

PSPP MANARA

ISRAEL

BASIC DESIGN

Power Water Way

Hydraulic Calculations

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Approved:	Nowotny	30.11.2020

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Abbreviations:

PSPP ...	Pump Storage Power Plant
PWW ...	Power Water Way
MOL...	Minimum Operation Level
FSL...	Full Supply Level
LC...	Load Case

REVISION NUMBER

- 1.0 First edition
- 2.0 Approved by Ellomay
- 2.1 Canceled word bifurcation and changed word units to unit in chapters 2.8 and 3.
- 3.0 Adaptation lower reservoir MOL level and small corrections

1 STATEMENT OF OBJECTIVE

The objectives of this report are the calculation of the hydraulic losses and the transients for the water hammer of the PSPP Manara (220 MW) power water way. The calculations are based on the basic design drawings which accompany this report. In the following Figure the longitudinal section of the power water way is shown.

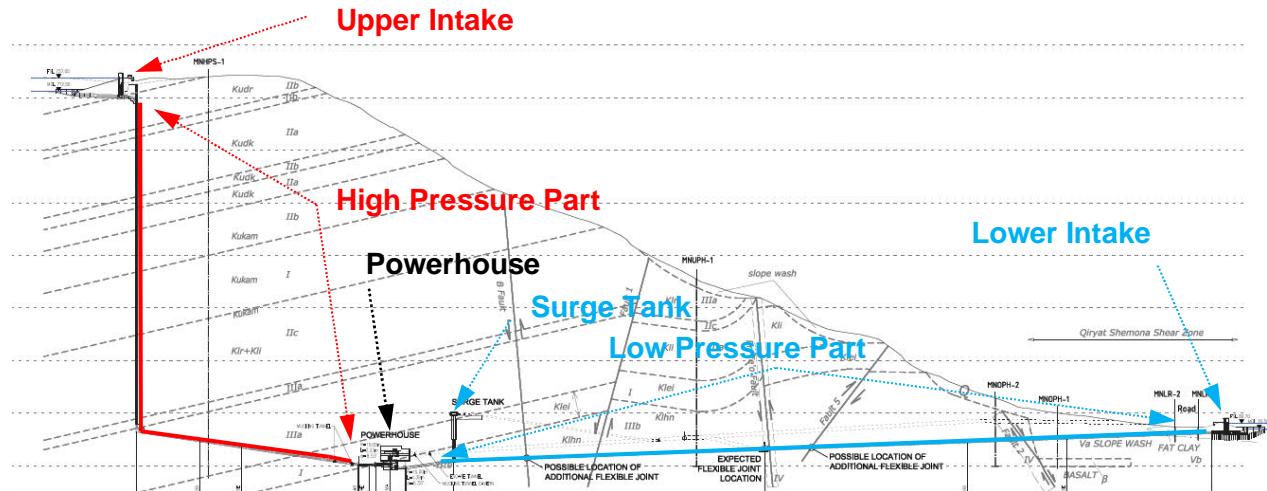


Figure 1-1: Longitudinal section PWW

2 BASIC DATA

2.1 Software and literature

Software

The calculations for the Hydraulic losses are calculated using the Program AFT Impulse 4.0, developed by Applied Flow Technology, Woodlandpark, USA

The transient calculations are calculated using the software Hammer V8i, developed by Bentley Corporation in 685 Stockton Drive Exton, PA 19341, USA.

Literature

G. Bollrich, technische Hydromechanik Band 1 – 5 Auflage, Verlag Bauwesen, Berlin 2000

I.E. Idelchik, Handbook of Hydraulic Resistance – 3rd Edition, CRC Press, Inc., N.W.: Boca Raton, Florida 1994

2.2 Reference drawings

The calculation is based on the following drawings:

MANARA/BD/CD/02/005 Upper Reservoir – Intake

MANARA/BD/CD/02/006 Upper Reservoir – Intake

MANARA/BD/CD/03/005 Lower Reservoir – Intake

MANARA/BD/CD/04/001 Power Water Way – Layout

MANARA/BD/CD/04/002 Power Water Way – Longitudinal Section

MANARA/BD/CD/04/003 Power Water Way – Surge Tank

2.3 Main project data

The calculation is based on the following main data:

	Value	Unit
Upper reservoir – Full supply level	737.0	masl
Upper reservoir – Minimal operation level	712.5	masl
Lower reservoir – Full supply level	80.7	masl
Lower reservoir – Minimal operation level	73.25	masl
Maximum gross head - H_{max}	666.5	m
Number of units	1	-
Rated discharge turbine mode $Q_{a,Turbine}$	36.6 (max.37.6)	m^3/s
Rated discharge pump mode $Q_{a,Pump}$	31.1 (max. 29.9)	m^3/s

Table 2-1: Main project data

2.4 Main input data for hydraulic loss calculation

The hydraulic friction losses are calculated based on the Prandtl-Colebrook formula, whereat the used absolute roughness values are summarized in the table below. The local losses are calculated based on the quadratic resistance law, whereat the used values are based on experience and values from literature.

	Value	Unit
Steel manifold	0.03	mm
Steel pressure tunnel	0.05	mm
Concrete tunnel	0.8	mm

Table 2-2: k-values for roughness

2.5 Main input data for transient calculation

For the wave speed in the power water way system the following values are used.

	Value	Unit
HP tunnel (Type A and B)	960	m/s
HP manifold (Type C)	1130	m/s
LP manifold (Type D)	940	m/s
LP tunnel (Type E)	630	m/s

Table 2-3: Wave speed for the power water way

2.6 Main unit data

The power unit for the PSPP Manara is a single stage Francis runner reversible pumpturbine with the following main data:

	Value
Type	reversible pumpturbine
Number of units	1
Runner speed (synchron)	750 min ⁻¹
Maximal power on shaft (Turbine mode / Pump mode)	212.6 / 220,9 MW
Max. discharge unit (Turbine mode / Pump mode)	37.4 / 30.9 m ³ /s
Stages	1
Specific runner speed (n_q)	31,2
Moment of inertia (Generator + Pump + Water)	288 t m ²
Closing law of valve	20 s (linear)
Opening law of valve	20 s (linear)

Table 2-4: Main unit data

Note:

The characteristic unit curve of the pumpturbine is based on projects with similar boundary conditions. The characteristic curves of pump turbines differ between the unit supplier. Therefore the results of the transient calculation of the different suppliers can vary in a range of some percent (experience of last projects). The final maximal pressure line has to be based on the unit curve of the final chosen pump turbine supplier. The measurement of the four quadrant curves related to the specific runner speed and the guide vane opening position will be evaluated during the model test and is the basis for the final transient calculation.

2.7 Switch over times required by IEC

In the following figure the required switching times by IEC are shown.

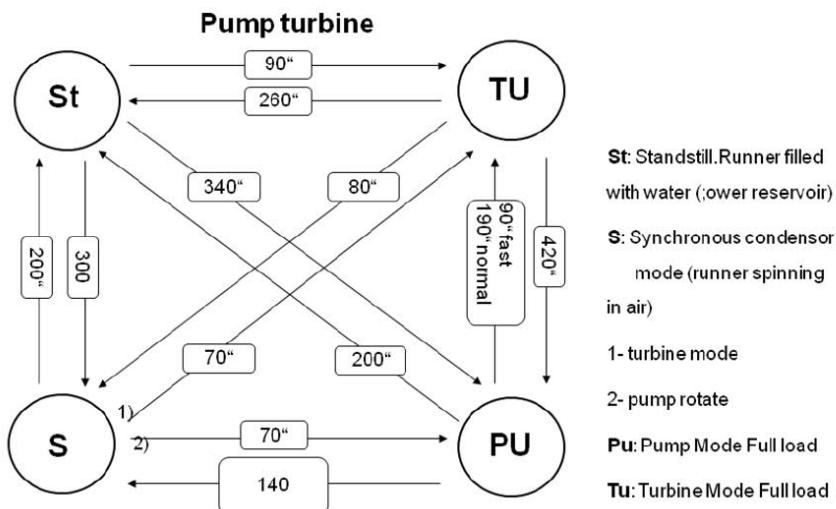


Figure 2-1: Mandatory switch-over times according to IEC

With the designed power water way system, the required switching times can be achieved.

2.8 Surge tank

To prevent the low pressure tunnel from water hammer effects during unit regulation and to improve the regulation of the pumpturbine itself, a throttled surge tank is situated downstream of the powerhouse. The throttle is situated after the junction where the surge tank is connected to the lower pressure tunnel. The throttle is designed as jet throttle with an inner diameter of $d = 2000$ mm as shown in the figure below. The final geometry and loss coefficient of the throttle has to be defined by the unit supplier considering the final characteristic of the pumpturbine.

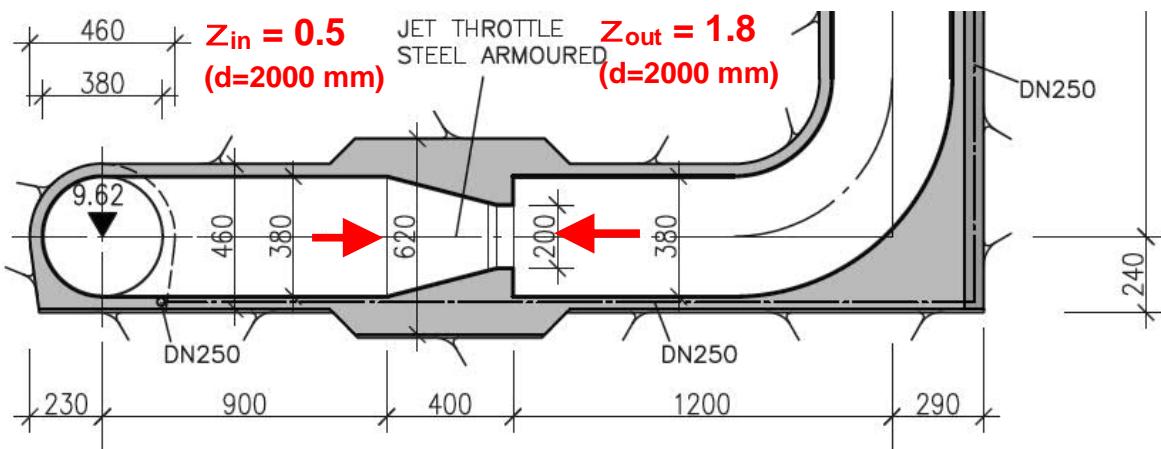


Figure 2-2: Throttle

From elevation 50 masl to the top of the surge tank with an elevation of 96.0 masl, the tank has a volume of 3325 m³. The volume / height ratio is shown in the diagram below.

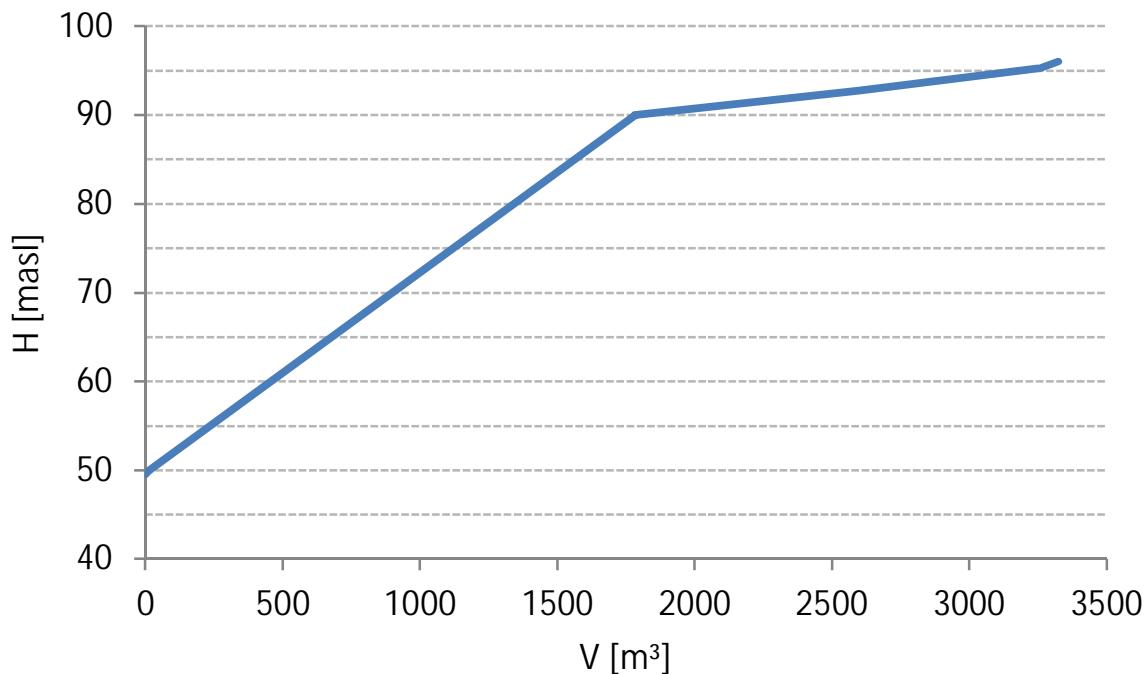


Figure 2-3: Surge tank - volume / height ratio

3 RESULTS OF HYDRAULIC LOSS CALCULATION

The hydraulic losses in the power water way can be summarized as follows.

