notes:
1. BPS 4 pumping to proposed high point reservoir at elevation 404 meters
2. Standpipe weir crest HGL set 2.5 meters above HHWL of downstream forebay
3. Assumed pump discharge pipe minor losses (k value = 4)
4. A 2.2-m pipe is closed between IPS 1 and BPS 2
5. All 12 pumps operating; 1 pump at each BPS cycles every 2 hours

FIGURE 3-25
Scenario 12B: BPS Forebay Levels (Phase 4 Design, New Standpipes, Pipe Closed Between BPS 3 and BPS 4)
New Cairo Raw Water System Hydraulic Modeling Study



Notes:
1. BPS 4 pumping to proposed high point reservoir at elevation 404 meters
2. Standpipe weir crest HGL set 2.5 meters above HHWL of downstream forebay
3. Assumed pump discharge pipe minor losses (k value = 4)
4. A 2.2-m pipe is closed between BPS 3 and BPS 4
5. All 12 pumps operating at BPS 3; 11 pumps operating at IPS 1, BPS 2, and BPS 4
6. BPS 3 cycles one pump every 2 hours, and BPS 4 cycles one pump every 4 hours

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FIGURE 3-26
Scenario 12C: BPS Forebay Levels (Phase 4 Design, New Standpipes, Pipe Closed Between BPS 4 and NCWTP)
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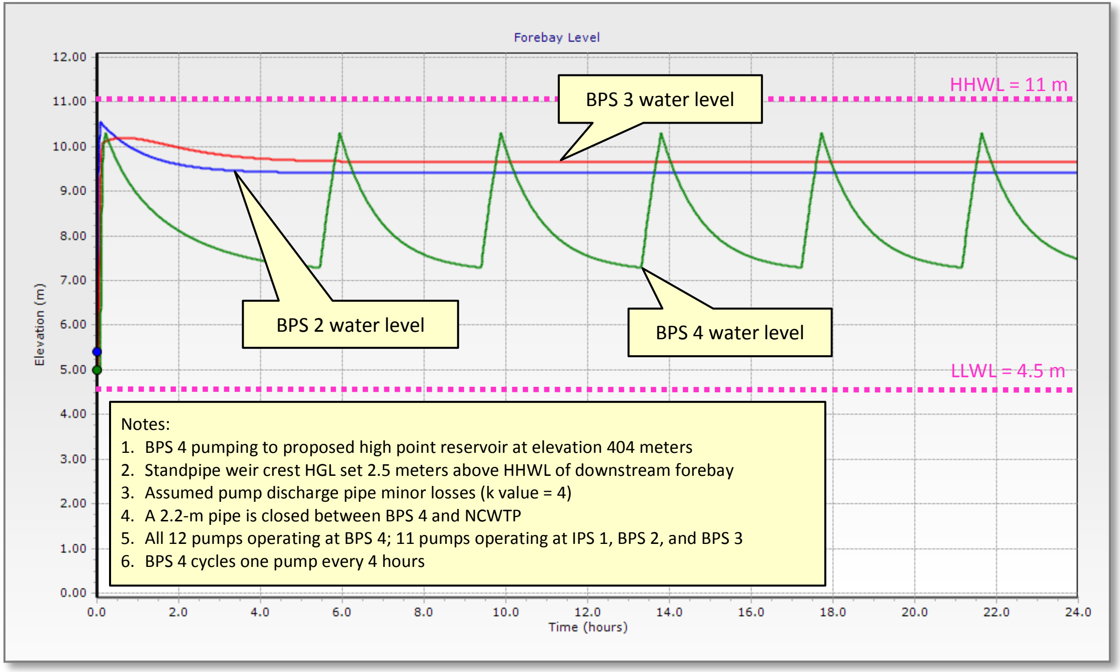

Notes:
1. BPS 4 pumping to proposed high point reservoir at elevation 404 meters
2. Standpipe weir crest HGL set 2.5 meters above HHWL of downstream forebay
3. Assumed pump discharge pipe minor losses (k value = 4)
4. A 2.2-m pipe is closed between BPS 4 and NCWTP
5. All 12 pumps operating at BPS 4; 11 pumps operating at IPS 1, BPS 2, and BPS 3
6. BPS 4 cycles one pump every 4 hours

3.6 EPS Modeling Analysis Conclusions and Recommendations

The EPS modeling analysis shows that constant speed pumps and existing forebay volumes are adequate during normal operation for the existing and proposed Phase 1 and Phase 4 designs using the control strategy described in Section 2.4 and by incorporating the specific recommendations described below. However, the greatest risk is potential forebay overflow during a power loss scenario while the upstream pump station continues to operate. Additional emergency storage is recommended as well as a new EMWL control set-point that shuts down the upstream pumping station. The following recommendations are provided:

- Recommendation 1 (Pump Controls) - CH2M HILL recommends the control strategy described in Section 2.4. An EMWL control set-point that shuts down the upstream pumping station is critically important to prevent forebay overflow.
- Recommendation 2 (Emergency Storage) - CH2M HILL has proposed several emergency storage options for consideration (Alternatives 1A, 1B, and/or 1C). Table 3-2 provides the approximate volumes of Alternative 1A and 1B. However, the volume that can be constructed for Alternative 1C is dependent on local site conditions and for this reason was not provided in this report.
- Recommendation 3 (Temporary Control Valve Throttling) – During Phase 1, it may be necessary to use the electric control valve to throttle and balance flows in the system to

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prevent BPS 2 forebay level from rising too quickly. If the proposed standpipe surge control structure is constructed for Phase1, the need for throttling the IPS 1 control valves becomes more necessary. However, the modeling analysis shows that by Phase 4 the IPS 1 control valves will not need to be throttled to balance flows in the system.

- Recommendation 4 (Pipe Maintenance Strategy) – The EPS modeling analysis shows that when a pipe is taken out-of-service during Phase 1 conditions, the system remains balanced and forebay level operation is not a problem. However, at Phase 4 flows with and without the proposed standpipe, forebay water level balancing becomes more challenging if a pipe is taken out-of-service. Typically, if a pipe is taken out-of-service, the modeling shows that all 12 pumps can remain in service upstream of the off-line pipe, and the remaining pumping stations should only run 11 pumps. Based on the complexity of the NCRWS and potential for forebay water levels to become imbalanced during pipeline maintenance, a real-time hydraulic model linked with the SCADA system (i.e., Derceto Aquadapt system) could be used to plan maintenance and emergency strategies as well as to optimize pumping costs.
- Optional Recommendation 5 (Variable Speed Drives) – The EPS modeling analysis shows that VSD pumps are not a requirement for satisfactory pump and forebay level operation. However, the owner and operator of the NCRWS may wish to have 2 of the 16 pumps to be VSD pumps to balance flow during pipeline maintenance or emergency conditions.

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4.0 Surge Analysis

This section of the report includes a discussion of various surge control strategies, a comparison of previously conducted surge studies, and a summary of the findings from CH2M HILL's surge analysis. This section of the report is presented as follows:

- Section 4.1 – Steady State Pump and System Curve Analysis
- Section 4.2 – Surge Control Theory
- Section 4.3 – Results of Previous Surge Studies
- Section 4.4 – Computer Model Surge Analysis

4.1 Steady State Pump and System Curve Analysis

Prior to conducting the surge analysis, CH2M HILL conducted a steady state analysis to verify the compatibility of the pumps with the pipeline system hydraulics. The computer model was used to generate system curves for three primary conditions:

- Pumping from the upstream forebay at HHWL to the downstream forebay at LLWL with all pipes open to determine the lower system curve operating band
- Pumping from the upstream forebay LLWL to the downstream forebay HHWL with one pipe closed to determine the upper system curve operating band
- Pumping from the upstream forebay LLWL to the downstream forebay HHWL with all pipes open for comparison to having one pipe closed

Figures 4-1, 4-3, 4-5, and 4-7 show the combined pump curves for each pump station for each design phase along with the system curves described above.

Figures 4-2, 4-4, 4-6, and 4-8 show a single pump curve for each pump station and the operating conditions at Phase 1 and Phase 4 flows. The Phase 4 operating points shown in these figures are based on the following:

- Pumping from the upstream forebay at HHWL to the downstream forebay at HHWL which close to the normal operating condition based on the control set-points described in Section 2 of this report
- Pumping from the upstream forebay at HHWL to the proposed "standpipe with weir" crest elevation

As shown in Figures 4-2, 4-4, 4-6, and 4-8, each pump at IPS 1, BPS 2, BPS 3, and BPS 4 can pump at least 2 m^3/sec under existing and proposed design conditions for a combined capacity of at least 24 m^3/sec.

It should be noted in Figure 4-8, that the Phase 4 operating point for BPS 4 is at the maximum head rating per the Torishima pump curve data sheet for the following boundary

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conditions: if a reservoir is built upstream of the WTP (pipe high point centerline elevation of 399 m and proposed reservoir water level of 404 m), if one pipe is out of service, and if the BPS 4 forebay is operating at LLWL. While not a significant concern, the design point for future pump phases at BPS 4 should take into account the proposed reservoir if constructed.

FIGURE 4-1
Multiple Pump and System Curves for IPS1 to BPS2
New Cairo Raw Water System Hydraulic Modeling Study

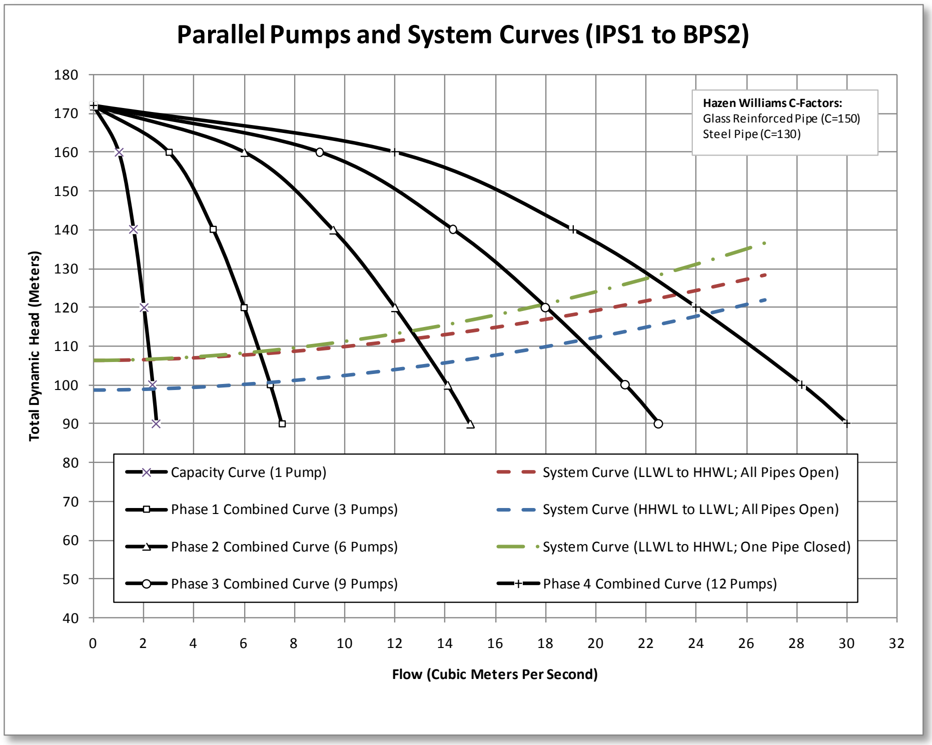

FIGURE 4-2
Single Pump and System Curves for IPS1 to BPS2
New Cairo Raw Water System Hydraulic Modeling Study

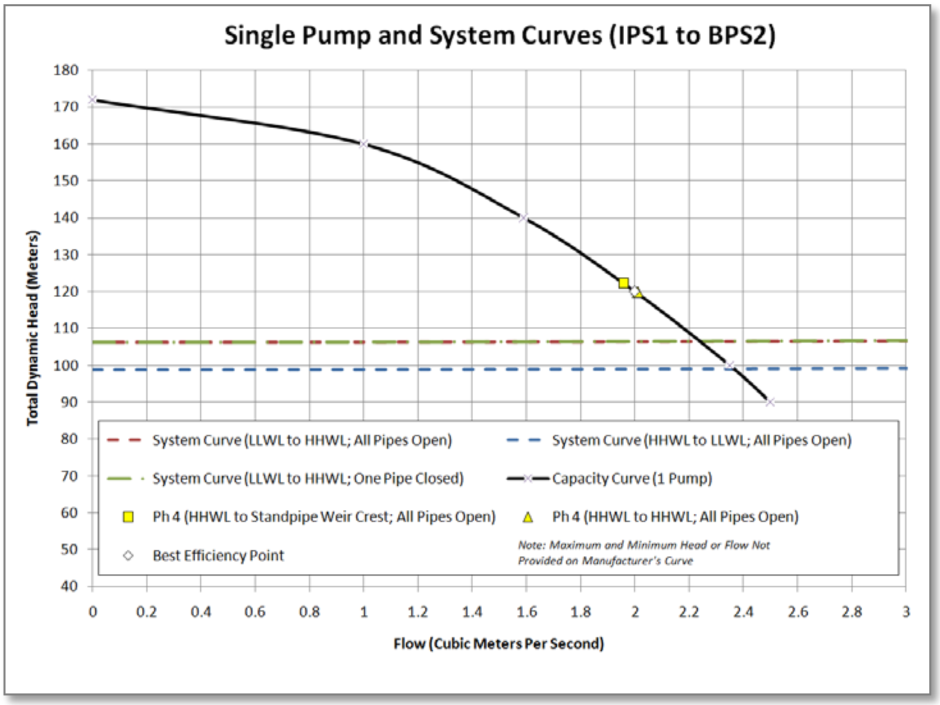

FIGURE 4-3
Multiple Pump and System Curves for BPS2 to BPS3
New Cairo Raw Water System Hydraulic Modeling Study