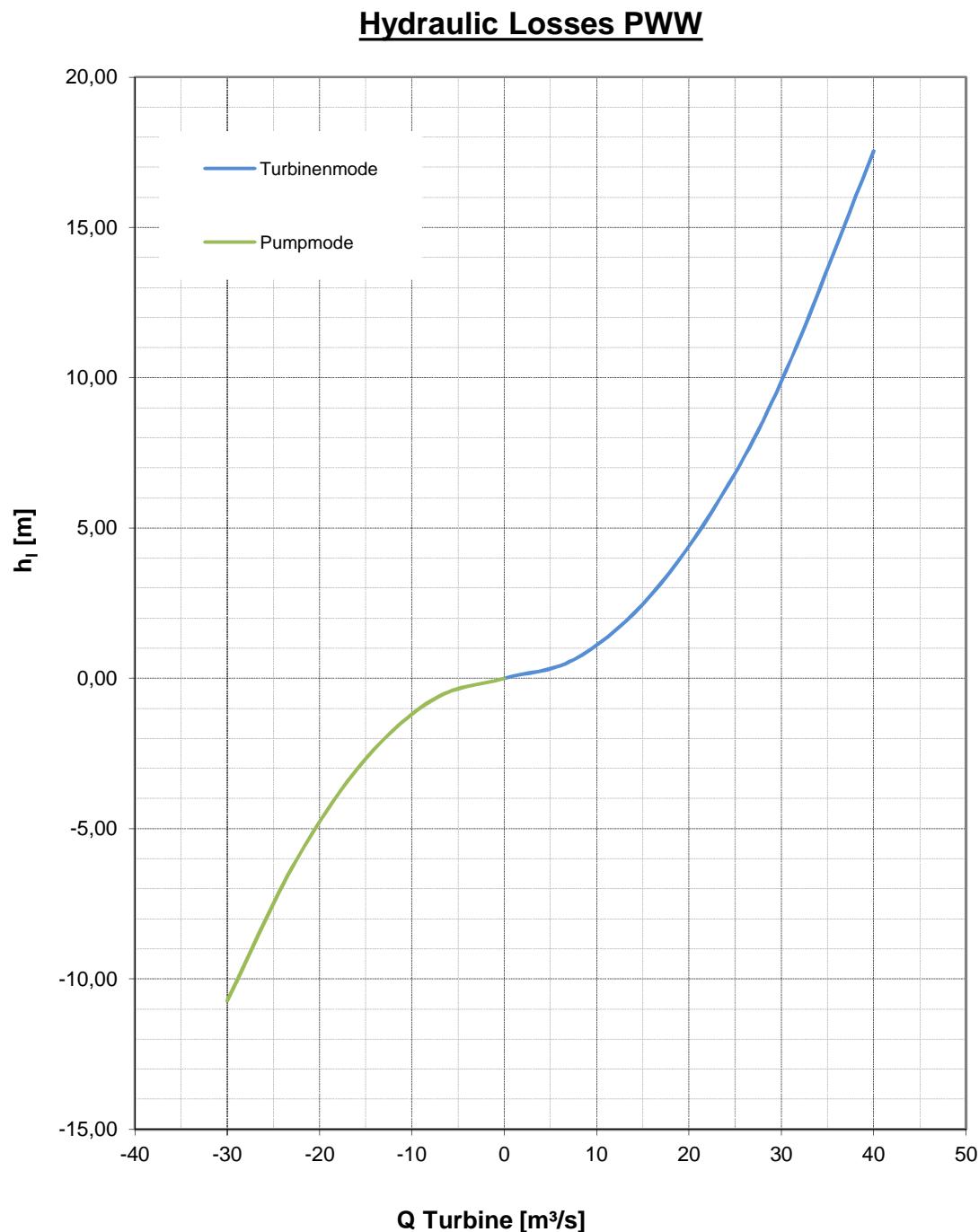


Figure 3-1: Hydraulic head losses of the PWW

The discharge on the x-axis is specified for one unit. The turbine mode is shown in blue and the pump mode is shown in green.

The losses can be given with the following quadratic equations:

$$\text{Pumpturbine in turbine mode: } h_{L,T} = 0.0109619 \times Q_{\text{Turbine}}^2$$

$$\text{Pumpturbine in pump mode: } h_{L,P} = 0.0119165 \times Q_{\text{Pump}}^2$$

Load Case	Q_r [m³/s]	h_L [m]	% of max. gross head *
Turbine mode	36.6	14.68	2.2 %
Pump mode	29.9	10.65	1.6 %

Table 3-1: Hydraulic head losses for the rated discharge Q_r

* ... 737.0 masl – 73.25 masl = 663.75 m

4 TRANSIENT CALCULATION

4.1 Load cases

The following Load Cases (LC) have been considered:

Turbine mode:

- LC 1a Controlled shut down of unit (Wicket gate closes in 20s)
- LC 1b Load rejection (Wicket gate closes in 20s)
- LC 1c Start of operation (Wicket gate opens in 20s)

Pump mode:

- LC 2a Controlled shut down of unit (Wicket gate closes in 20s)
- LC 2b Load rejection (Wicket gate closes in 20s)
- LC 2c Start of operation (Wicket gate opens in 20s)
- LC 2d Load rejection (Wicket gate does not close)

Change of operation mode:

- LC 3a Pump Mode → Turbine Mode in resonance of surge tank (max. upsurge)
- LC 3b Turbine Mode → Pump Mode in resonance of surge tank (min. downsurge)

The load cases are calculated for the following reservoir level combinations:

Upper reservoir FSL 736.8 masl and Lower Reservoir MOL 73.25 masl (Annex B)

Upper reservoir FSL 711.0 masl and Lower Reservoir MOL 80.70 masl (Annex C)

4.2 Results of transient calculation

In the table below the results of the transient calculation are summarized.

Load Case	UR FSL / LR MOL		UR MOL / LR FSL	
	max. pressure HP [masl]	max. pressure LP [masl]	max. pressure HP [masl]	max. pressure LP [masl]
LC 1a	784	85	761	92
LC 1b *	911	85	870	92
LC 1c	758	92	733	98
LC 2a	775	88	751	93
LC 2b	754	95	860	102
LC 2c	799	74	761	85
LC 2d **	-	-	736	102
LC 3a	-	-	752	99
LC 3b	800	77	-	-

Table 4-1: Results of transient calculation

UR... Upper Reservoir

LR... Lower Reservoir

HP... High Pressure

LP... Low Pressure

*... Maximal pressure high pressure part

**... Maximal pressure low pressure part

Maximal upsurge in low pressure surge tank: 93.1 masl

Minimal downsurge in low pressure surge tank: 57.5 masl

The envelope of the maximal and minimal pressure line in the power water way for all load cases is shown in the diagram below.

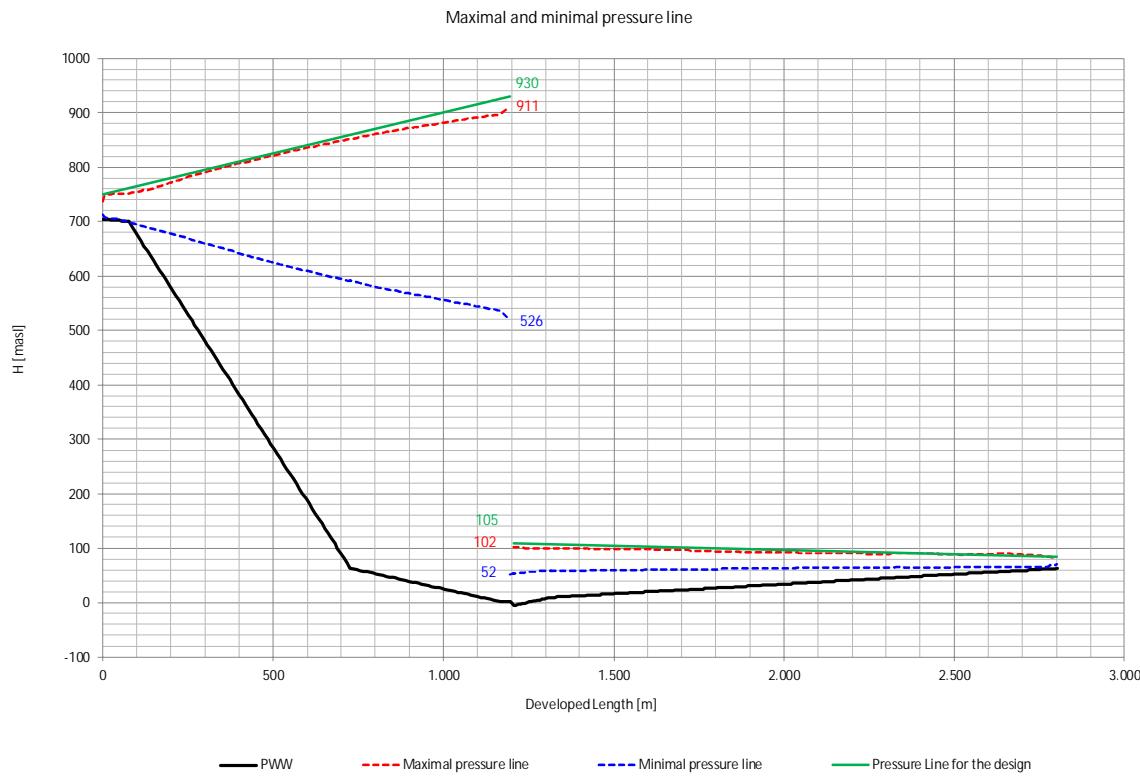


Figure 4-1: Envelope of maximal and minimal pressure line

The maximal pressure on the high pressure part occurs during load case (LC 1b) load rejection turbine mode. On the low pressure part the maximal pressure occurs during load case (LC 2d) load rejection pump mode.

No negative pressures occur in the calculated load cases along the whole power water way.

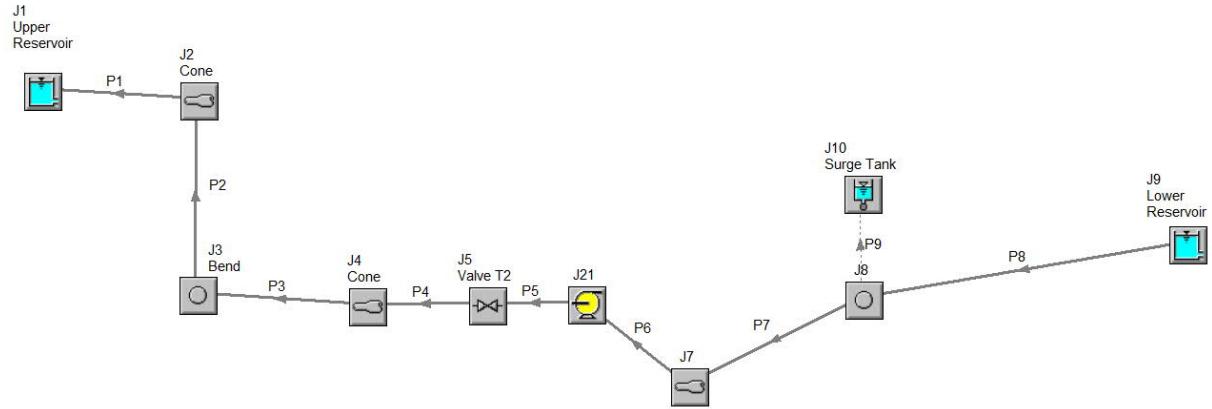
Maximal design pressure on the high pressure part: 930 masl

Maximal design pressure on the low pressure part: 105 masl

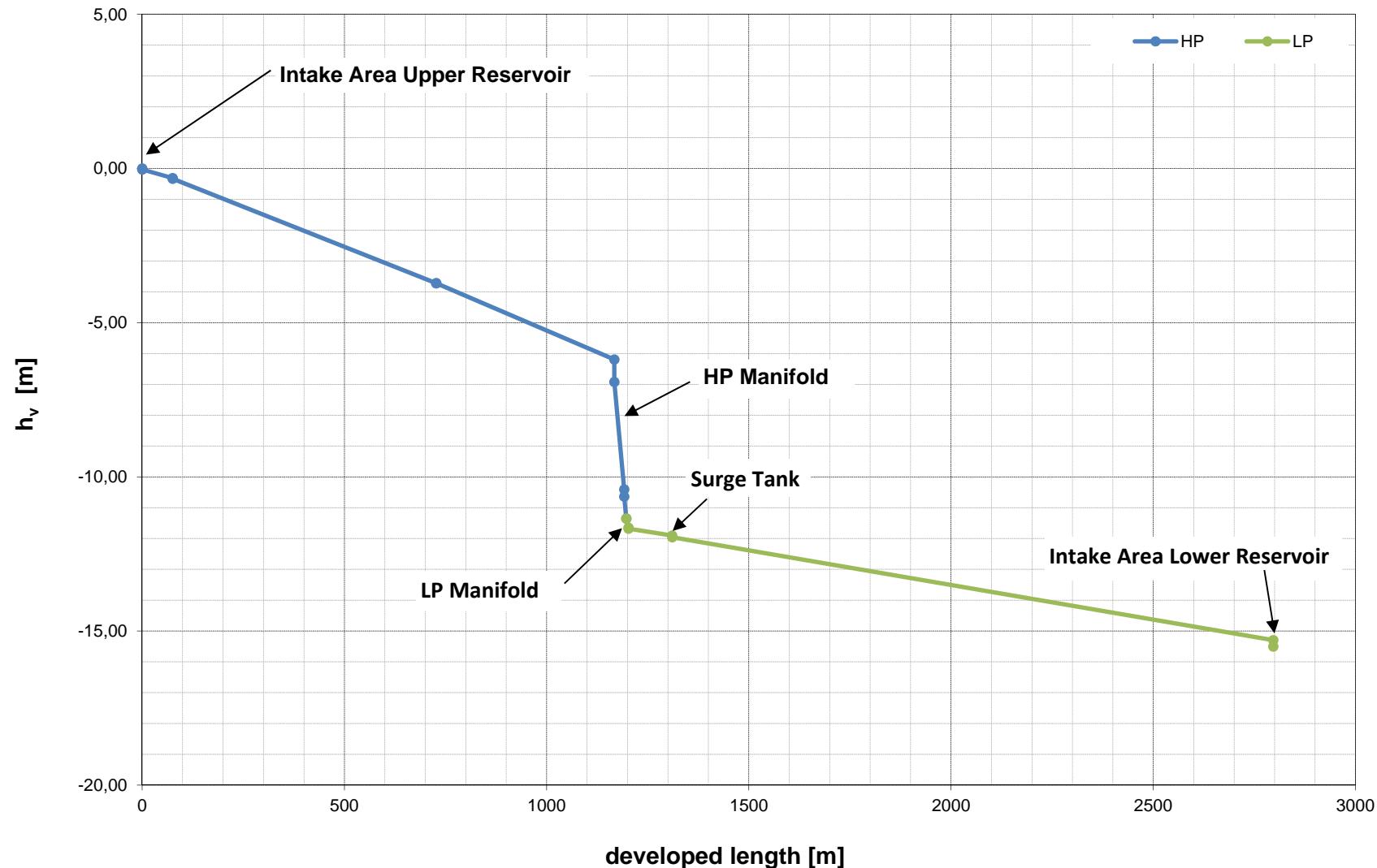
As mentioned in chapter 2.6 the calculation results depend on the characteristic of the pump turbine which is related to the unit supplier. Therefore the final maximal pressure line has to be based on the unit curve of the final chosen pump turbine supplier.

ANNEX A: HYDRAULIC LOSSES

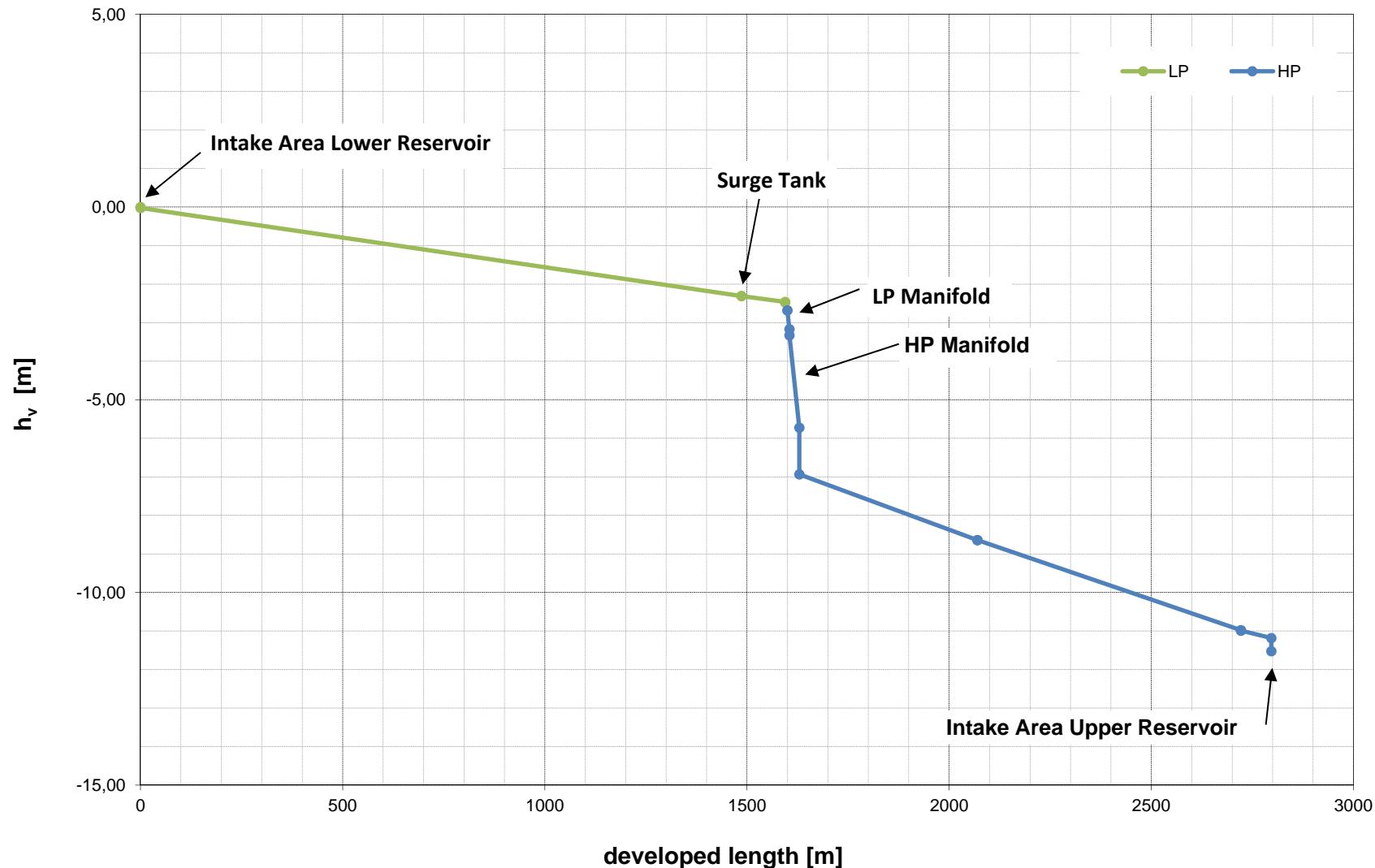
Model for the calculation of the hydraulic losses