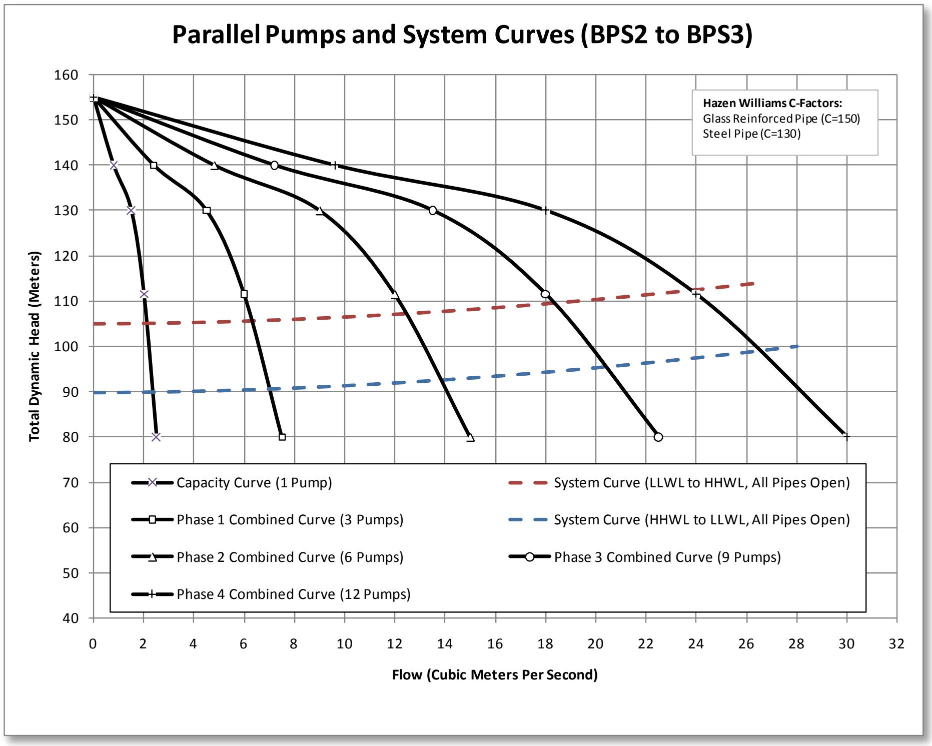

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FIGURE 4-4

Single Pump and System Curves for BPS2 to BPS3

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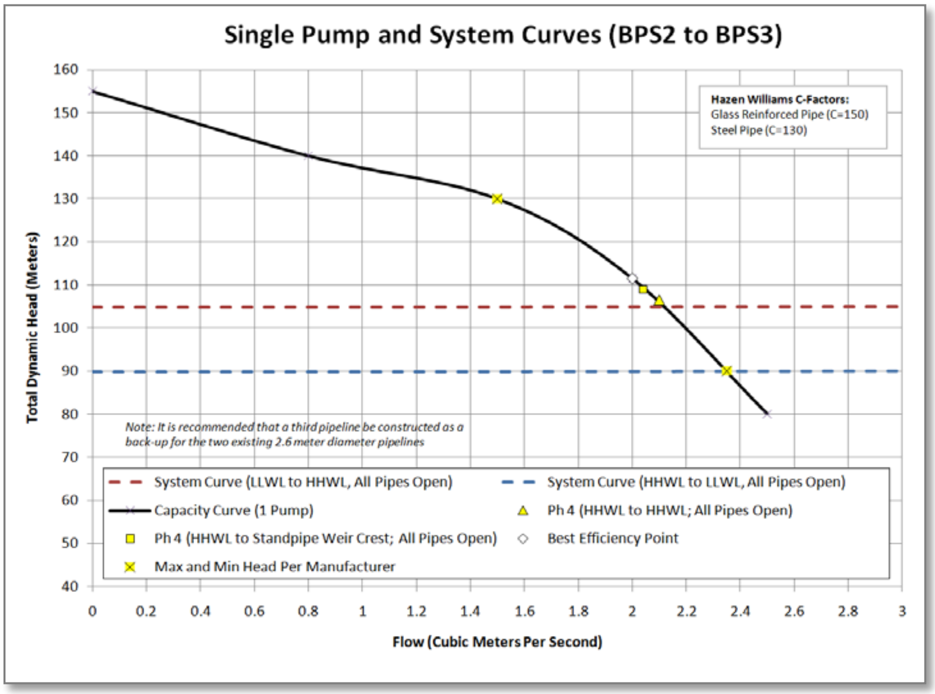

FIGURE 4-5

Multiple Pump and System Curves for BPS3 to BPS4

New Cairo Raw Water System Hydraulic Modeling Study

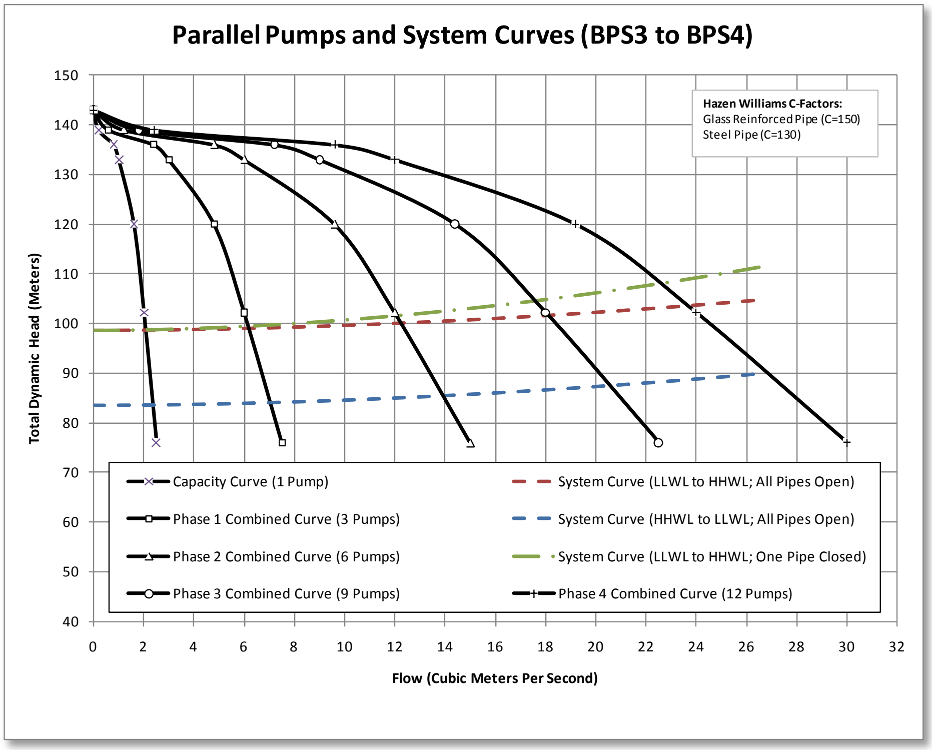

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FIGURE 4-6
Single Pump and System Curves for BPS3 to BPS4
New Cairo Raw Water System Hydraulic Modeling Study

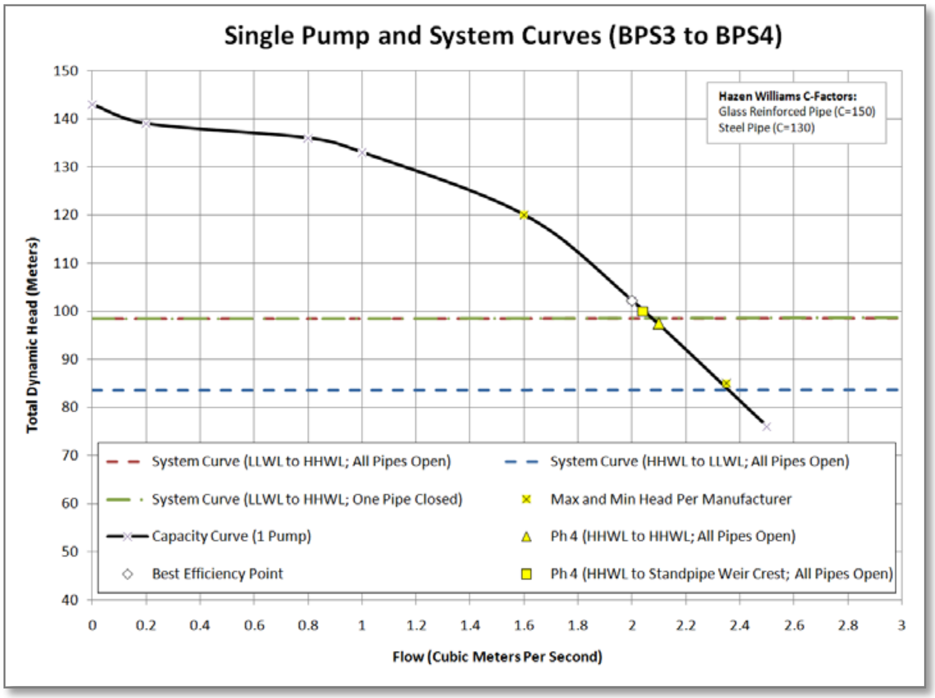

FIGURE 4-7
Multiple Pump and System Curves for BPS4 to WTP
New Cairo Raw Water System Hydraulic Modeling Study

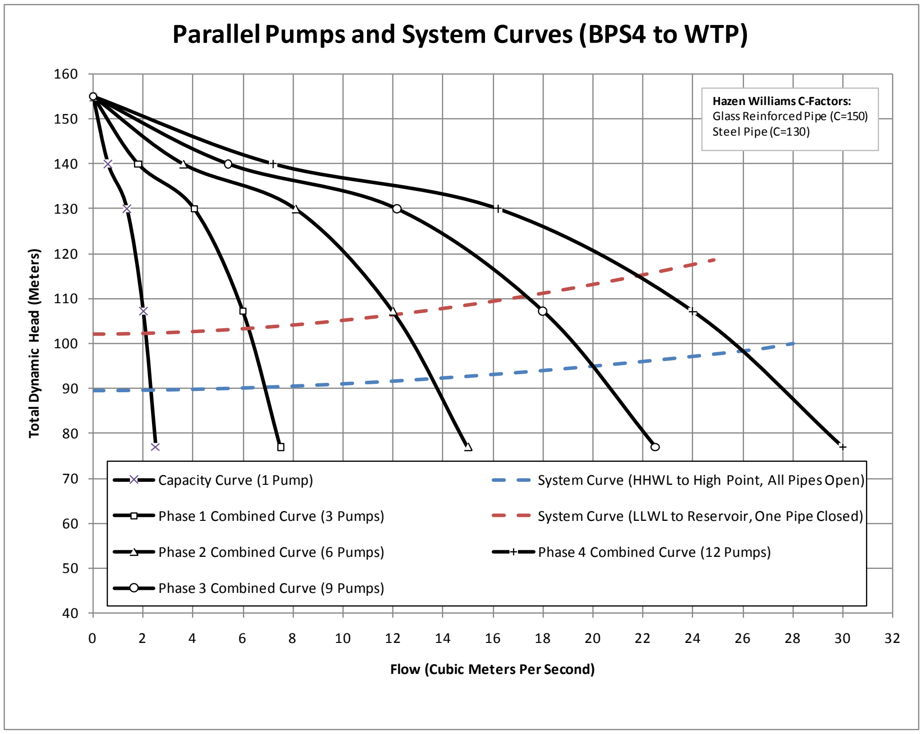

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FIGURE 4-8
Single Pump and System Curves for BPS4 to WTP
New Cairo Raw Water System Hydraulic Modeling Study

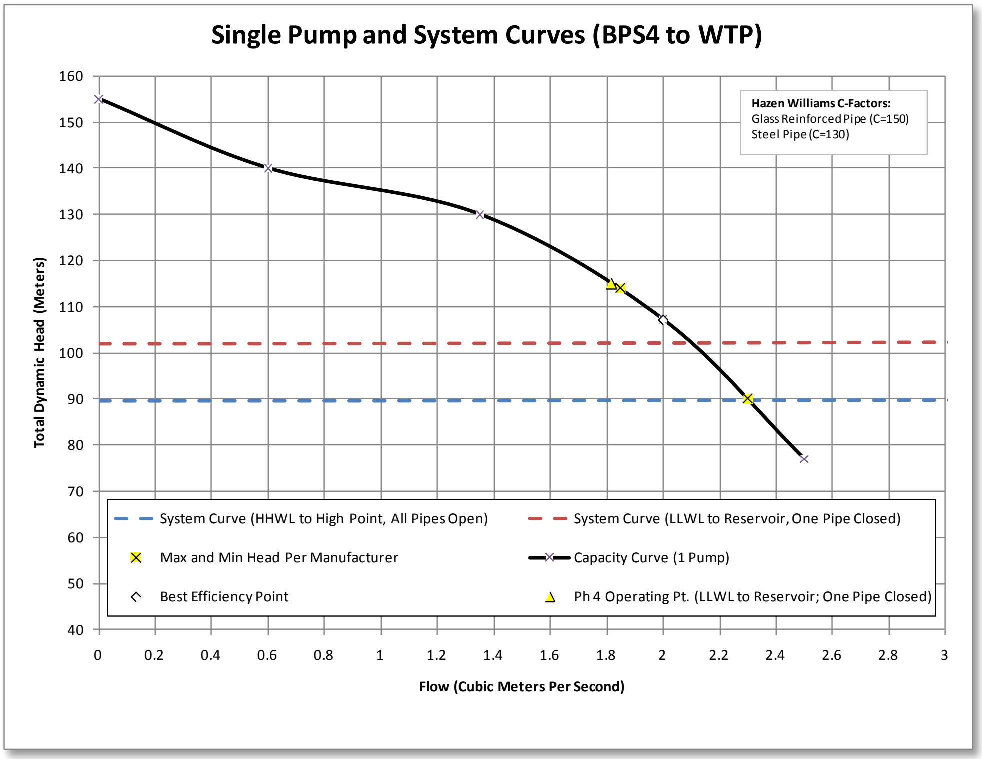

Table 4-1 summarizes the steady state conditions used for the Phase 1 surge analysis, indicating the number of pipes operating, the total flow rate, and the pre-surge velocity.