Hydraulic losses Turbinemode Q = 1 x 37,6 m³/s



Hydraulic losses Pumpmode Q = 1 x 31,1 m³/s

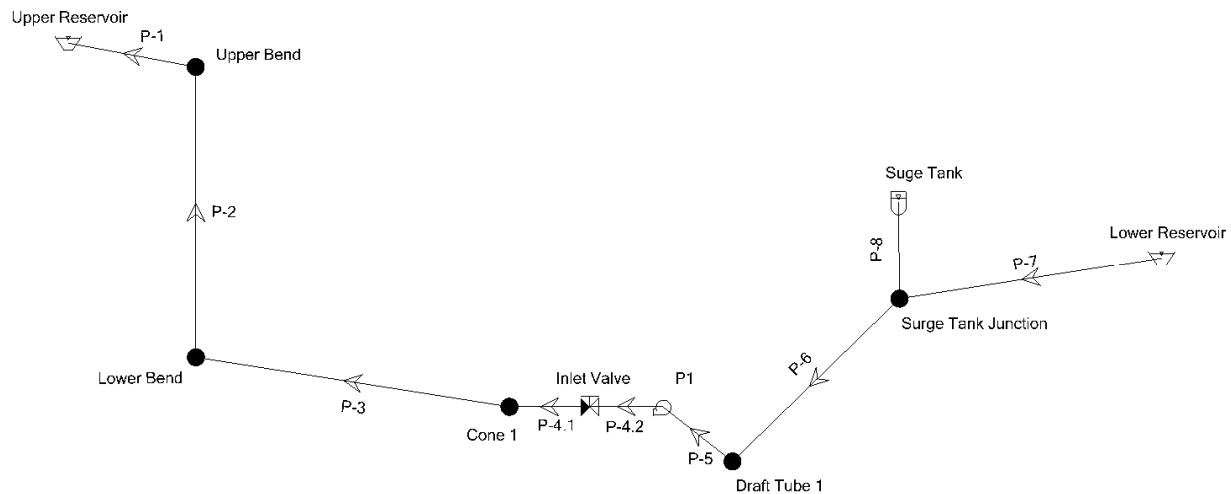


ANNEX B: TRANSIENT CALCULATION 1

Upper reservoir: FSL 737.00 masl

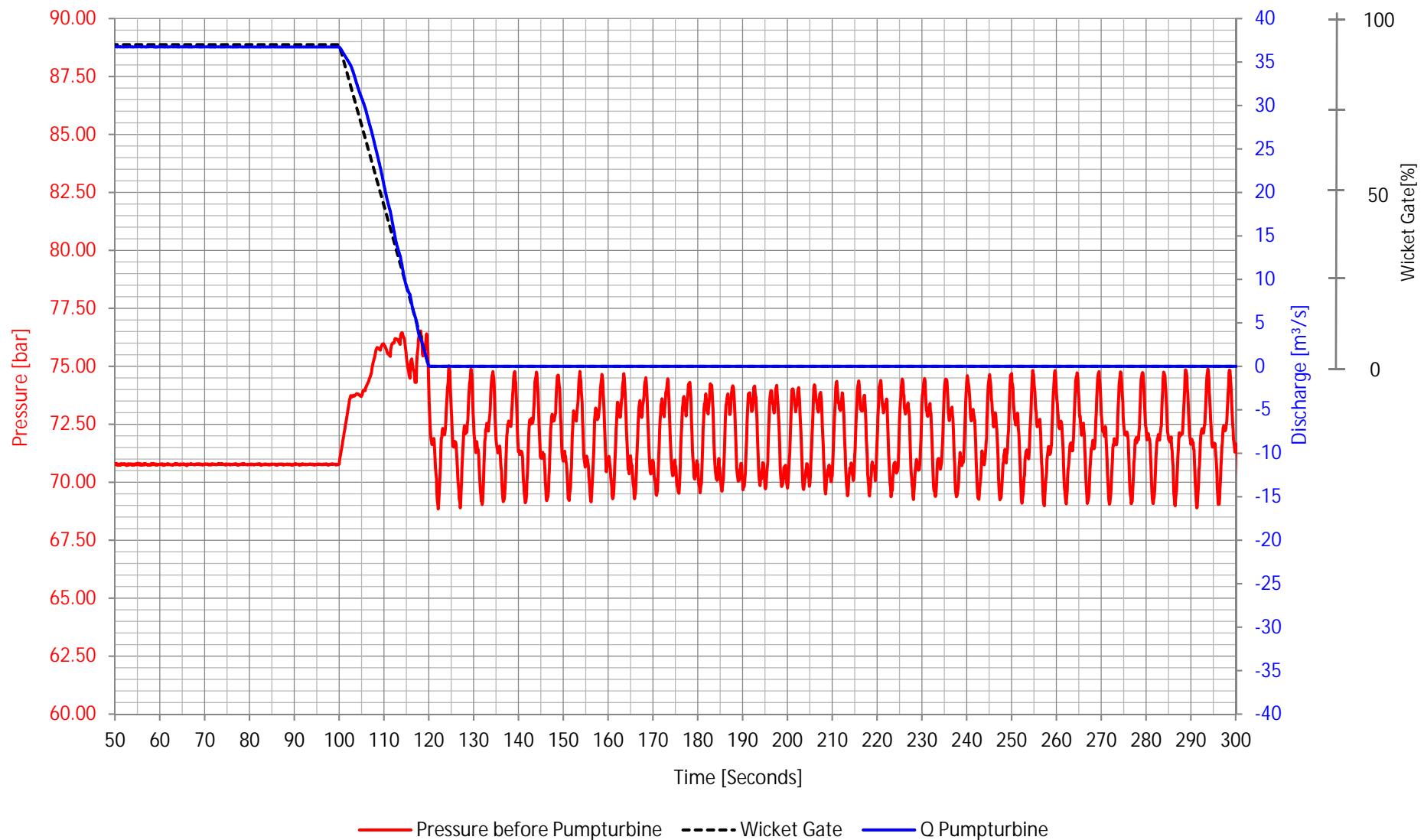
Lower reservoir: MOL 72.25 masl

Model for the transient calculation



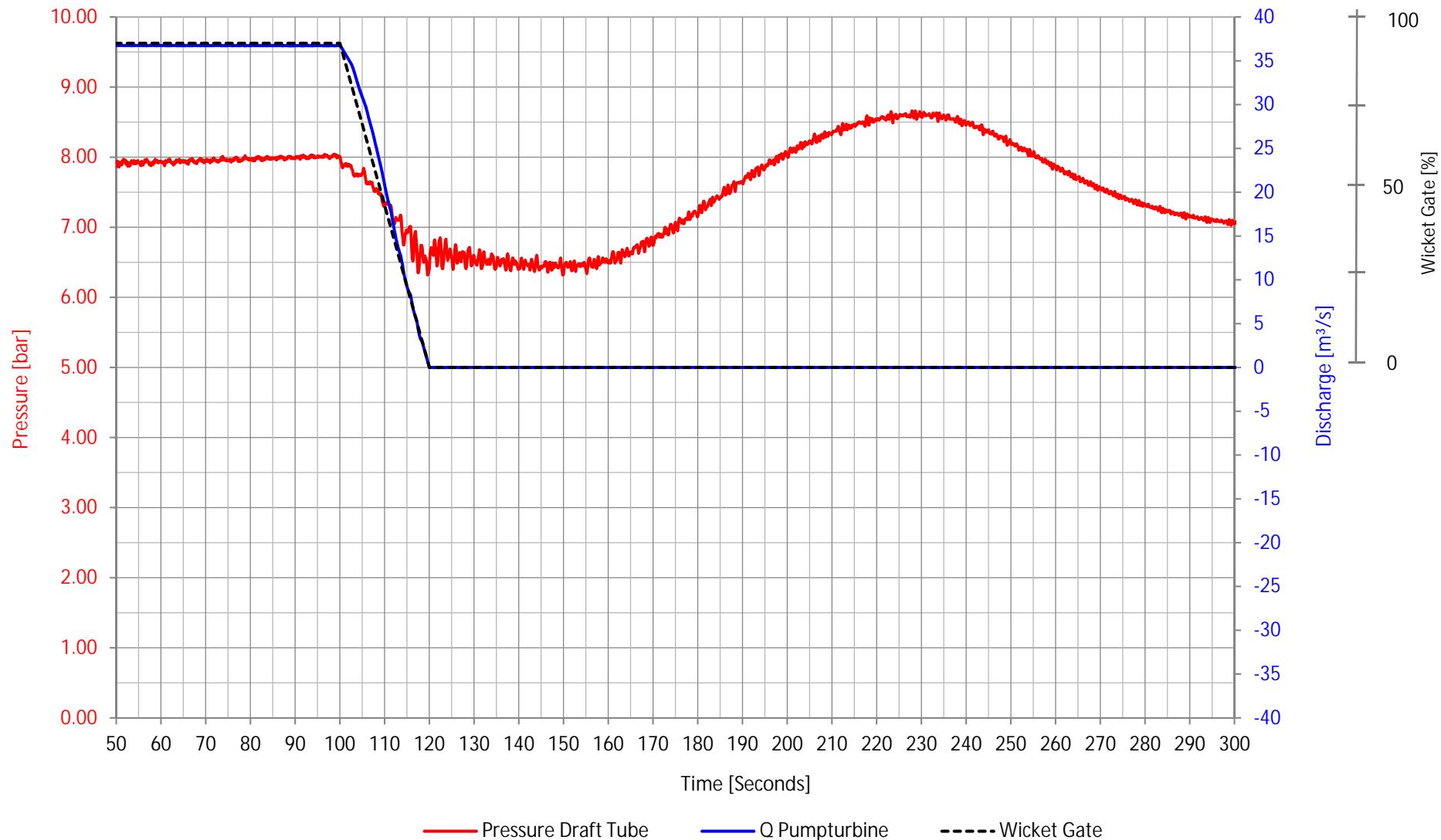
PSPP Manara 220 MW

Load Case 1a



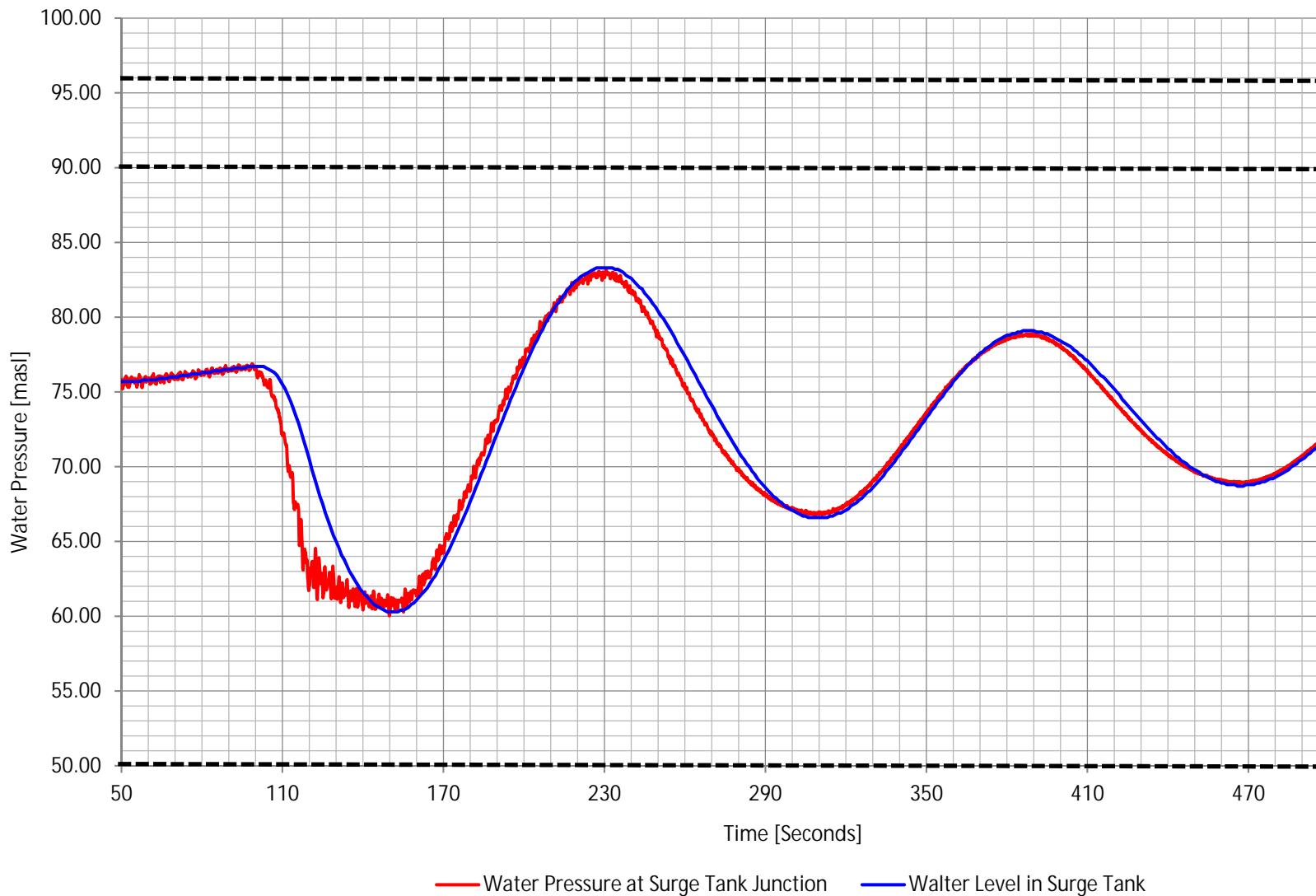
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Load Case 1a



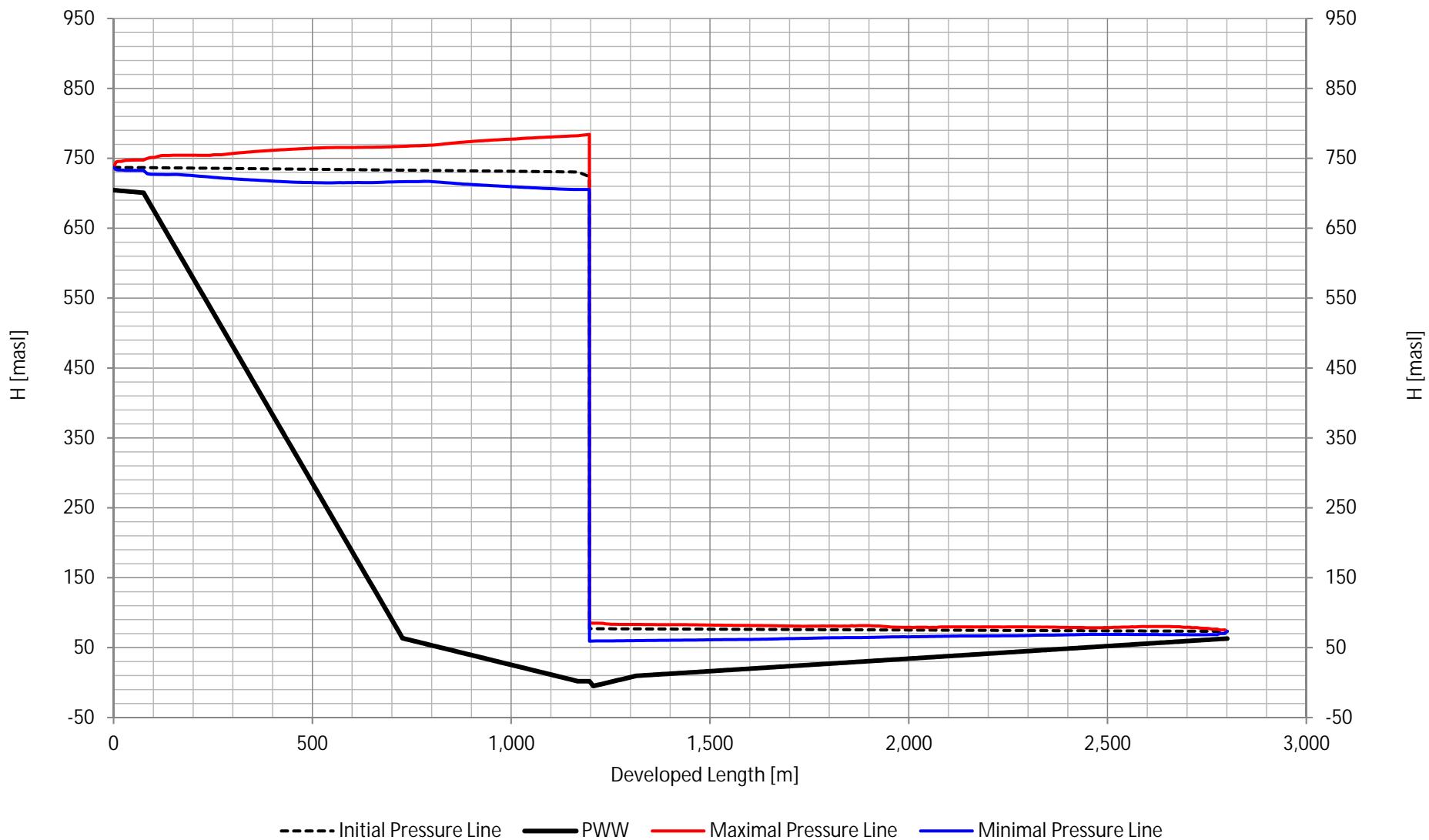
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Load Case 1a



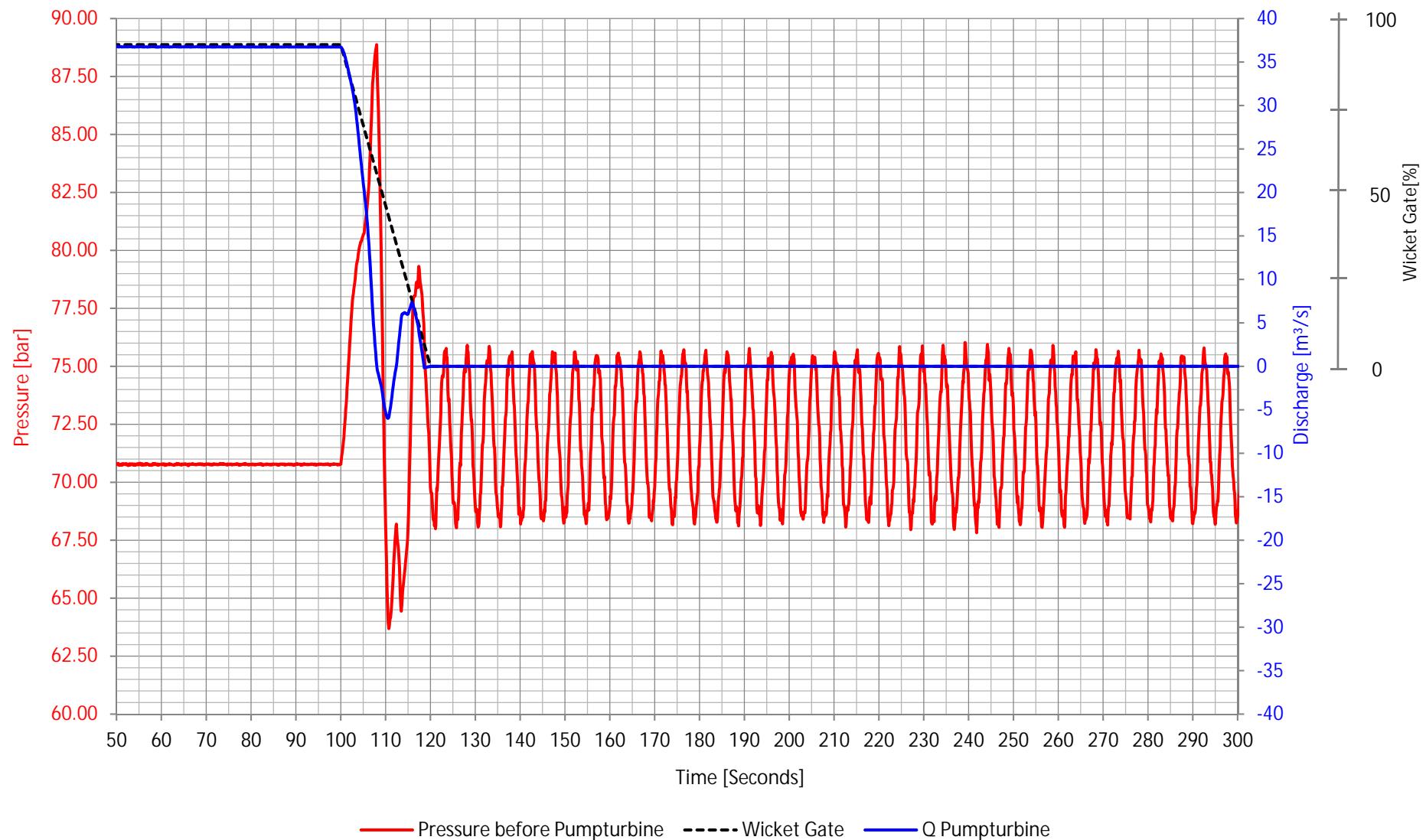
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Load Case 1a



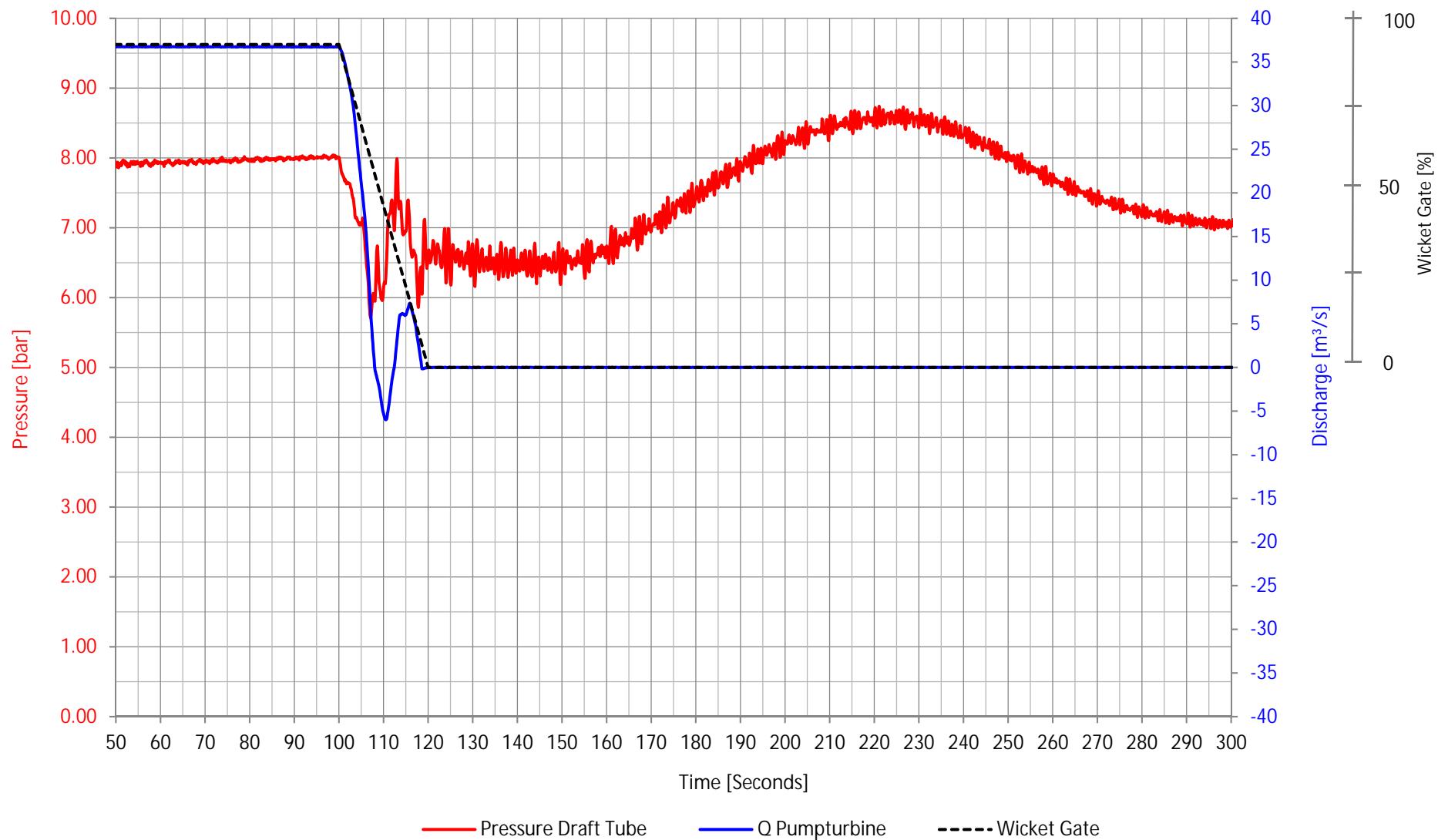
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Load Case 1b



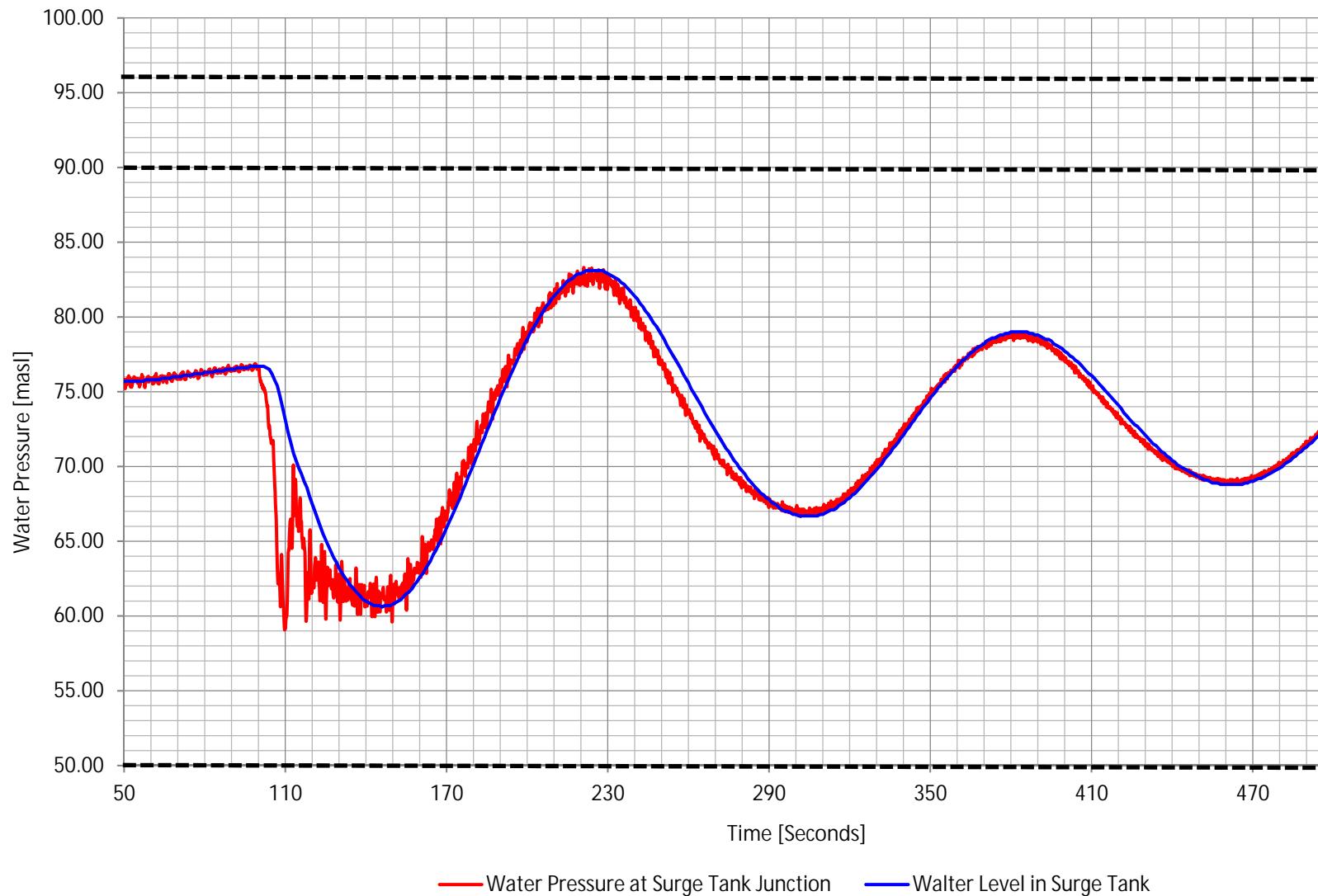
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Load Case 1b



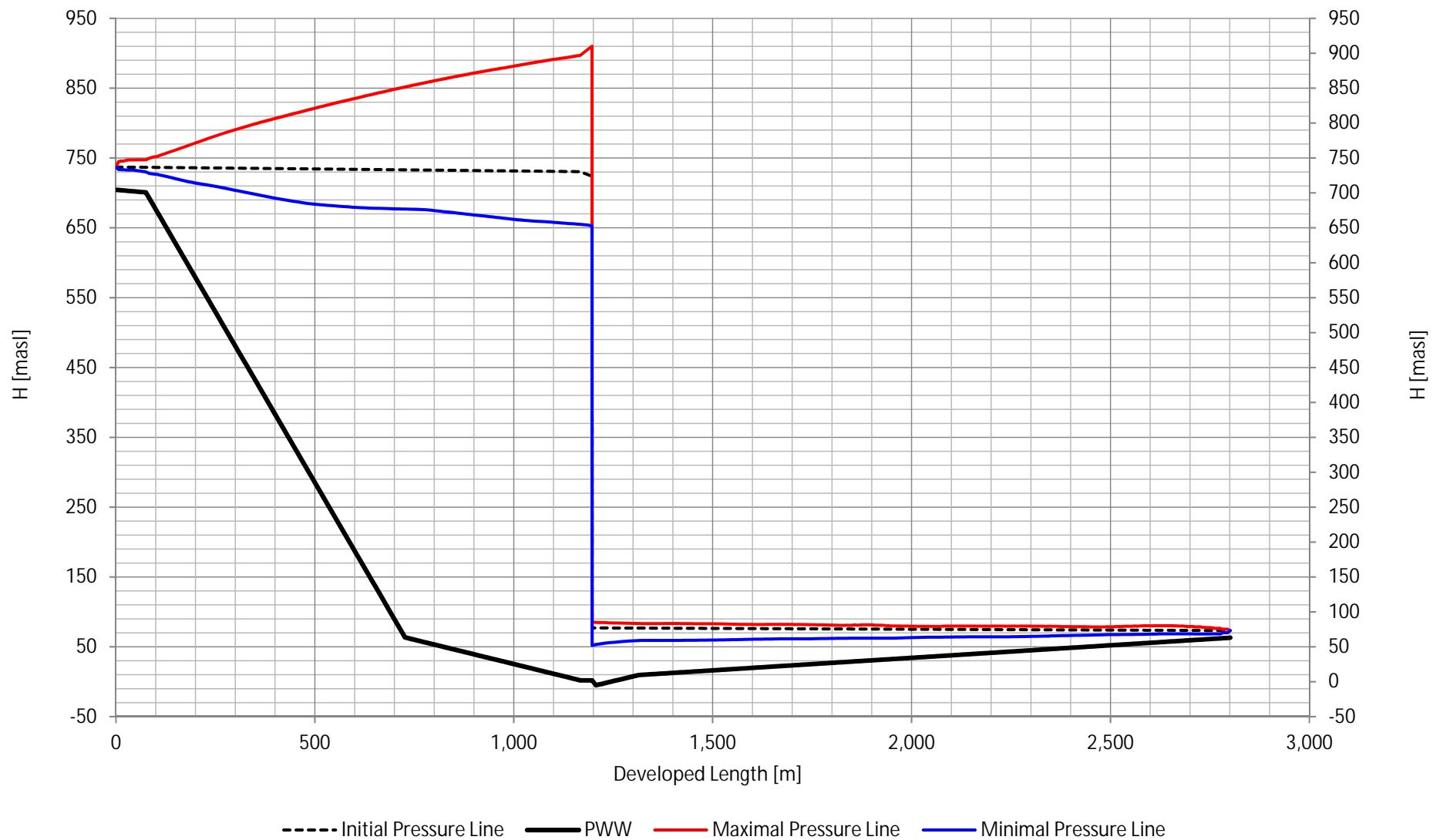
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Load Case 1b



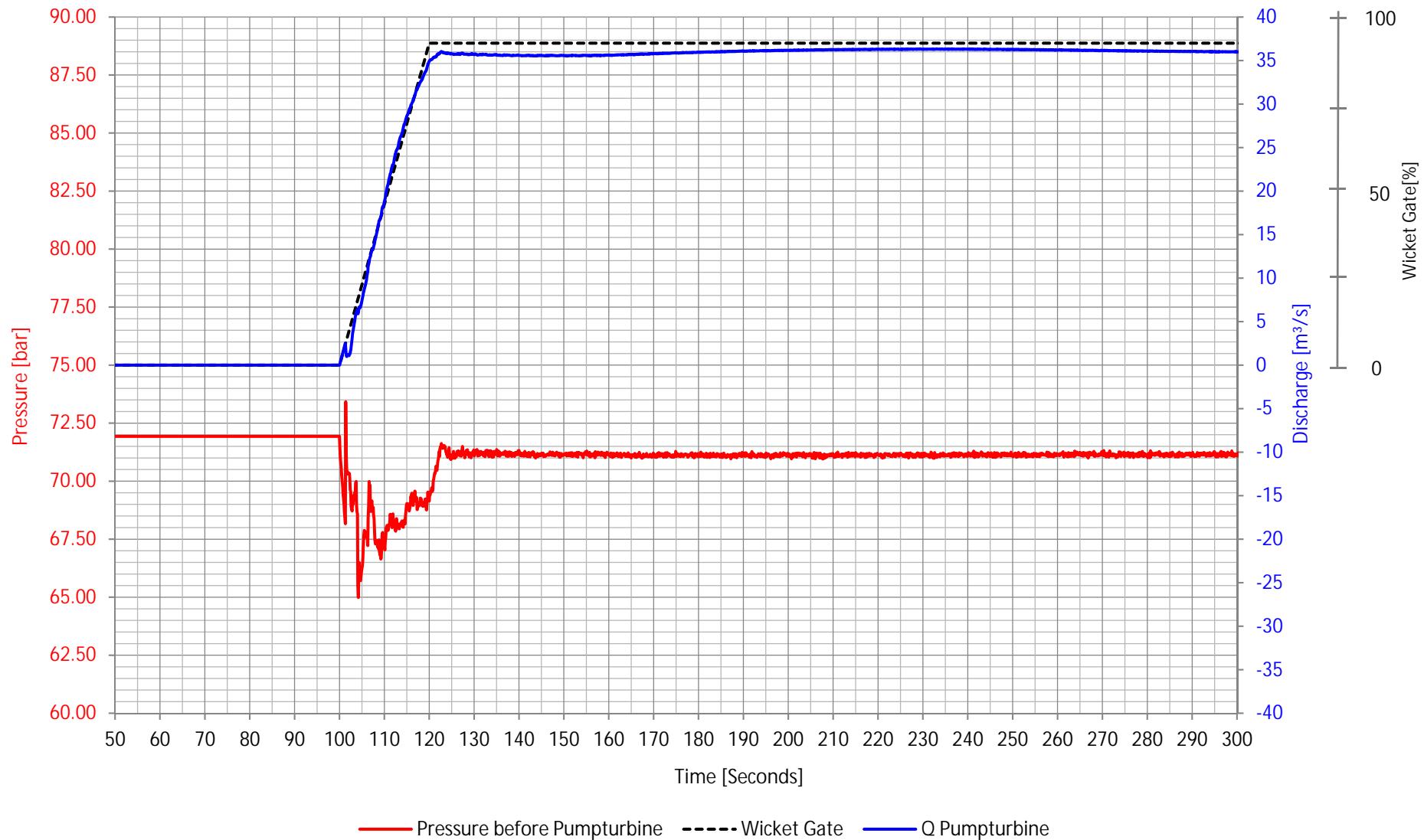
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Load Case 1b