TABLE 4-1
Steady State Flow Parameters – Phase 1
New Cairo Raw Water System Hydraulic Modeling Study

Segment	Flow Rate (Ph 1)	Pipe Segment	Pipes In Service	Velocity (Ph 1)
IPS TO BPS 2	6.89 m^3/s	1A-B	2 of 2	0.65 m/s
		1-C	2 of 3	0.91 m/s
		1-D	2 of 2	0.65 m/s
BPS 2 TO BPS 3	6.60 m^3/s	2-A	1 of 1	1.20 m/s
		2-B	1 of 1	1.20 m/s
		2-C	1 of 1	1.20 m/s
BPS 3 TO BPS 4	6.65 m^3/s	3-A	2 of 2	0.62 m/s
		3-B	2 of 3	0.88 m/s
		3-C	2 of 2	0.62 m/s
BPS 4 TO WTP	6.87 m^3/s	4-A	2 of 2	0.64 m/s
		4-B	2 of 3	0.90 m/s
		4-C	2 of 2	0.64 m/s

Note: flows are approximate and will vary based on various operating conditions

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Table 4-2 summarizes the steady state conditions used for the Phase 4 surge analysis, indicating the number of pipes operating, the total flow rate, and the pre-surge velocity.

TABLE 4-2
Steady State Flow Parameters – Phase 4
New Cairo Raw Water System Hydraulic Modeling Study

Segment	Flow Rate (Ph 4)	Pipe Segment	Pipes In Service	Velocity (Ph 4)
IPS TO BPS 2	24.23 m^3/s	1A-B	2 of 2	2.28
		1-C	2 of 3	3.19
		1-D	2 of 2	2.28
BPS 2 TO BPS 3	25.24 m^3/s	2-A	2 of 2	2.30
		2-B	2 of 2	2.30
		2-C	2 of 2	2.30
BPS 3 TO BPS 4	24.22 m^3/s	3-A	2 of 2	2.28
		3-B	2 of 3	3.18
		3-C	2 of 2	2.28
BPS 4 TO WTP	22.89 m^3/s	4-A	2 of 2	2.16
		4-B	2 of 3	3.01
		4-C	2 of 2	2.16

Note: flows are approximate and will vary based on various operating conditions

4.2 Surge Control Theory

Hydraulic transient (surge) pressure occurs due to rate-of-flow changes in full pipelines containing incompressible fluids such as water. Surge events can generate high or low pressure waves (or both), which can cause noise, pipe movement, pipe rupture, or pipe collapse. Power failure is usually the controlling surge scenario because it represents an uncontrolled event — all pumps are lost instantaneously and without warning. Other scenarios can be controlled with timed valve movements or staged pump startup or shutdown.

The object of surge analysis is to develop an approach to surge control that will protect the pipe from extreme high and low pressure events. High pressure events that exceed the design rating of the pipe can cause structural failure. Low pressure events are also dangerous, due to the effects of column separation. Column separation occurs in pipelines when pressures drop to water’s vapor pressure, causing pockets of unstable water vapor to appear in the pipeline. When these vapor cavities collapse, they can cause destructive localized pressure that may damage the pipeline. The behavior of water during column separation is difficult to predict with modeling tools and conditions with create this phenomenon should be avoided in design.

The following sections discuss accepted surge control methods, with a brief discussion of how each applies to NCRWS.

4.2.1 Hydro-pneumatic Tanks

Hydro-pneumatic tanks are a very reliable means of surge control, and are typically installed at pump stations (not along the pipeline). The tanks usually feature a compressed air charge maintained over a volume of water contained in the tank. The compressed air acts as a damper of pressure changes in the system, supplying energy following pump power failure and absorbing energy during upsurge events, such as pump startup or reverse flow following pump shutdown, respectively. Characteristically, they remove sharp pressure spikes and create smooth, controlled pressure oscillations until friction damps out transient pressure waves.

The required size of a hydro-pneumatic tank is a function of pipeline length, maximum flow rate, acoustic wave speed in the line, pipe profile, and the limiting assumptions of allowable pressures. In current practice the required size of these tanks is determined by computer analysis. Hydro-pneumatic tanks work well with simple check valves on the discharge side of pumps – the current arrangement at NCRWS. Previous analysis of the NCRWS system by Hitachi, Charlatte, and Dorsch led each firm to recommend the installation of hydro-pneumatic tanks at all pump stations.

4.2.2 Standpipes / Surge Tanks

Standpipes (sometimes called surge tanks) are another approach to controlling low pressures at pipeline highpoints, and represent an alternative to combination air/vacuum release valves (CAVs). A standpipe is open to atmospheric pressure and is sized so that the side walls are higher than the hydraulic grade line during pumping. This effect is not difficult to achieve at system high points near the end of pipelines, as is the case at NCRWS. During the surge event, water moves in an out of the tank with atmospheric pressure above the water surface. This movement of water in response to pressure waves provides simple, reliable protection against column separation.

Charlatte recommended individual standpipes (the same diameter as the pipelines) for the three segments of the NCRWS that they modeled. Dorsch Consult recommended CAVs, which perform a similar function, but with less simplicity. CH2M HILL has recommended standpipes for all segments of the NCRWS, with the potential to provide additional volume for the pump station forebays.

4.2.3 Pump Discharge Check Valve

There are several approaches to controlling flow with valves at the discharge of pumps. Discharge valves fall into two categories, controlled closure and uncontrolled closure. During a pump shutdown, a controlled closure valve would gradually close by means of a motor operator, with the pump shutdown occurring near the end of the valve stroke. During pump shutdown with uncontrolled closure valves (check valves), pump power is interrupted first followed by a flow reversal that closes the simple check valve.

The Hitachi study states that the IPS is equipped with a simple counter weighted check valves. Charlatte modeled check valves for the pumps in BPS 2, 3, and 4. Dorsch Consult also modeled simple checks for BPS 2, 3, and 4. CH2M HILL modeled simple swing checks in all cases.

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4.2.4 Surge Anticipator and Relief Valves

Surge anticipator valves open when the pressure drops below a specified set-point, remain open for a pre-set period of time, and then close in a manner that prevents high pressures resulting from rapid valve closure. Anticipator valves can also be set to open when line pressures exceed a pre-set value, thus operating as a surge relief valve. Surge relief valves can also reduce maximum surge pressures if they are adjusted properly.

No firms have recommended surge anticipator or surge relief valves on the NCRWS. CH2M HILL also does not recommend them in this application. This approach to surge control relies heavily on precise settings and presents risk of catastrophic failure if not properly set and maintained. This approach to surge control also would not address low pressures in the pipeline – a known risk factor in the NCRWS.

4.2.5 Combination Air Valves

Combination air admission/air release valves (CAV) allow air into the line when the pressure drops below atmospheric and discharges air (if any) when the pressure becomes positive. CAVs are most effective when placed as system high points where column separation may appear during pump shutdown events. The application of CAVs to control down surge comes with some risk due to maintenance requirements.

In the case of NCWRS, only Dorsch Consult has considered the application of CAVs at pipeline system high points. Hitachi made no recommendation for air admission on the pipeline, while Charlatte investigated the use of standpipes. CH2M HILL does not recommend CAVs in this setting due to the required number and size of the valves as well as the significant maintenance requirements.

Table 4-3 summarizes the recommended surge control measures considered by CH2M HILL during this study.

TABLE 4-3
Recommended Surge Control Measures
New Cairo Raw Water System Hydraulic Modeling Study

#	Surge Control Measure	Recommended
1	Hydro-pneumatic Tanks	Yes
2	Standpipes/Surge Tanks	Yes
3	Pump Discharge Check Valve	Yes
4	Surge Anticipator/Relief Valve	No
5	Combination Air Admission/Release Valves (CAV)	No

4.3 Results of Previous Surge Studies

Three surge study reports by other firms were provided to CH2M HILL during this study. Hitachi Plant Technologies produced a report in 2009 limited to the IPS, while Charlatte Reservoirs (Fayat Group) and Dorsch Consult both produced reports in 2010. Table 4-4 summarizes the pipeline segments covered by each of the reports.

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TABLE 4-4
Previous Transient (Surge) Studies
New Cairo Raw Water System Hydraulic Modeling Study

Segment	Hitachi	Charlatte	Dorsch Consult
IPS TO BPS 2	Phase 1 & 4		
BPS 2 TO BPS 3		Phase 1	Phase 1 & 4
BPS 3 TO BPS 4		Phase 1	Phase 1 & 4
BPS 4 TO WTP		Phase 1	Phase 1 & 4

4.3.1 Hitachi Plant Technologies

The design criteria applied in the Hitachi report are summarized in Table 4-5.

TABLE 4-5
Hitachi Design Criteria
New Cairo Raw Water System Hydraulic Modeling Study

Minimum Allowable Pressures	Maximum Allowable Pressures	Reverse Flow at Pumps	Maximum Velocities
-0.6 bar (-6 meters water column [mwc])	Not Specified	No (check valves)	2.3 m/s

Hitachi's recommendations for surge control at the IPS are summarized in Table 4-6 based on Document 5 in Table 1-1. Their detailed recommendation for tank sizing included a diameter of 4.5 m with a height of 12.8 m above the pipe connection, creating an effective volume of 197 m^3.

TABLE 4-6
Hitachi Surge Control Recommendations
New Cairo Raw Water System Hydraulic Modeling Study

Segment	Phase	Major Glass Reinforced Pipe (GRP) Lines in Service	Tanks	Total Volume	Other Devices
IPS TO BPS 2	1	1 of 3	2 @ 197 m^3	400 m^3	n/a
	1	2 of 3	2 @ 197 m^3	400 m^3	n/a
	4	2 of 3	8 @ 197 m^3	1580 m^3	n/a
	4	3 of 3	8 @ 197 m^3	1580 m^3	n/a

4.3.2 Charlatte Reservoirs (Fayat Group)

Charlatte Reservoir's design criteria for surge control are summarized in Table 4-7 with an internal minimum allowable transient pressure of -0.3 bar and differential pressure of -0.7 bar to account for the net effect of the external loading on the pipe and internal transient pressure.

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TABLE 4-7
Charlatte Design Criteria
New Cairo Raw Water System Hydraulic Modeling Study

Minimum Allowable Pressures	Maximum Allowable Pressures	Reverse Flow at Pumps	Maximum Velocities
-0.3 bar (-3.1 mwc) internal -0.7 bar (-7.1 mwc) differential	Not Specified	No (check valves)	2.5 m/s

Table 4-8 summarizes Charlatte's surge control recommendations based on Document 11 in Table 1-2. Their vertical pressure vessels are sized using the firm's internal standards. Based on their sales literature, the 50 m^3 tanks would likely have a vessel diameter of 3 m with a height of 8m. Charlatte also developed a set of recommendations based on changes in the pipeline profile, which are not included in Table 4-8.

TABLE 4-8
Charlatte Surge Control Recommendations
New Cairo Raw Water System Hydraulic Modeling Study

Segment	Phase	Major GRP Lines In Service	Tanks	Total Volume	Other Devices
BPS 2 TO BPS 3	1	1 of 2	8 @ 50 m^3	400 m^3	Concentric vertical pipes at sta 7+463
	4	n/a	n/a	n/a	n/a
BPS 3 TO BPS 4	1	1 of 3	11 @ 50 m^3	550 m^3	Standpipe (2.2-m dia.) at station 4+596
	4	n/a	n/a	n/a	n/a
BPS 4 TO WTP	1	1 of 3	5 @ 41 m^3	205 m^3	Open chamber at station 7+073
	4	n/a	n/a	n/a	n/a

Note: n/a = not applicable

4.3.3 Dorsch Consult

The design criteria applied in the Dorsch Consult report are summarized in Table 4-9.

TABLE 4-9
Dorsch Consult Design Criteria
New Cairo Raw Water System Hydraulic Modeling Study

Minimum Allowable Pressures	Maximum Allowable Pressures	Reverse Flow at Pumps	Maximum Velocities
-0.3 bar (-3.1 mwc)	1.5 x Operating	No (check valves)	2.1 to 2.3 m/s

Table 4-10 summarizes the recommendations by Dorsch Consult, who recommended a minimum pressure vessel diameter of 4.5 m with a height of 8 m, with half of the tank volume reserved for air charge under steady state operation. The Dorsch Consult report was not specific as to the exact locations of the proposed CAV devices.

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TABLE 4-10
Dorsch Consult Surge Control Recommendations
New Cairo Raw Water System Hydraulic Modeling Study

Segment	Phase	Major GRP Lines In Service	Tanks	Total Volume	Other Devices
BPS 2 TO BPS 3	1	1 of 2	3 @ 130 m^3	390 m^3	300 mm CAV
	4	2 of 2	12 @ 130 m^3	1600 m^3	300 mm CAV
BPS 3 TO BPS 4	1	1 of 3	3 @ 130 m^3	390 m^3	300 mm CAV
	4	3 of 3	12 @ 130 m^3	1600 m^3	300 mm CAV
BPS 4 TO WTP	1	1 of 3	3 @ 130 m^3	390 m^3	n/a
	4	3 of 3	12 @ 130 m^3	1600 m^3	n/a

Note: location and number of CAV valve vaults was not specified

4.4 Computer Model Surge Analysis (CH2M Hill)

CH2M HILL completed an independent surge analysis of the NCRWS system based on the background information summarized in previous sections. The surge analysis was conducted using the Hammer software by Bentley and was based on the steady state model described in Section 2.

4.4.1 Design Criteria

The design criteria utilized by CH2M HILL during the computer surge analysis are summarized in Table 4-11.

TABLE 4-11
Surge Control Design Criteria
New Cairo Raw Water System Hydraulic Modeling Study

Minimum Allowable Pressures	Maximum Allowable Pressures	Reverse Flow at Pumps	Maximum Velocities
0 bar (atmospheric)	1.5 x Operating	No (check valves)	3.2 m/s

CH2M HILL understands that only “air release” valves have been incorporated into the design of the NCRWS pipelines. Allowing negative transient pressures may pose a risk of pipeline or gasket failure due to the combined external load plus negative internal transient pressures in the pipeline. Replacing existing air release valves along with constructing multiple CAV vaults near the end of each major pipeline segment would result in additional capital expense and significant maintenance requirements. For this reason, CH2M HILL adopted a design criterion of maintaining positive pressures at all times during steady state and surge conditions.

A maximum allowable pressure criterion of 1.5 times the normal operating pressure was used to size the proposed hydro-pneumatic tanks. This assumption directly impacts the sizing of the hydro-pneumatic tanks and should be confirmed by the designers of the NCRWS.

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4.4.2 Surge Model Input Data

For the surge analysis, CH2M HILL utilized wave speed of 1,000 m/s for steel pipe and 500 m/s for GRP in the computer model. Table 4-12 summarizes additional pump information relevant to the surge analysis. The combined pump and motor inertia value for the IPS pumps was obtained from the manufacturer's representative. The inertia for the booster pumps was obtained from Charlatte.

TABLE 4-12
Pump and Motor Summary
New Cairo Raw Water System Hydraulic Modeling Study

Segment	**Make / Model**	**Duty Pumps (PH1 / PH 4)**	**Speed/ Power**	**Moment of Inertia (Pump and Motor)**
IPS TO BPS 2	HITACHI	3 /12	745 rpm / 3100 kW	876 kg m^2
BPS 2 TO BPS 3	TORISHIMA / SPV1000	3 /12	740 rpm / 3000 kW	586 kg m^2
BPS 3 TO BPS 4	TORISHIMA / SPV1000	3 /12	740 rpm / 3000 kW	586 kg m^2
BPS 4 TO WTP	TORISHIMA / SPV1000	3 /12	740 rpm / 3000 kW	586 kg m^2

4.4.3 Standpipe/Surge Tank Alternatives

It has been established in the previously conducted surge studies by Charlatte, Hitachi, and Dorsch Consult and the current study by CH2M HILL that hydro-pneumatic tanks are required at each pump station for surge protection. However, different strategies for controlling negative pressures at the end of the pipelines have been proposed. Two methodologies were analyzed by CH2M HILL during the surge modeling analysis.

- Traditional surge tank
- Standpipe with weir

4.4.3.1 Traditional Surge Tank

A traditional surge tank, also called a standpipe, is described in Section 4.2.2. The tank water level varies based on the hydraulic grade line in the pipeline. If the downstream forebay water level is low, the water level in the surge tank will be low. As shown in Figure 2-3, the pump "STOP" levels at Phase 1 and 4 conditions are low in the sump which only provides approximately 0-2 m of head on the upstream pipeline. For this reason, a traditional surge tank would have to be sized fairly large to keep the pipeline pressurized during a pump power failure induced surge event.

4.4.3.2 Standpipe with Weir

Due to the limitations of the traditional surge tank configuration, a "standpipe plus weir" arrangement is proposed for consideration to maintain a higher hydraulic grade line in the pipeline as previously described in Section 3.3.1.3. This concept was also proposed to provide additional operational storage volume (storage alternative 1C). As shown in Figure 3-4, incoming flow enters the inner "standpipe" or concrete structure and continuously

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flows over a weir and spillway into an outer tank. Raw water in the outer tank would then flow by gravity to the downstream pump station forebay. This configuration is much more effective at maintaining positive pressures in the pipeline for the same size surge tank.

Both the traditional surge tank and “standpipe with weir” configurations were evaluated in the computer surge model, and hydro-pneumatic surge tanks were sized for both configurations. Due to the fact that the “standpipe with weir” configuration resulted in much smaller hydro-pneumatic tanks for some booster pump stations, only the results of these model runs are presented in this report.

4.4.4 Surge Model Results

The findings of the following surge model scenarios are presented in this report:

- Scenario 1 - Power Failure at Phase 1 Flows (Hydro-pneumatic Tanks Only)
- Scenario 2 - Power Failure at Phase 1 Flows (Hydro-pneumatic Tanks and Standpipes with Weir)
- Scenario 3 - Power Failure at Phase 4 Flows (Hydro-pneumatic Tanks and Standpipes with Weir)
- Scenario 4 - Pipeline Isolation Valve Actuation
- Scenario 5 - Pump Start

Figure 4-9 through Figure 4-24 show the results of the surge modeling analysis and includes the following information: pipeline profile (green line), steady state HGL (black line), minimum HGL (blue line), maximum HGL (red line), and air/vapor volume along the pipeline. Recommended hydro-pneumatic tank and surge tank volumes are provided in Tables 4-13 and 4-14. Figure 4-27 shows the system schematic including boundary conditions used for the Phase 4 surge modeling analysis along with the proposed tank recommendations.

4.4.4.1 Scenario 1 - Power Failure at Phase 1 Flows (Hydro-pneumatic Tanks Only)

Scenario 1 was used to evaluate the effects of a power failure with only hydro-pneumatic tanks at the pump stations and without any form of protection against negative pressures at system high points at the end of each major pipeline segment. Profile results for each major pipeline segment are shown in Figures 4-9 through 4-12, which indicate that the hydro-pneumatic tanks alone cannot reduce negative pressures. Figure 4-12 shows that full vacuum pressure occurs on the hill just upstream of the NCWTP.

4.4.4.2 Scenario 2 - Power Failure at Phase 1 Flows (Hydro-pneumatic Tanks and Standpipes with Weir)

Scenario 2 was used to evaluate the effects of a power failure with hydro-pneumatic tanks at the pump stations and with a “standpipe with weir” structure at the end of the pipelines (standpipe location varies on each pipeline segment from 300 m to 1,000 m upstream of the booster pump station). Profile results for each major pipeline segment are shown in Figures 4-13 through 4-16 which shows that positive pressures are maintained along each major

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pipeline segment during the simulation using the tank volumes provided in Tables 4-13 and Table 4-14.

4.4.4.3 Scenario 3 - Power Failure at Phase 4 Flows (Hydro-pneumatic Tanks and Standpipes with Weir)

Scenario 3 was used to evaluate the effects of a power failure at Phase 4 flows with hydro-pneumatic tanks and a "standpipe with weir" structure. Profile results for each major pipeline segment are shown in Figure 4-17 through 4-20 which shows that positive pressures are maintained along each major pipeline segment during the simulation using the tank volumes shown in Table 4-13 and 4-14.

Figures 4-25 and 4-27 show the flow and water level/pressure response at SP3-4, which is similar to each of the standpipe/weir structures. The pumps are shut down at t=5 seconds, and from t=5 seconds to t=13 seconds, a constant flow continues to spill over the weir until the low pressure wave arrives at the tank, at which point the flow starts to decrease over the weir. At t=45 seconds, the water level drops below the weir (310.5 meters) and drops nearly to the bottom of the tank at 303.5 meters and back up to 309 meters over the course of approximately 3-4 minutes.

Scenario 3 also revealed an acute sensitivity to the diameter and length of the hydro-pneumatic tank manifold which if sized too small results in a down surge that causes negative pressures at the end of the pipelines even with the proposed standpipe. Based on a design of one spherical tank per transmission main (two tanks total), the manifold was sized with a diameter of 2.6-m and length of 12-m (minimum).

4.4.4.4 Scenario 4 - Pipeline Isolation Valve Actuation

Large isolation valves are part of the NCRWS system and are designed to be closed in the event of a pipeline break. CH2M HILL modeled this case and determined that the isolation valves could be closed over time period of not less than 120 seconds if parallel pipelines are kept in service during the closure. The operational limits of the isolation valves should be verified through consultation with the valve and control manufacturers.

In order to open an isolation valve, bypass valves should be installed around the large diameter isolation valves to equalize pressure across the isolation valve before opening.

4.4.4.5 Scenario 5 - Pump Start

It is a best practice to check the recommended solution against other surge scenarios such as a pump start. For the pump start case, a single pump came up to speed over a 20 second interval. Figures 4-21 through 4-24 shows the modeling results of a single pump start at the IPS and BPS 2, 3, and 4. No negative effects were found in this analysis and the pressures created were well within the design criteria.

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FIGURE 4-9
Surge Model Scenario 1 – IPS1 to BPS2 (Hydro-pneumatic Tanks Only at Phase 1 Flows)
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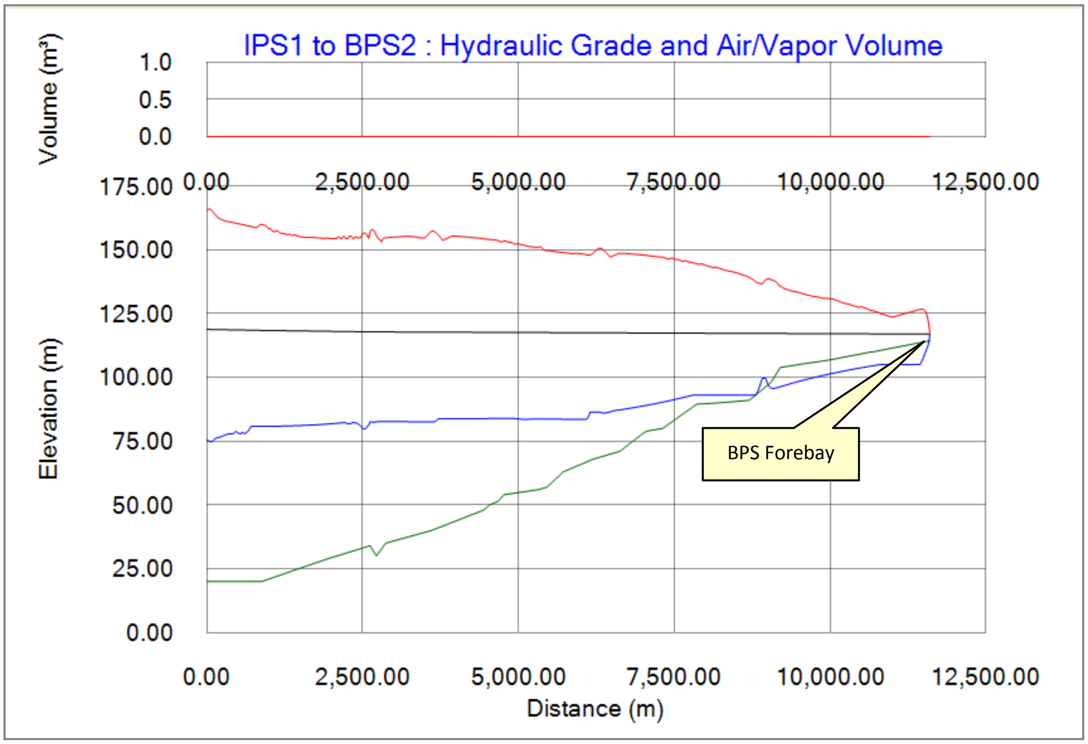

FIGURE 4-10
Surge Model Scenario 1 – BPS2 to BPS3 (Hydro-pneumatic Tanks Only at Phase 1 Flows)
New Cairo Raw Water System Hydraulic Modeling Study