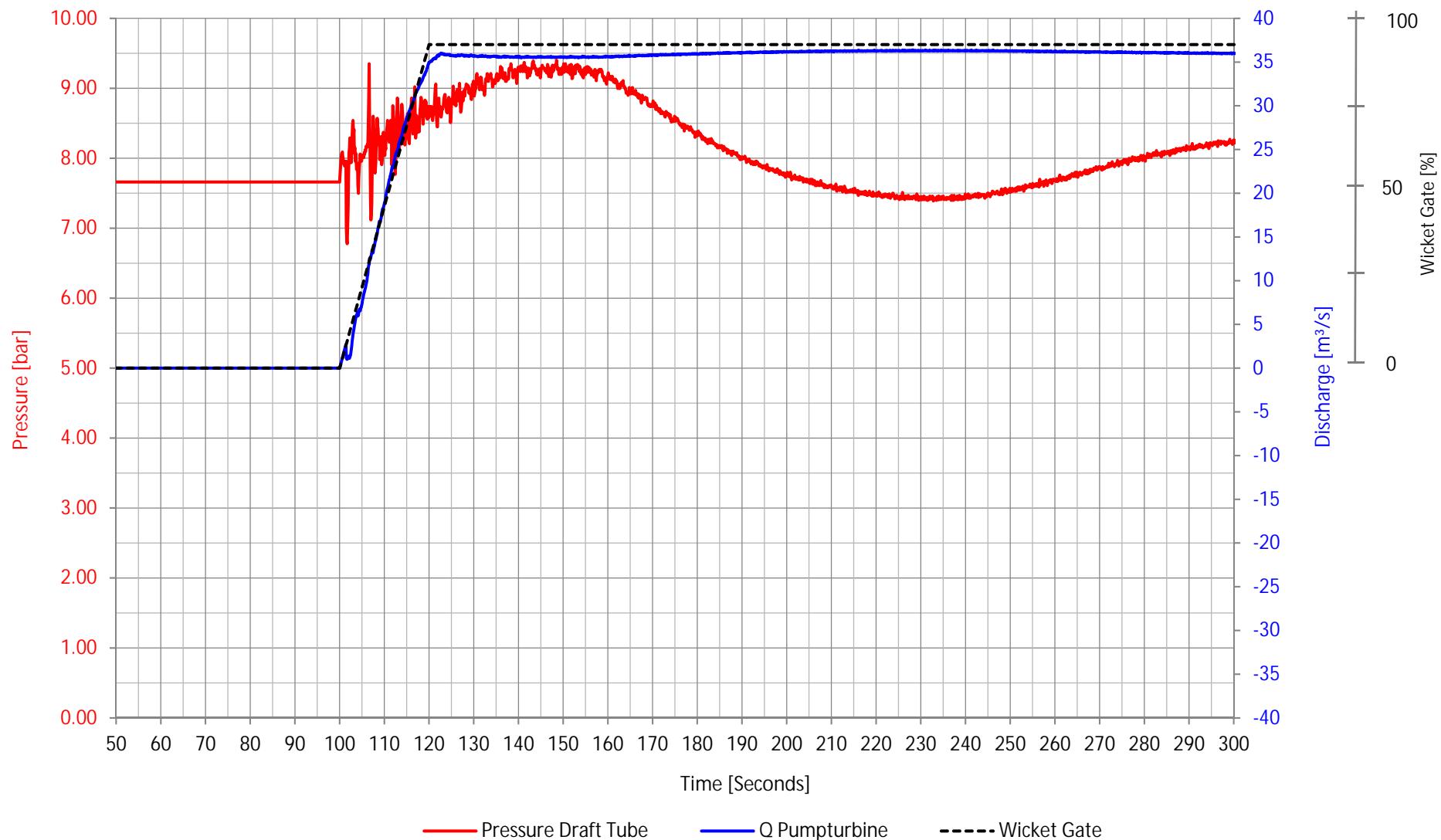
PSPP Manara 220 MW

Load Case 1c



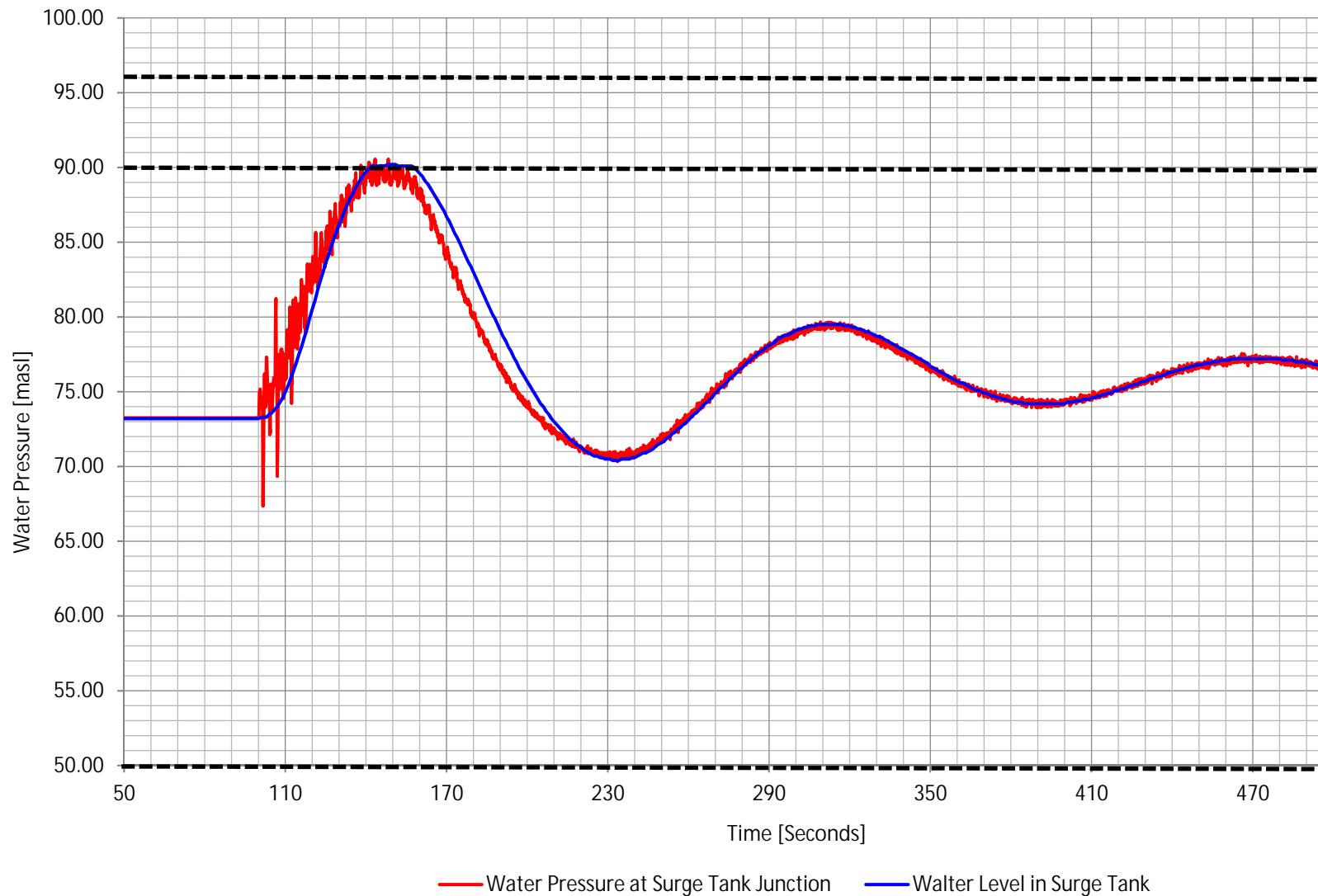
PSPP Manara 220 MW

Load Case 1c



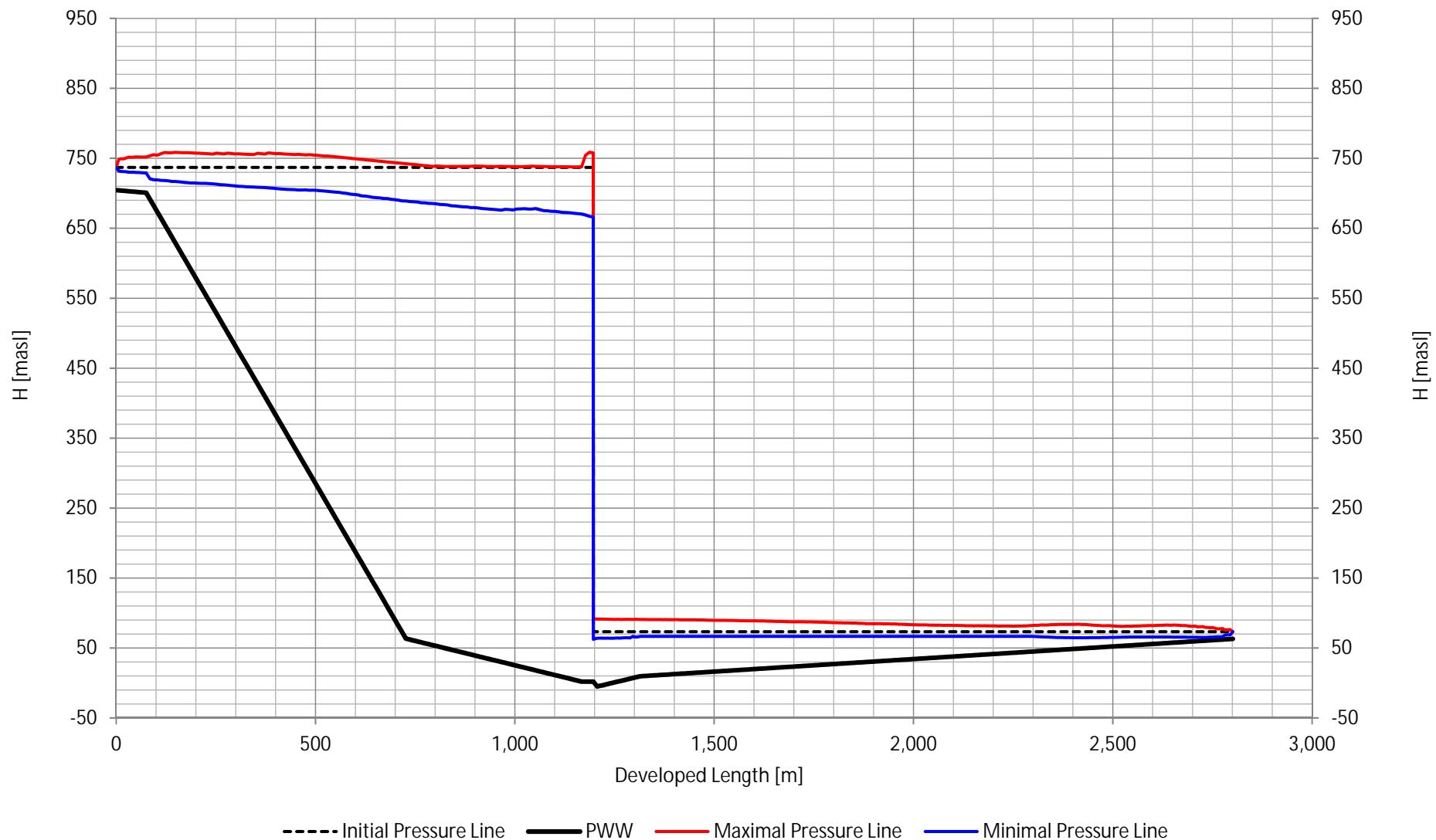
PSPP Manara 220 MW

Load Case 1c



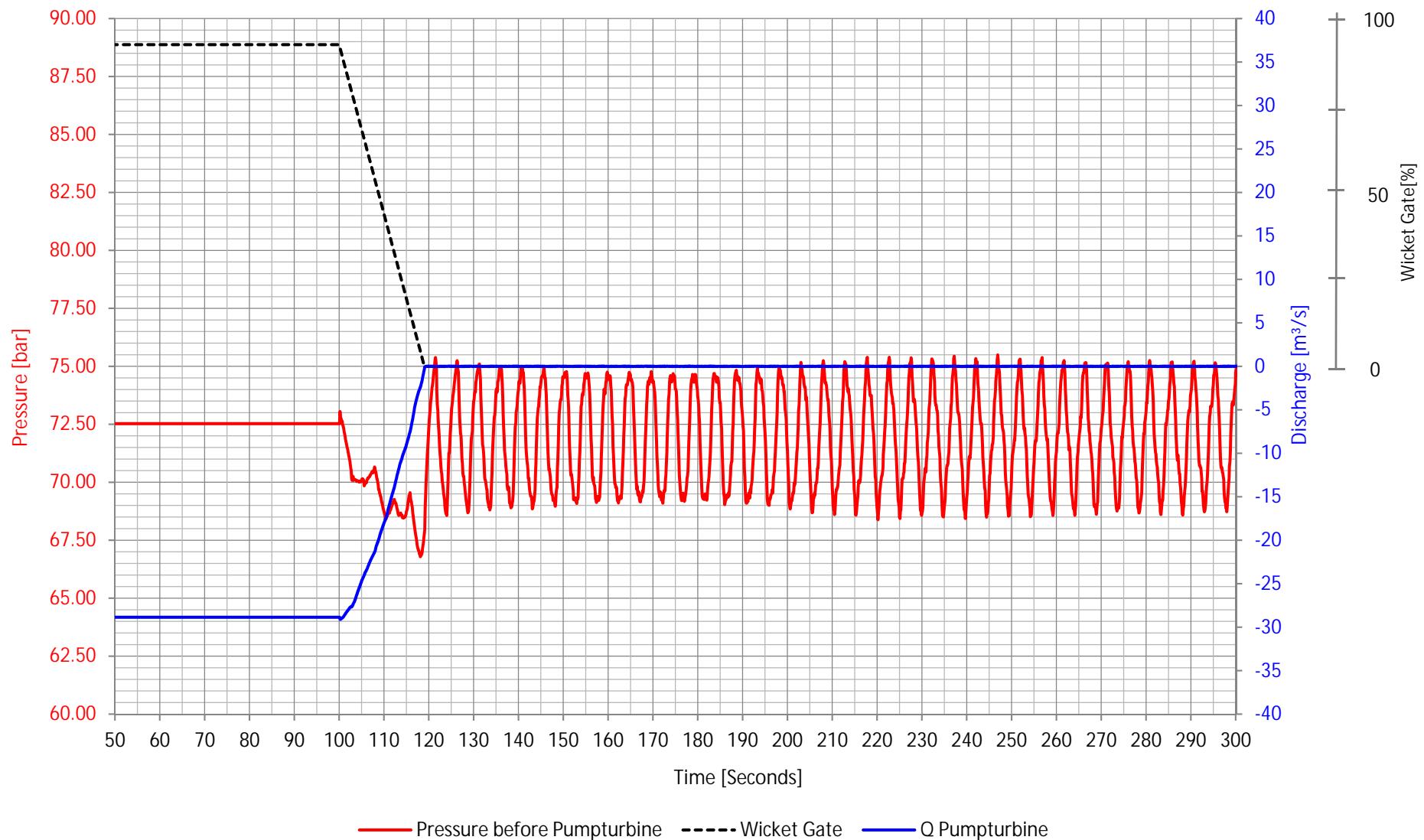