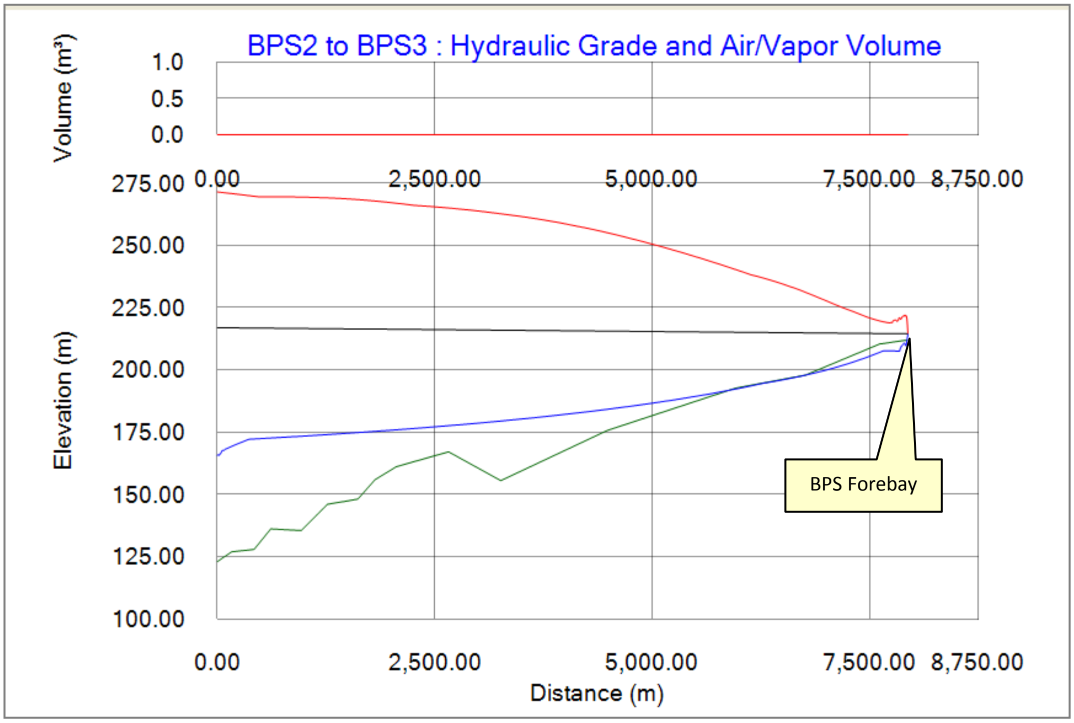

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FIGURE 4-11
Surge Model Scenario 1 – BPS3 to BPS4 (Hydro-pneumatic Tanks Only at Phase 1 Flows)
New Cairo Raw Water System Hydraulic Modeling Study

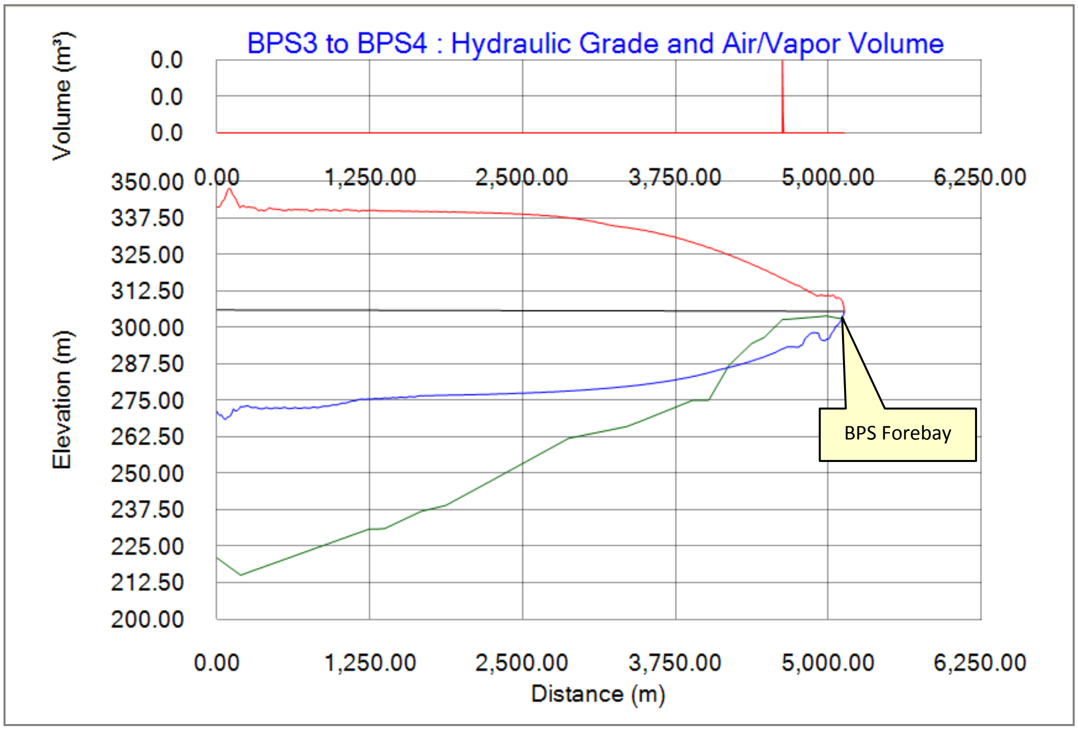

FIGURE 4-12
Surge Model Scenario 1 – BPS4 to NCWTP (Hydro-pneumatic Tanks Only at Phase 1 Flows)
New Cairo Raw Water System Hydraulic Modeling Study

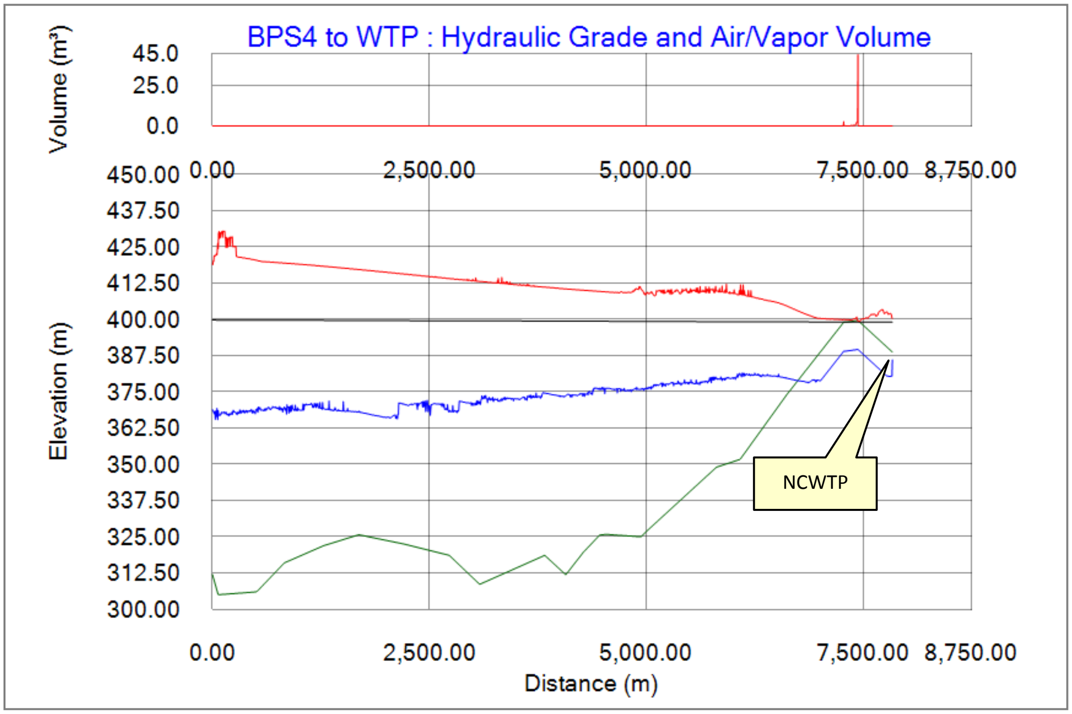

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FIGURE 4-13
Surge Model Scenario 2 – IPS1 to BPS2 (Hydro-pneumatic Tanks and Standpipe/Weir at Phase 1 Flows)
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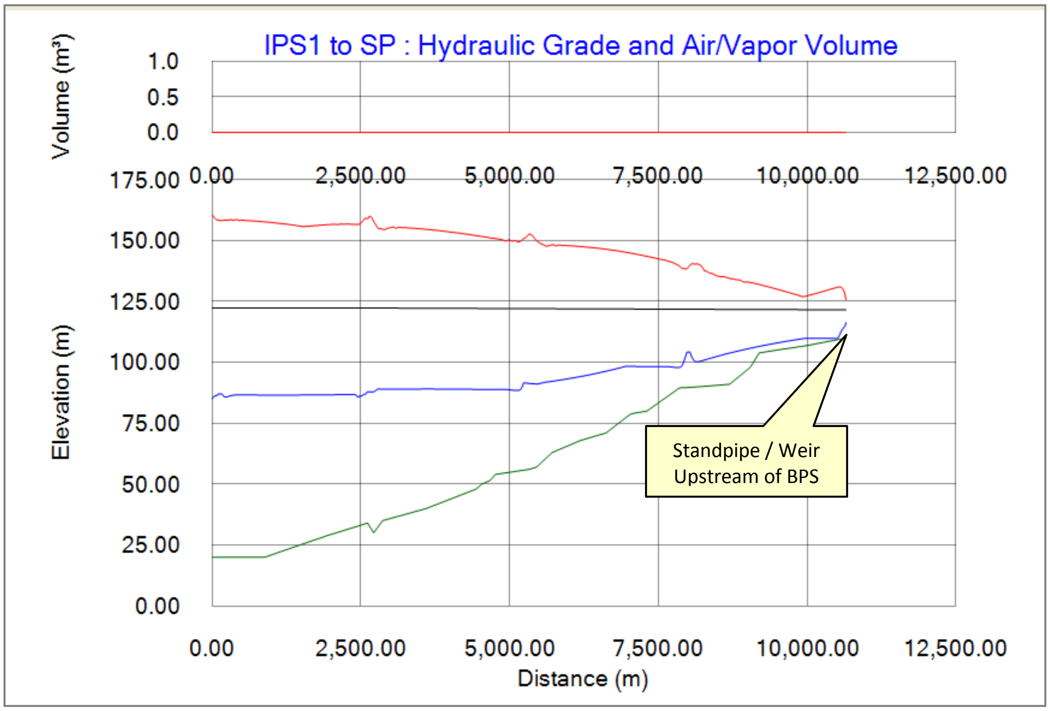

Standpipe / Weir Upstream of BPS

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FIGURE 4-14
Surge Model Scenario 2 – BPS2 to BPS3 (Hydro-pneumatic Tanks and Standpipe/Weir at Phase 1 Flows)
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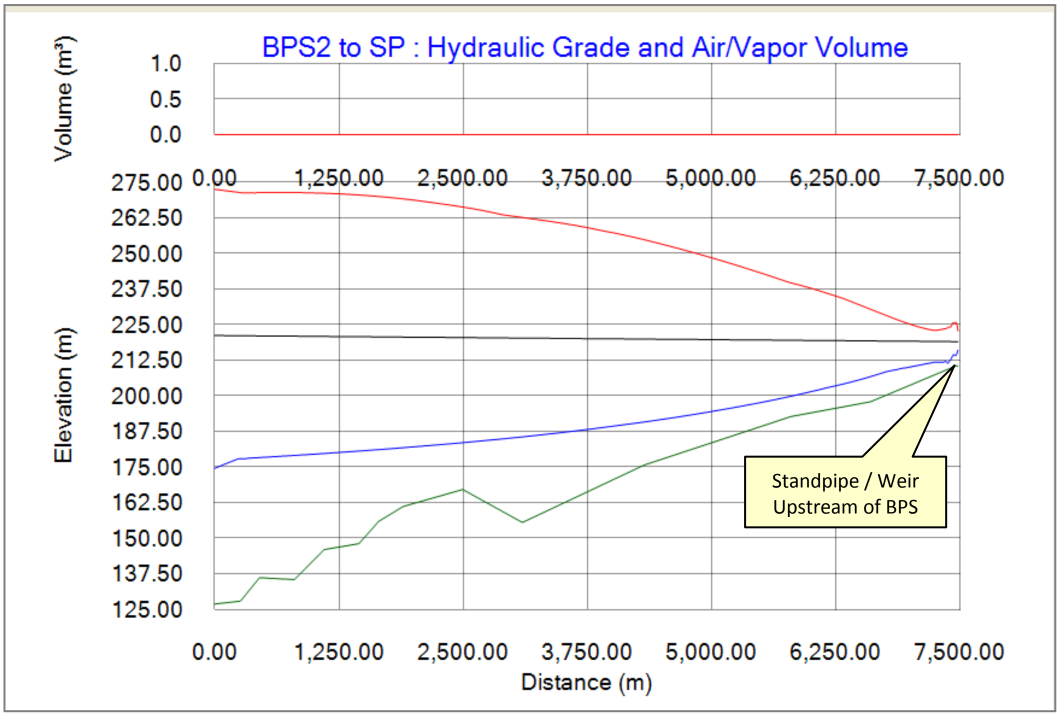

FIGURE 4-15
Surge Model Scenario 2 – BPS3 to BPS4 (Hydro-pneumatic Tanks and Standpipe/Weir at Phase 1 Flows)
New Cairo Raw Water System Hydraulic Modeling Study