PSPP Manara 220 MW

Load Case 1c



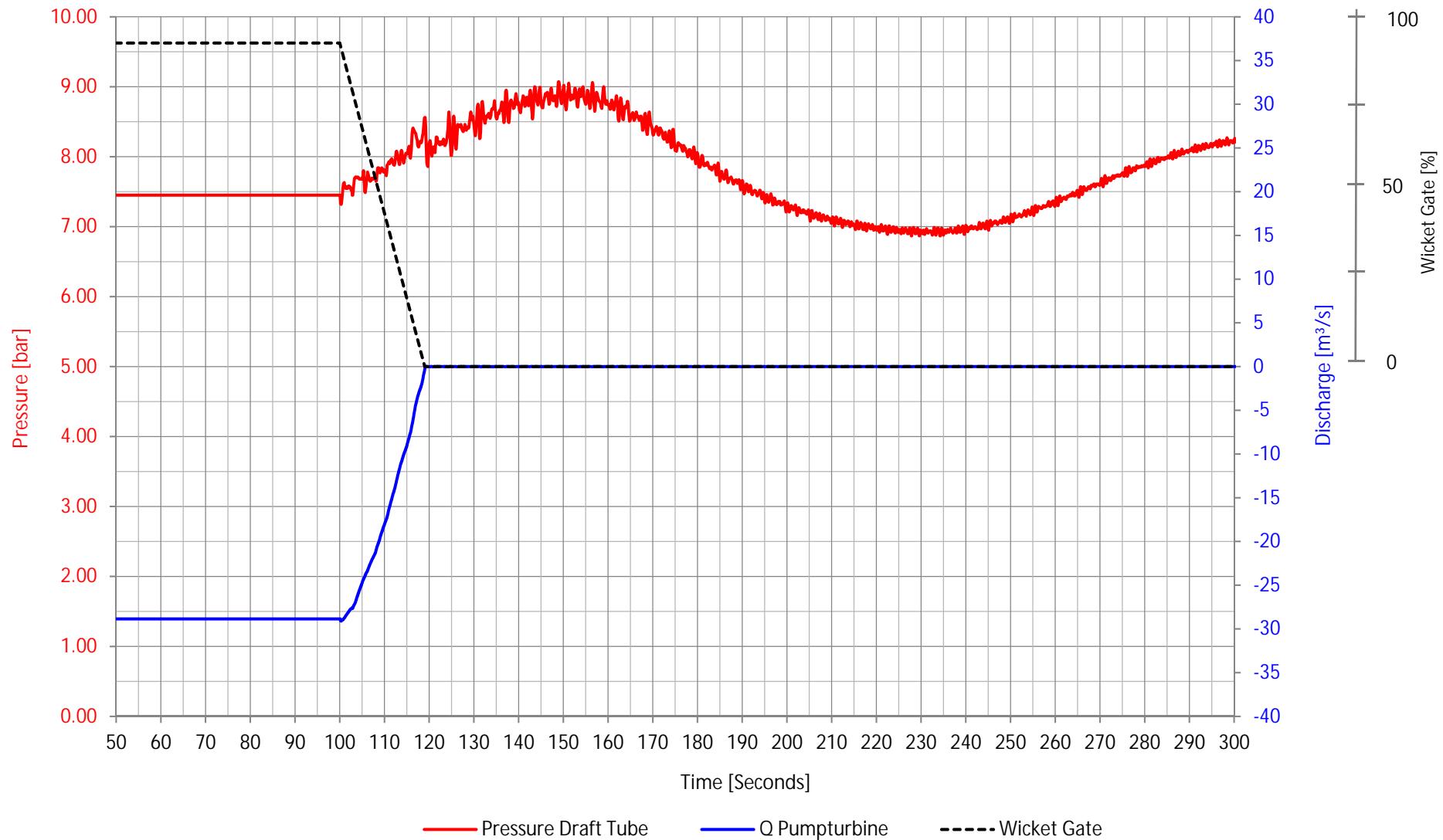
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Load Case 2a



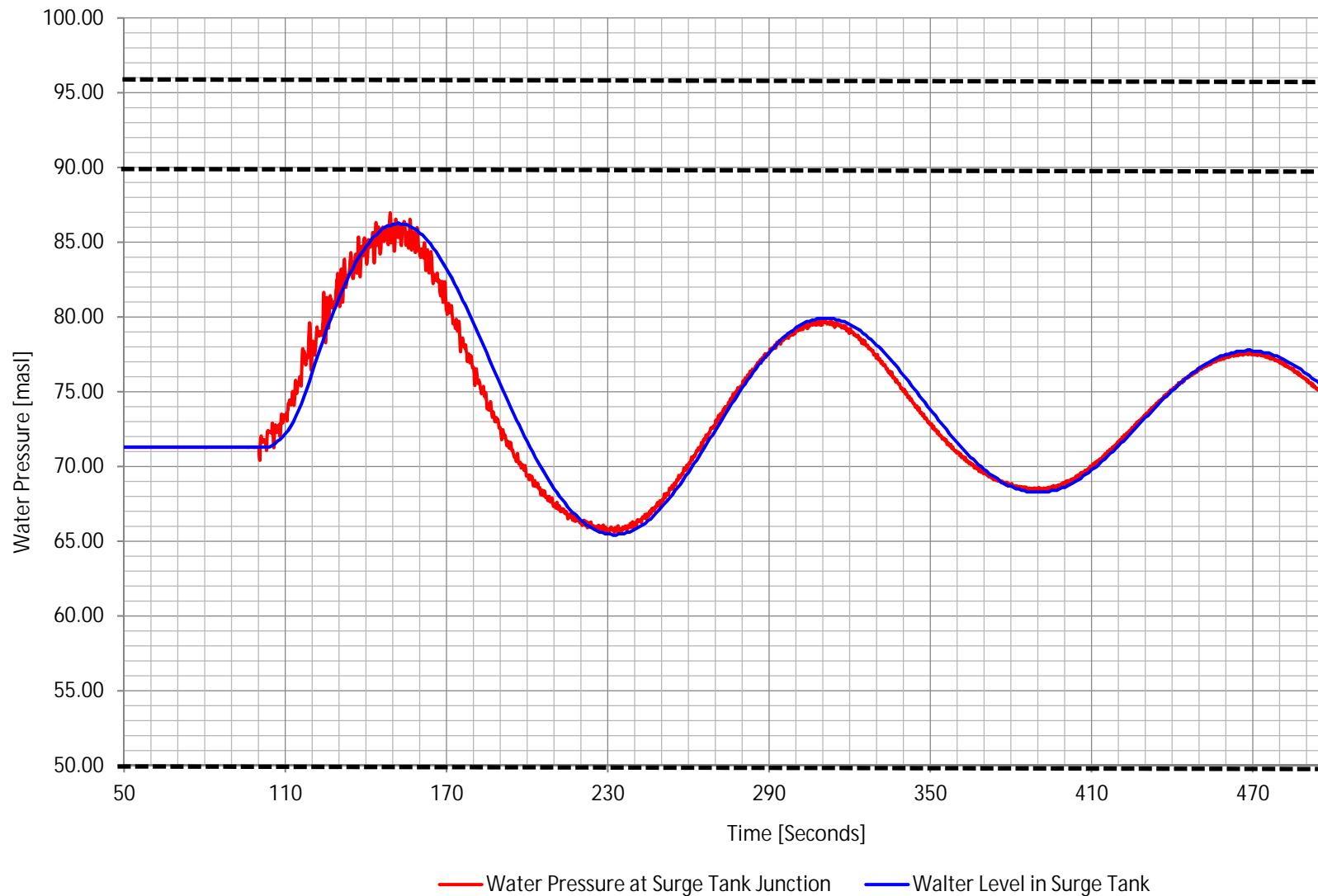
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Load Case 2a