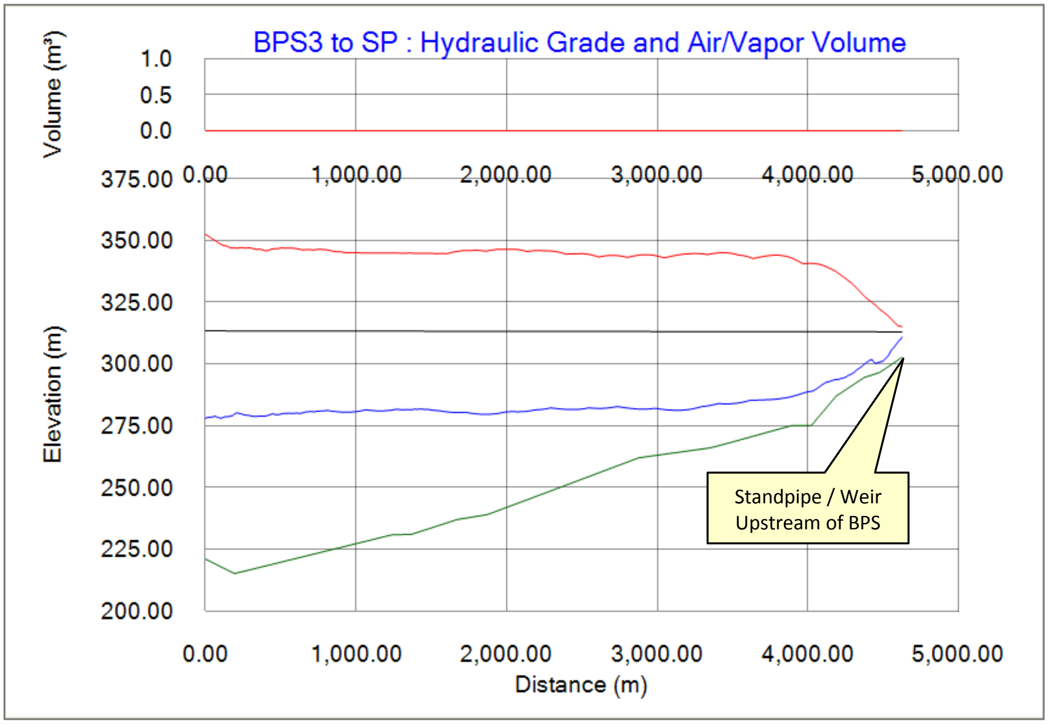

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FIGURE 4-16
Surge Model Scenario 2 – BPS4 to NCWTP (Hydro-pneumatic Tanks and Standpipe/Weir at Phase 1 Flows)
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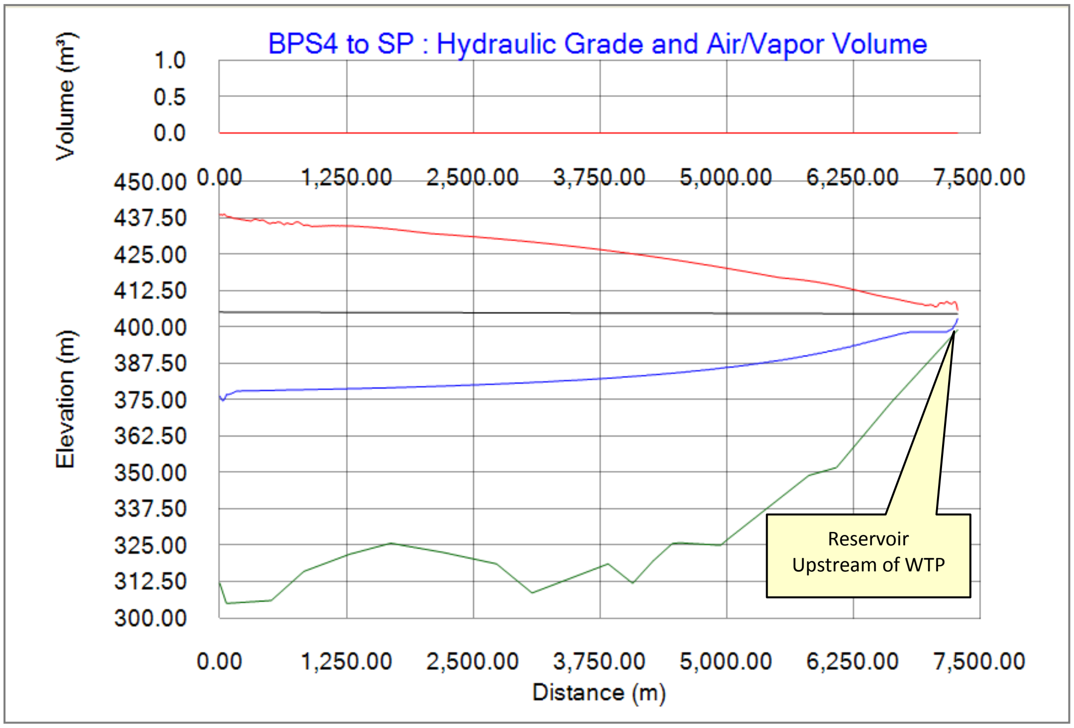

FIGURE 4-17
Surge Model Scenario 3 – IPS to BPS2 (Hydro-pneumatic Tanks and Standpipe/Weir at Phase 4 Flows)
New Cairo Raw Water System Hydraulic Modeling Study

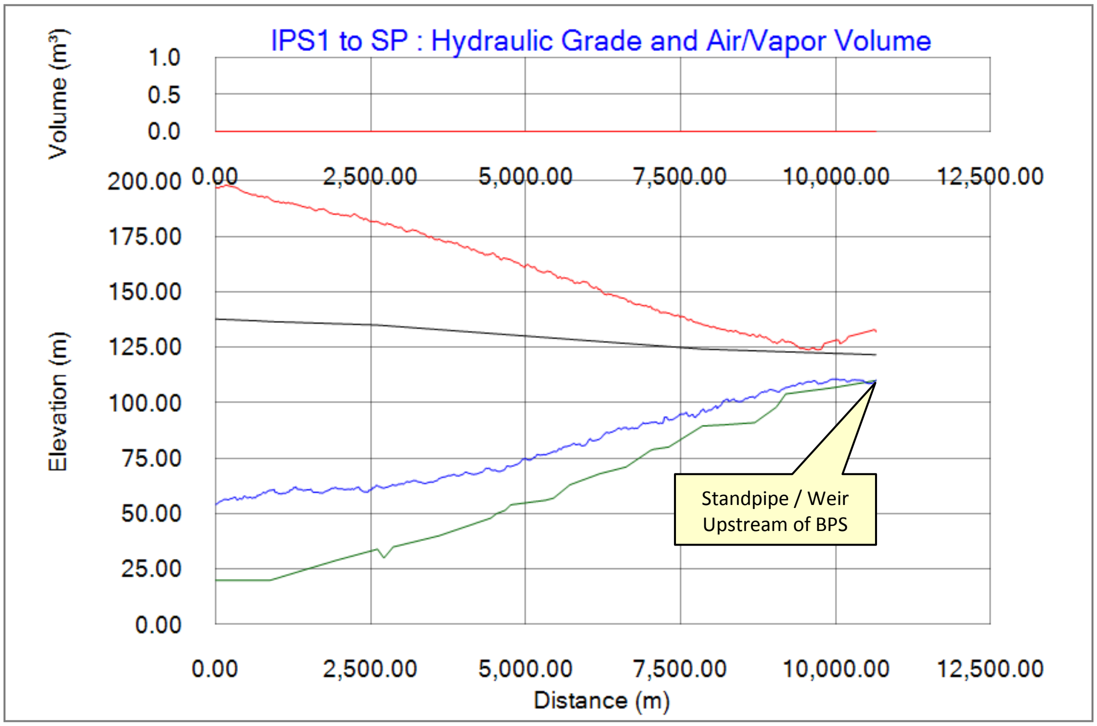

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FIGURE 4-18
Surge Model Scenario 3 – BPS2 to BPS3 (Hydro-pneumatic Tanks and Standpipe/Weir at Phase 4 Flows)
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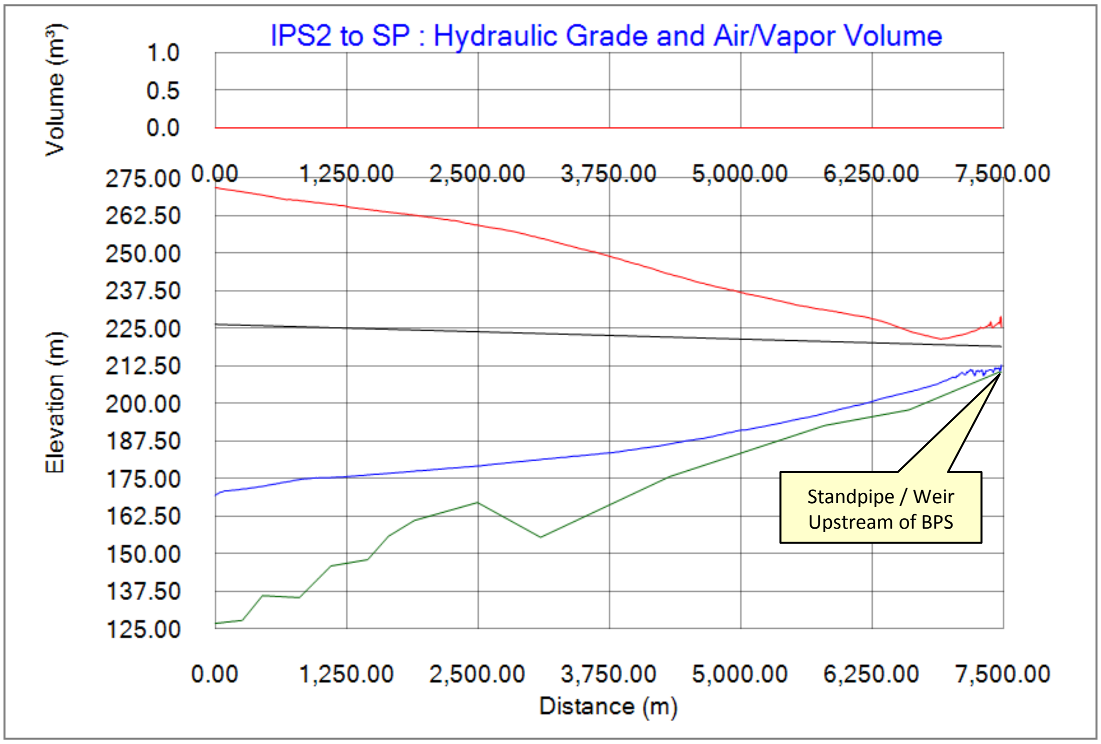

FIGURE 4-19
Surge Model Scenario 3 – BPS3 to BPS4 (Hydro-pneumatic Tanks and Standpipe/Weir at Phase 4 Flows)
New Cairo Raw Water System Hydraulic Modeling Study

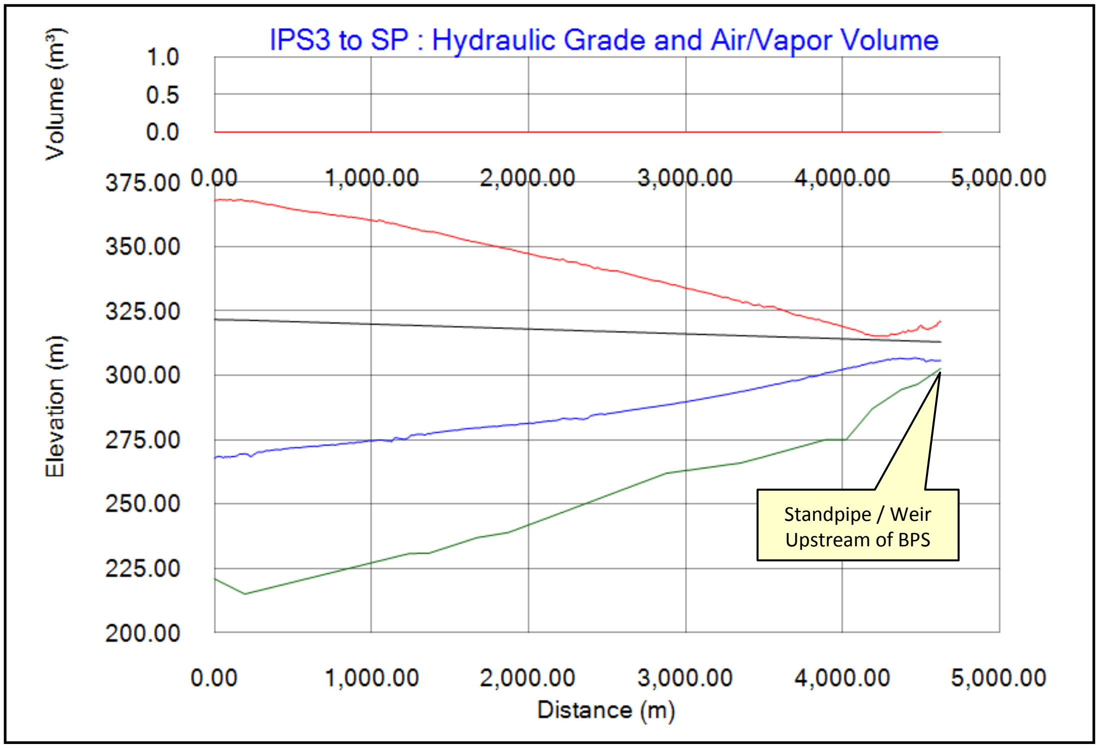

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FIGURE 4-20
Surge Model Scenario 3 – BPS4 to NCWTP (Hydro-pneumatic Tanks and Standpipe/Weir at Phase 4 Flows)
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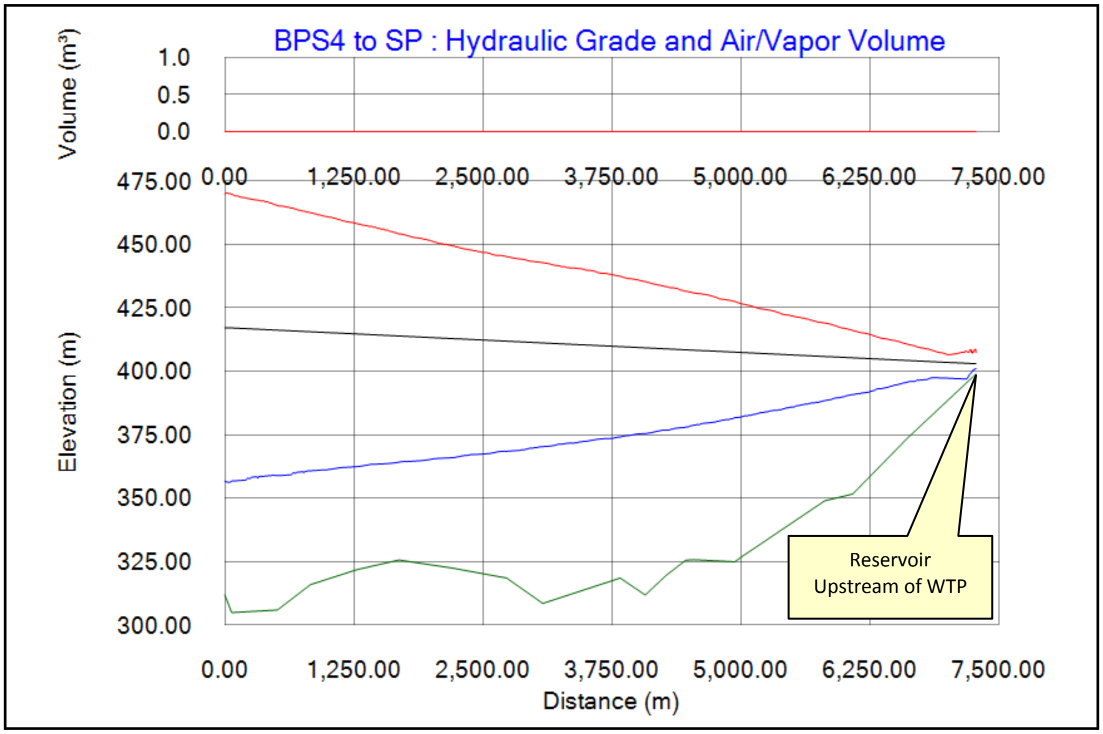

FIGURE 4-21
Surge Model Scenario 5 - Pump Start IPS1 to BPS2
New Cairo Raw Water System Hydraulic Modeling Study

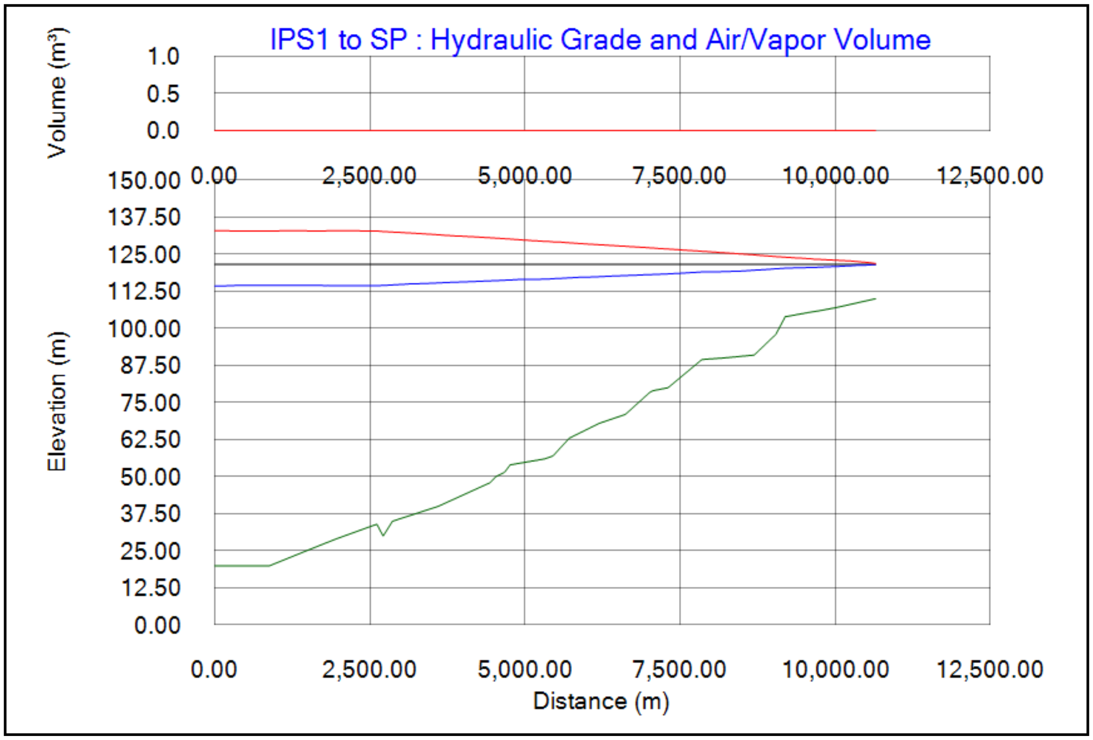

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FIGURE 4-22
Surge Model Scenario 5 - Pump Start BPS2 to BPS3
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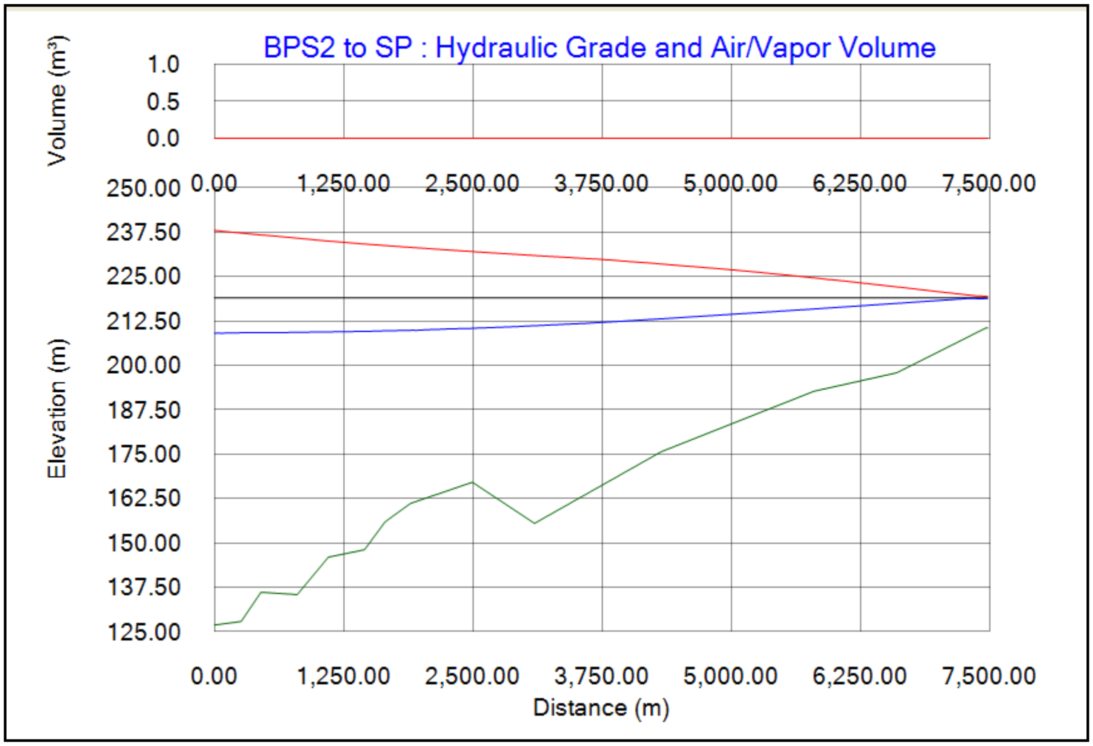

FIGURE 4-23
Surge Model Scenario 5 - Pump Start BPS3 to BPS4
New Cairo Raw Water System Hydraulic Modeling Study

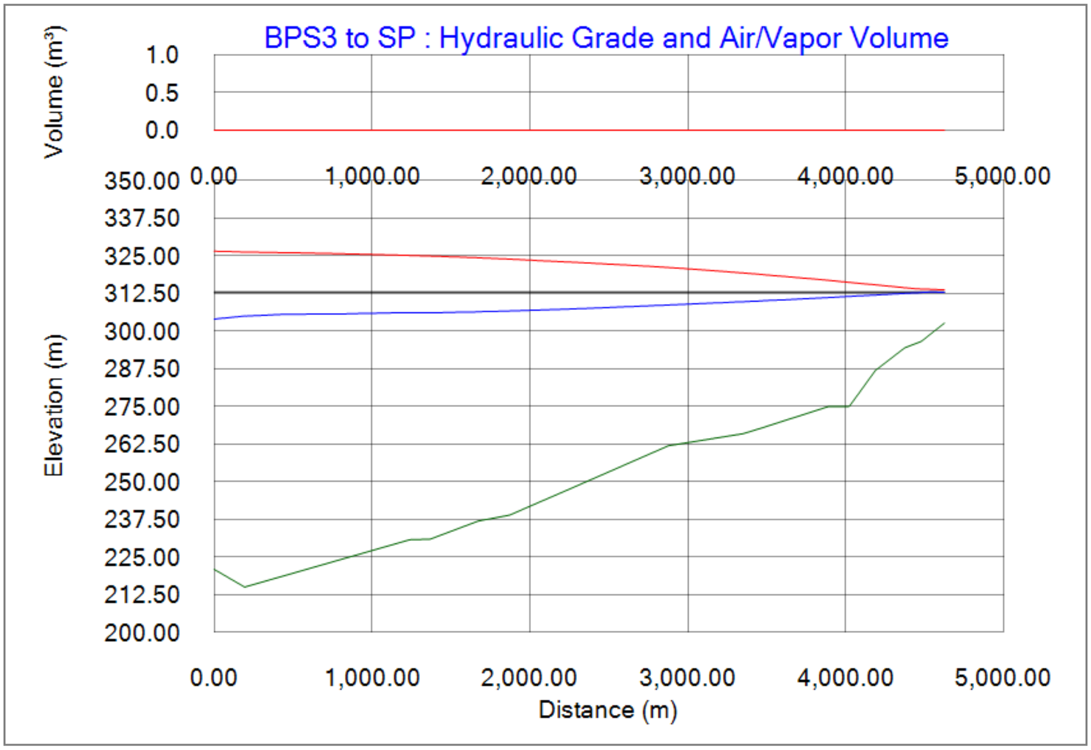

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FIGURE 4-24
Surge Model Scenario 5 - Pump Start BPS4 to WTP
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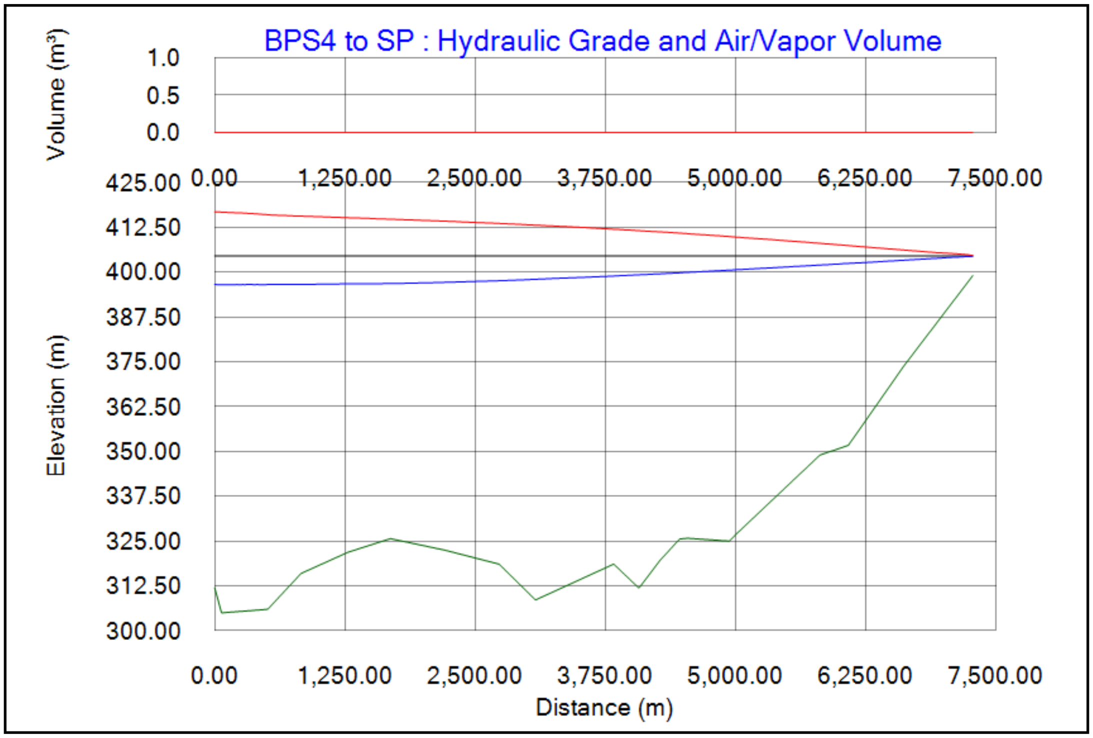

FIGURE 4-25
Flow and Water Level Variation in Standpipe #3-4 after Power Loss at BPS3
New Cairo Raw Water System Hydraulic Modeling Study

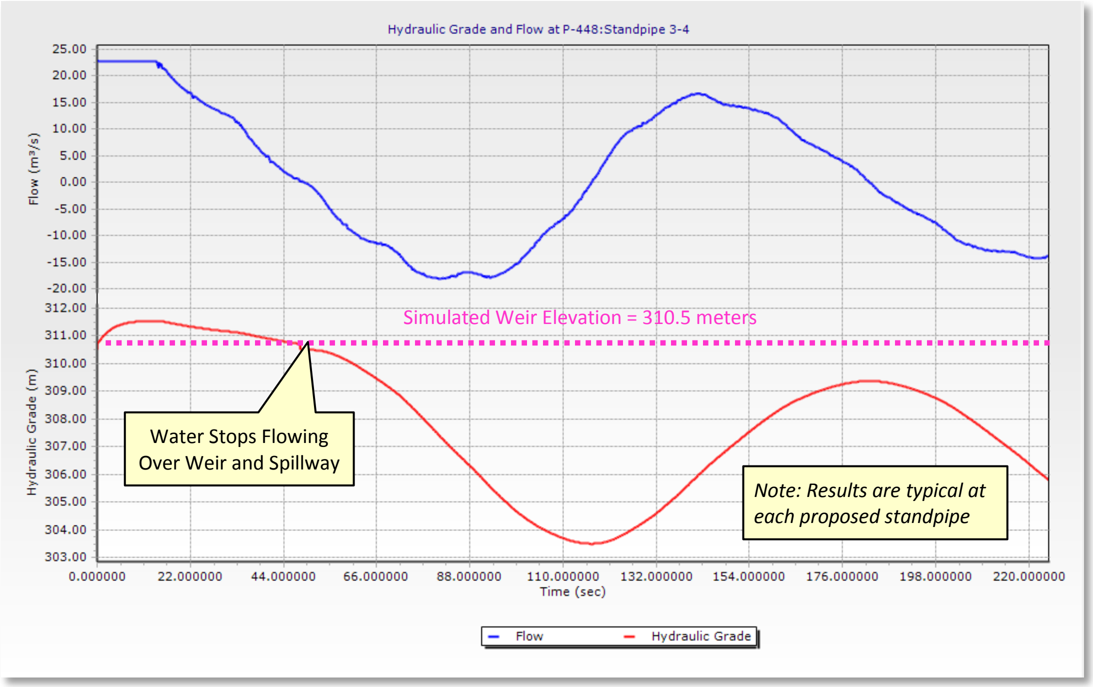

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FIGURE 4-26
Flow and Pressure Variation in Standpipe #3-4 after Power Loss at BPS3
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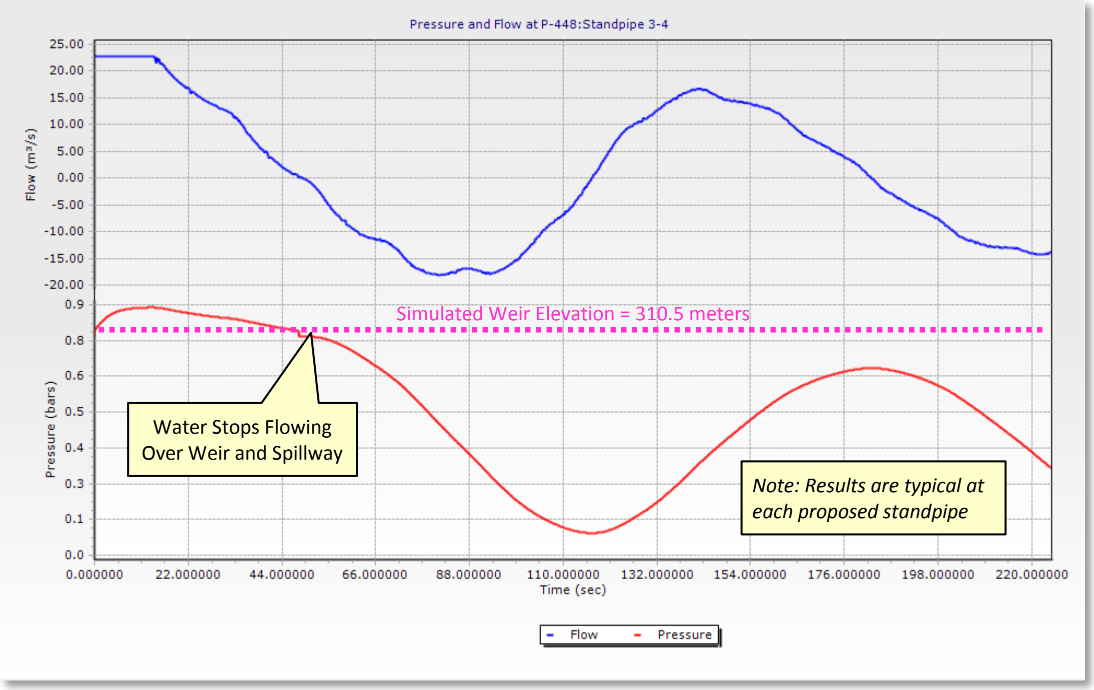

Simulated Weir Elevation = 310.5 meters

Water Stops Flowing Over Weir and Spillway

Note: Results are typical at each proposed standpipe

4.5 Surge Analysis Conclusions and Recommendations

CH2M HILL conducted a comprehensive study of surge conditions including power failure, pump starts, and valve actuation. The recommendations shown in Tables 4-13 and 4-14 and Figure 4-27 provide a robust surge control strategy for the NCRWS.

The following conclusions and recommendations are provided:

- Both hydro-pneumatic tanks and "standpipes with weir" structures are recommended for Phase 1 and Phase 4 conditions. This strategy maintains positive pressures along the entire length of pipeline under the power failure surge scenarios. Constructing the standpipes by Phase 1 negates the need to modify existing air release valve vaults or construct new combination air dissipation/air release valve (CAV) vaults at numerous locations in the NCRWS.
- Two large spherical hydro-pneumatic tanks (one on each header) provide an economical solution to satisfy Phase 4 surge conditions.
- Much smaller hydro-pneumatic tank volumes are required at Phase 1 if the proposed "standpipe with weir" structures are constructed. There is some flexibility in the configuration and number of hydro-pneumatic tanks for Phase 1: either a single or multiple numbers of small tanks can be constructed at Phase 1 with a much larger tank(s) by Phase 4, or one of the two recommended spherical tanks for Phase 4 can be constructed early by Phase 1.

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- The diameter and length of the hydro-pneumatic tank manifold is a critical design constraint. If the manifold is sized too small, the down surge following a power failure can result in negative pressures at the end of the pipeline even with the proposed standpipe solution. For this reason, the hydro-pneumatic tank manifold was sized at 2.6-m and minimum length of 12-m for Phase 4 design conditions which results in relatively low peak velocities. Careful attention should be paid to this issue during detailed design of the final configuration including tank port, tank manifold losses and dissipation of energy during the upsurge event, and pump check valve closure during a surge event.
- In the event that the "standpipe with weir" recommendation is not implemented, a traditional surge tank (standpipe) can be constructed in its place. However, the required volume will in some cases be much larger than the "standpipe with weir" internal tank volume shown in Table 4-14. Additionally, the traditional surge tank configuration will result in larger hydro-pneumatic tank volumes at some of the booster pump stations.

TABLE 4-13
CH2M HILL Hydro-Pneumatic Tank Recommendations (When Used in Conjunction with Standpipe/Weir)
New Cairo Raw Water System Hydraulic Modeling Study

Segment	Phase	GRP Lines In Service	Total Volume Required	Proposed Tanks	Proposed Manifold Diameter
IPS TO BPS 2	1	2 of 3	330 m^3	See note	See note
	4	2 of 3	1600 m^3	8 @ 200 m^3	0.8 m each tank
BPS 2 TO BPS 3	1	2 of 2	350 m^3	See note	See note
	4	2 of 2	1300 m^3	2 @ 650 m^3	2.6 m each tank
BPS 3 TO BPS 4	1	2 of 3	35 m^3	See note	See note
	4	2 of 3	1500 m^3	2 @ 750 m^3	2.6 m each tank
BPS 4 TO WTP	1	2 of 3	290 m^3	See note	See note
	4	2 of 3	2100 m^3	2 @ 1050 m^3	2.6 m each tank

Note: Construct single or multiple small tanks at Phase 1 to satisfy total required volume or construct one of the two proposed Phase 4 tanks.

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FIGURE 4-27

Phase 4 Surge Model Boundary Conditions and Results

New Cairo Raw Water System Hydraulic Modeling Study

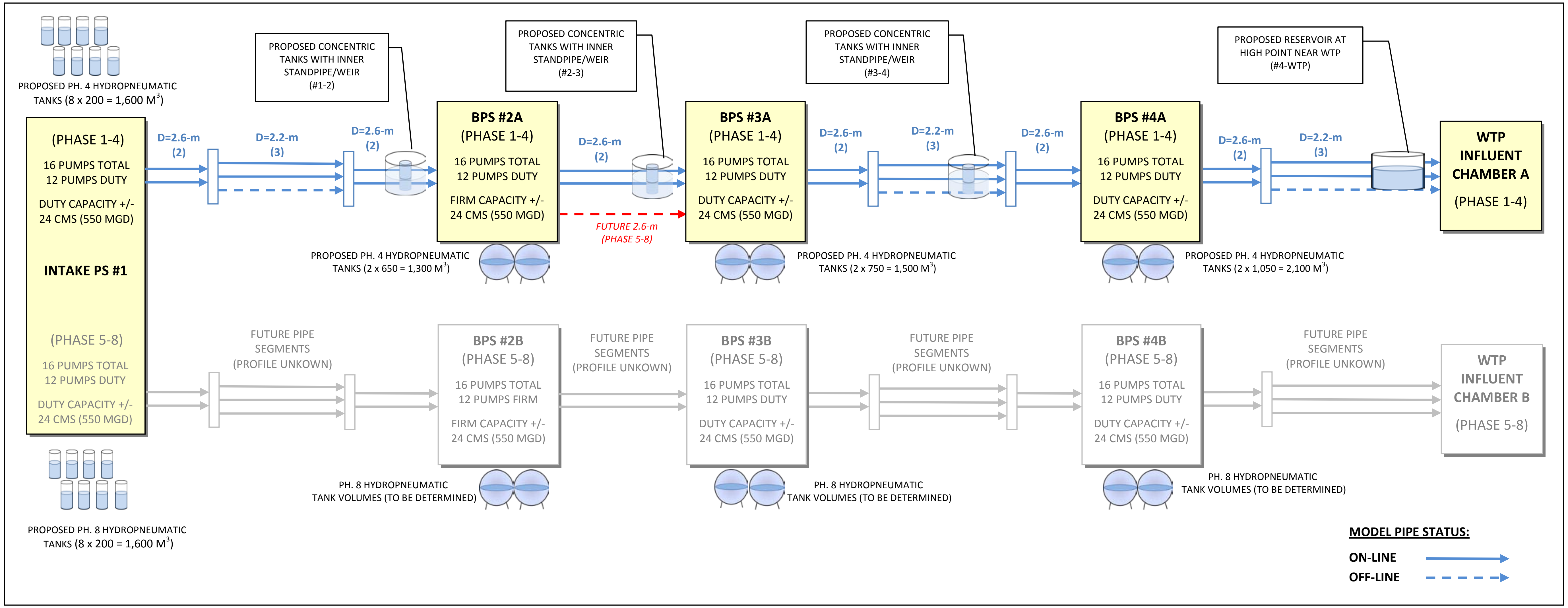

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TABLE 4-14
Standpipe/Weir (Surge Tank) Model Boundary Conditions
New Cairo Raw Water System Hydraulic Modeling Study

Tank #	Station #	Pipe Centerline Elevation (m)	Outer Storage Tank Volume (m^3)	Inner Surge Tank Volume (m^3)	Surge Tank Diameter (m)	Surge Tank Base Elev. (m)	Surge Tank Weir Elev. (m)	Surge Tank Height (m)	Total Number of Tank Inlet / Outlet Pipes
SP 1-2	8+050	110+/-	Note 1	1,310	12	110 (Note 3)	122.1	12.1	4
SP 2-3	7+190	210.5	Note 1	1,240	14	211 (Note 3)	219.5	8.5	4
SP 3-4	4+250	302.7	Note 1	1,140	12	303 (Note 3)	310.5	7.5	6
SP 4-WTP	7+000	399	Note 1	7,850 (Note 2)	50 (Note 2)	399 (Note 3)	404	5	6

Notes:
1. Outer storage tank volume dependent on local site constraints with approximate goal of 20,000 m^3 (minimum)
2. Actual dimensions and volume of SP “4-WTP” is dependent on WTP process/equalization requirements and off-peak pumping goals (to be determined)
3. Inner surge tank base elevation dependent on local site constraints and is not critical to design

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