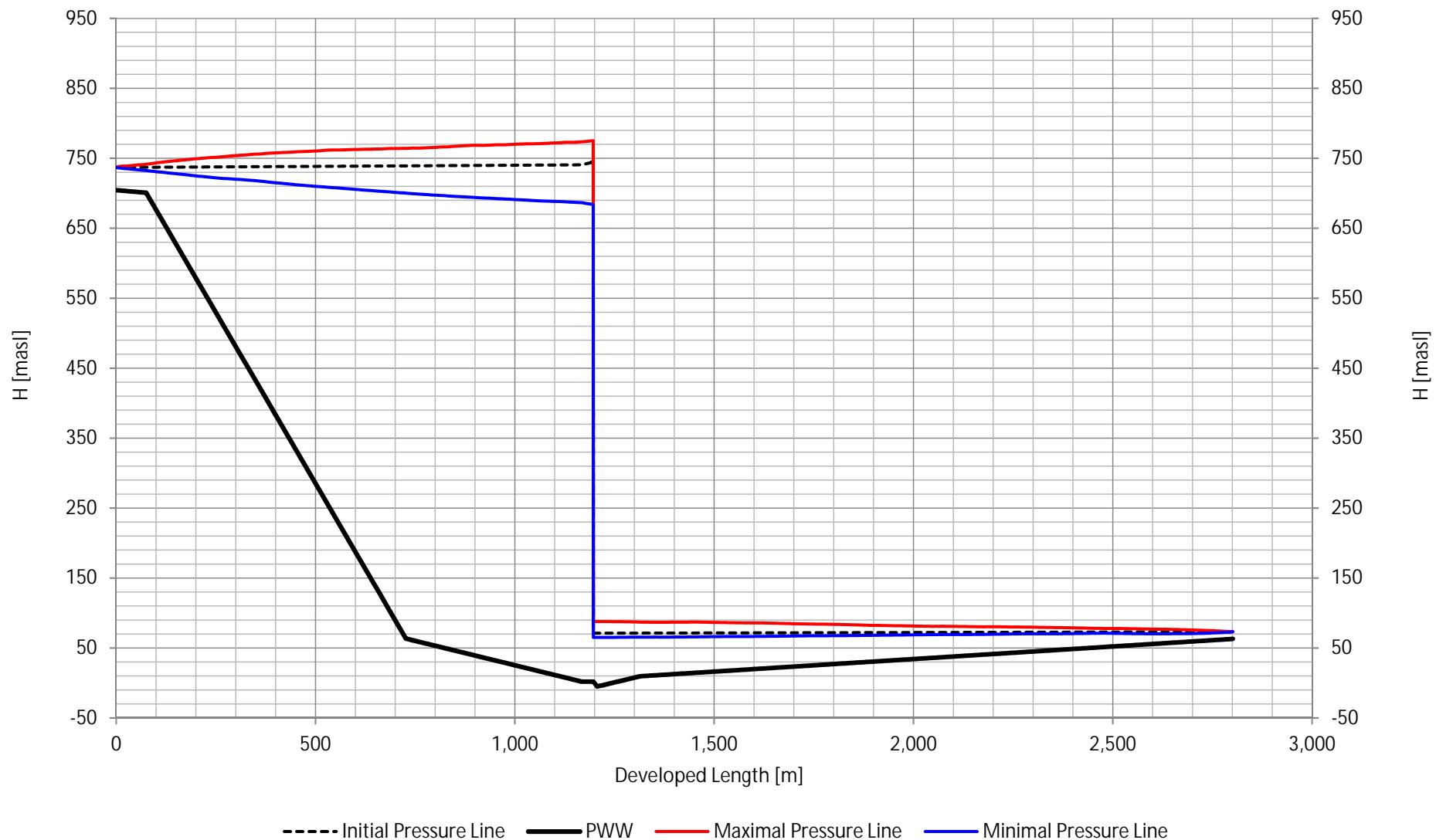
PSPP Manara 220 MW

Load Case 2a



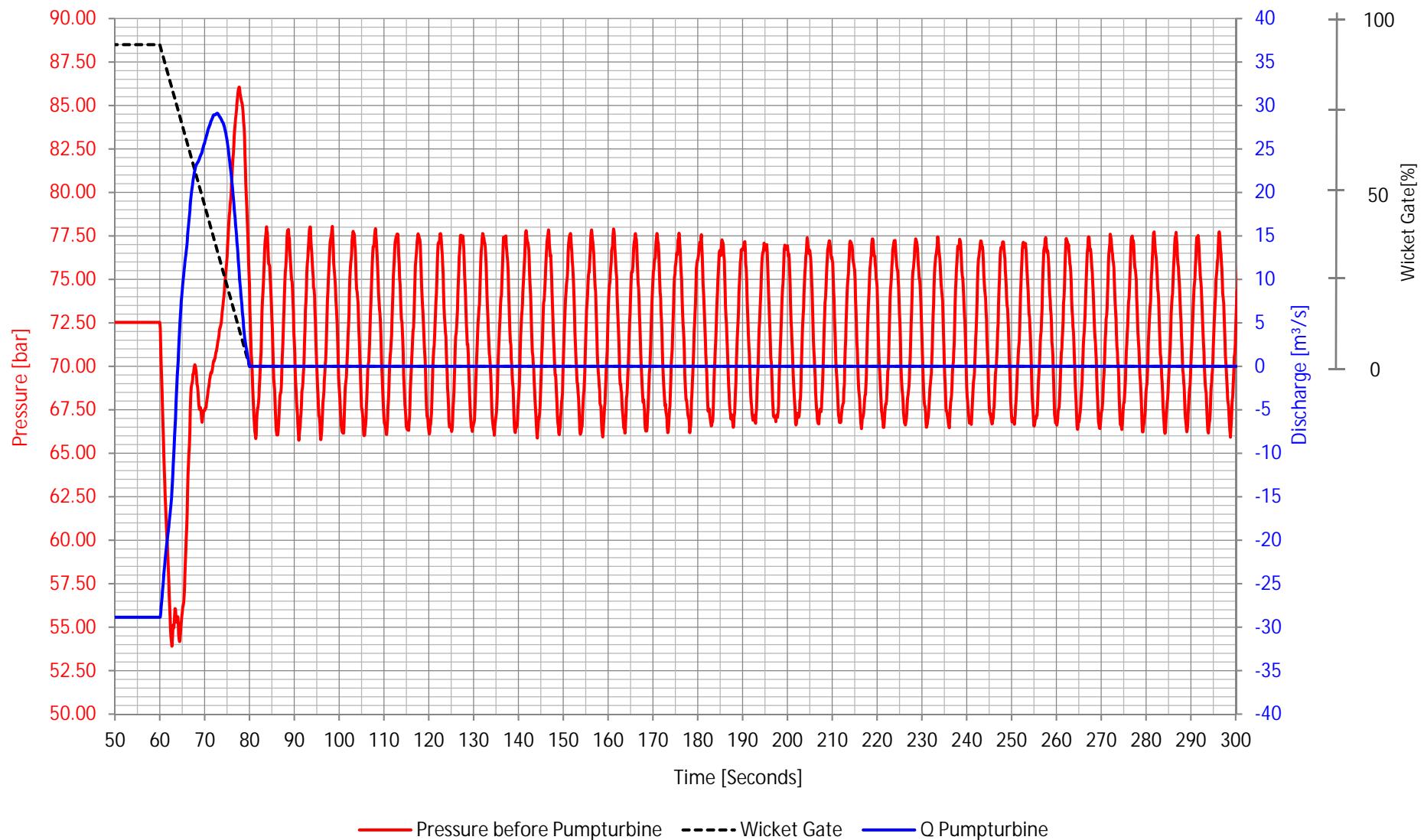
PSPP Manara 220 MW

Load Case 2a



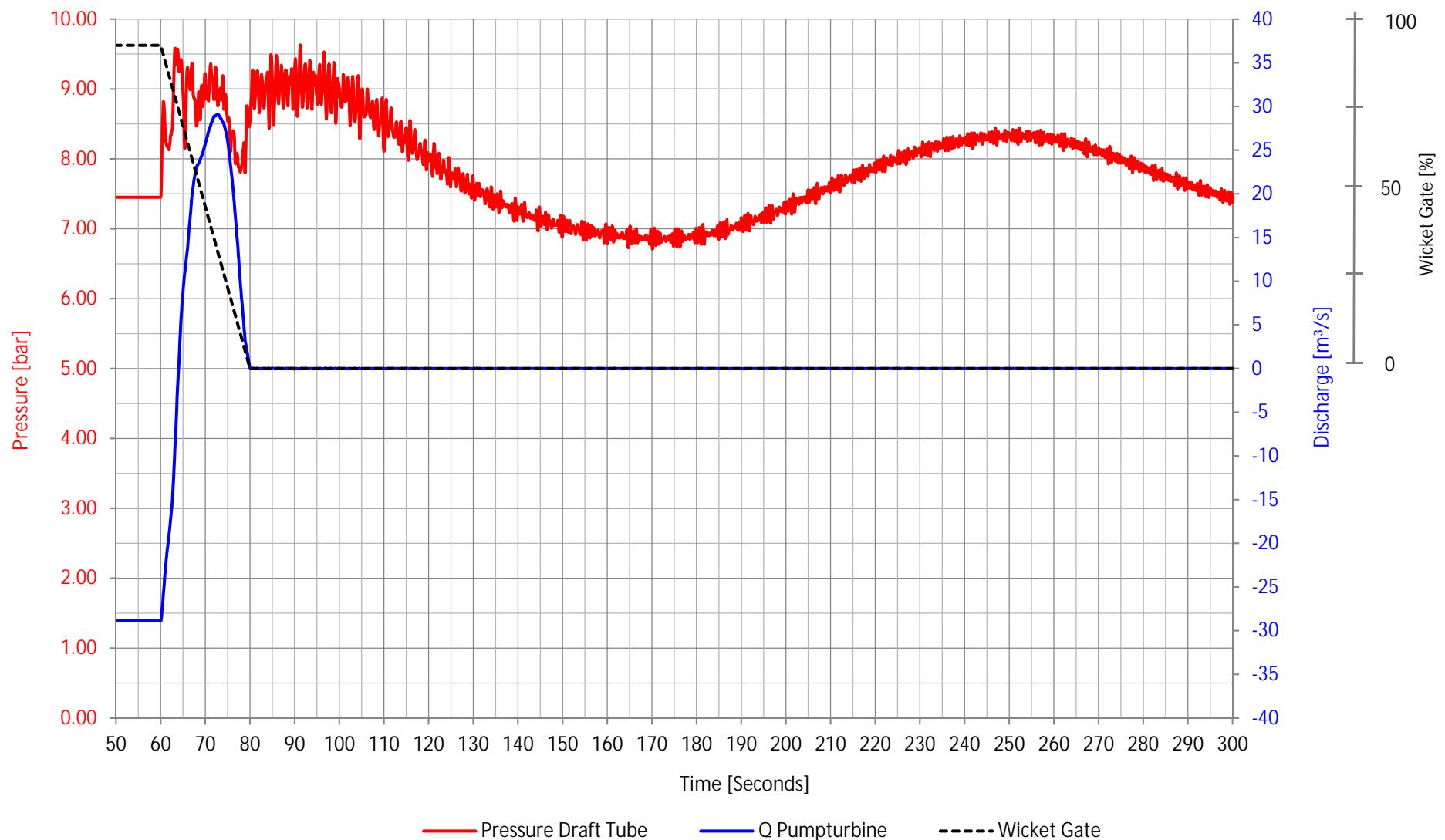
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Load Case 2b



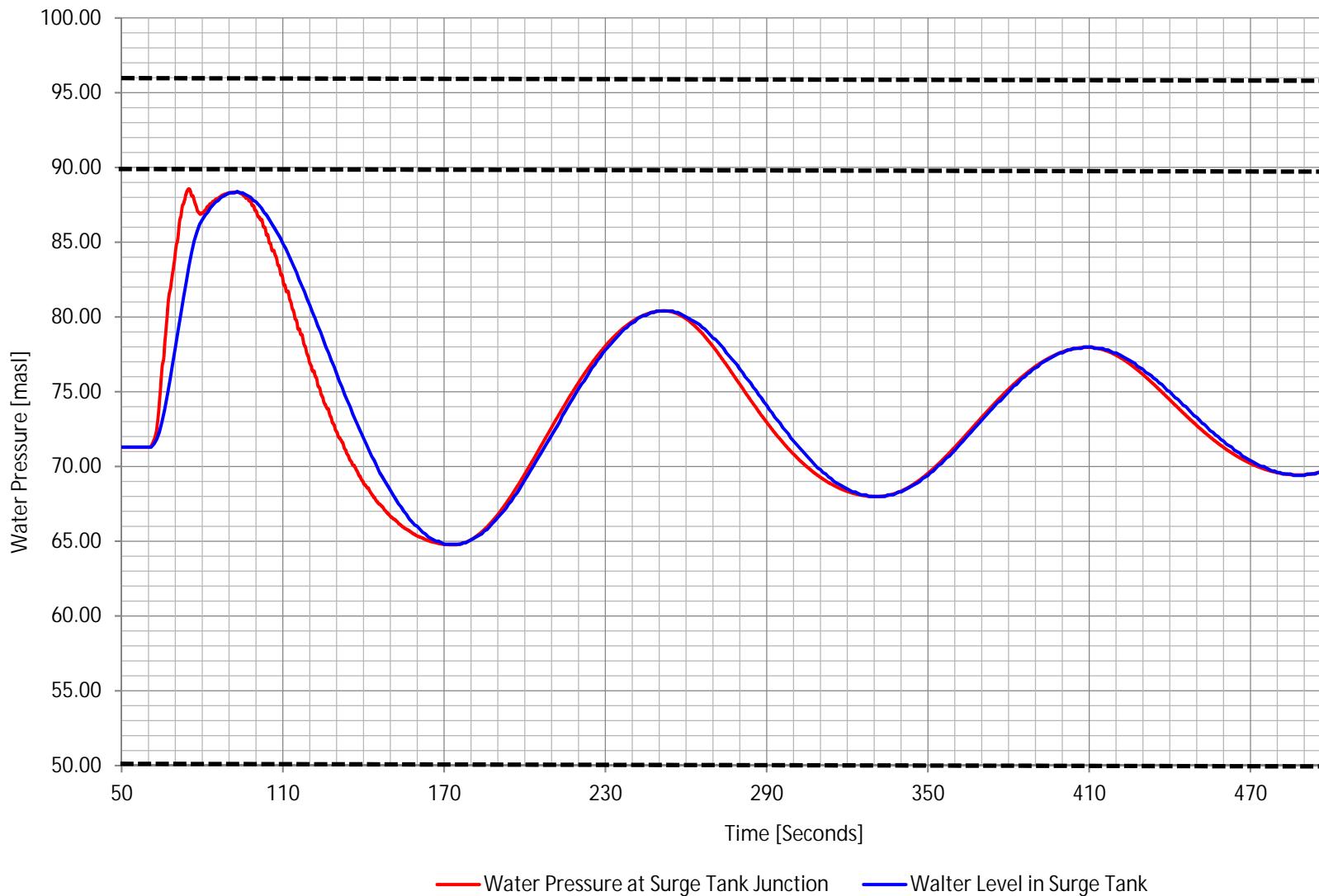
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Load Case 2b



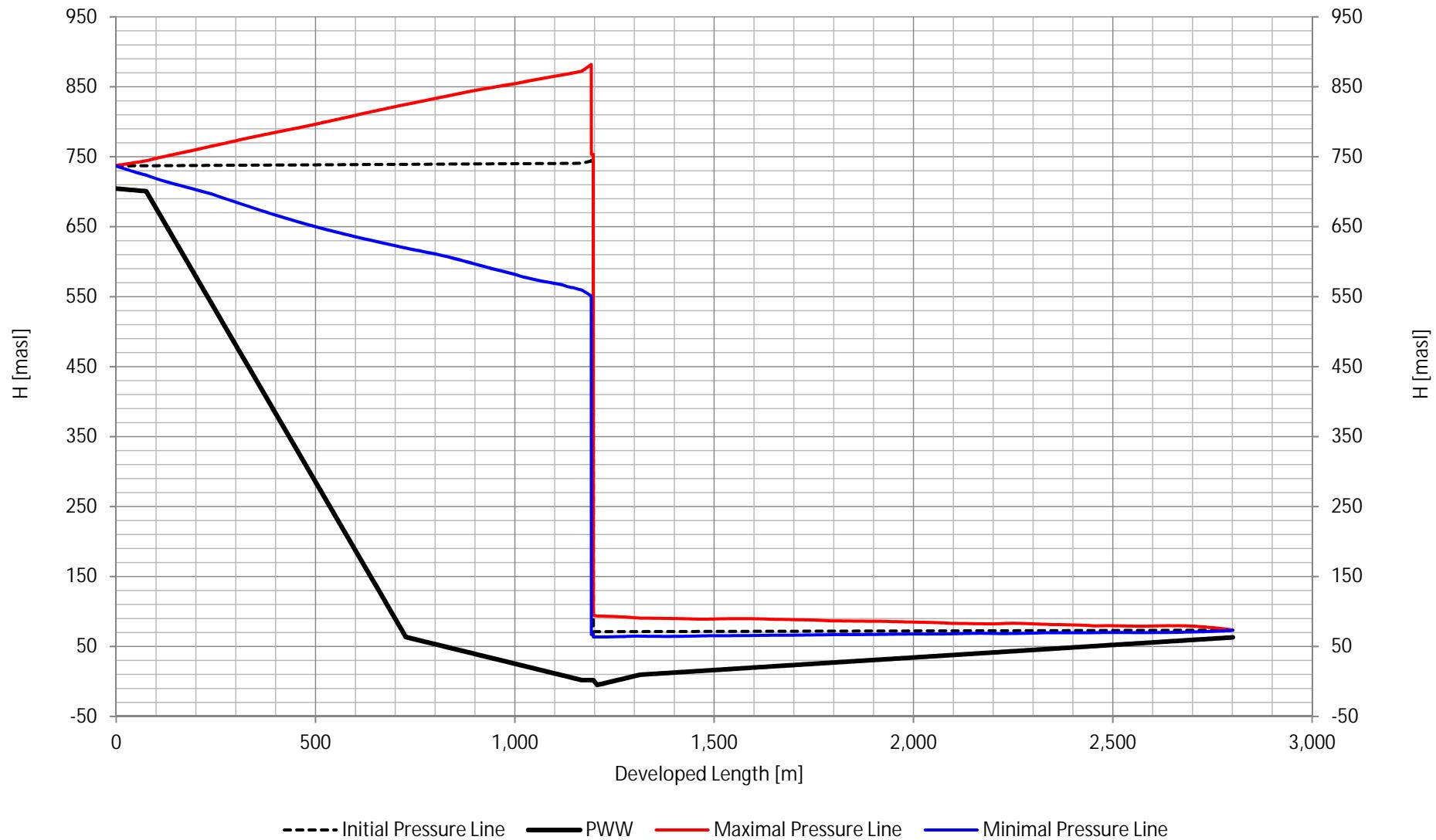
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Load Case 2b



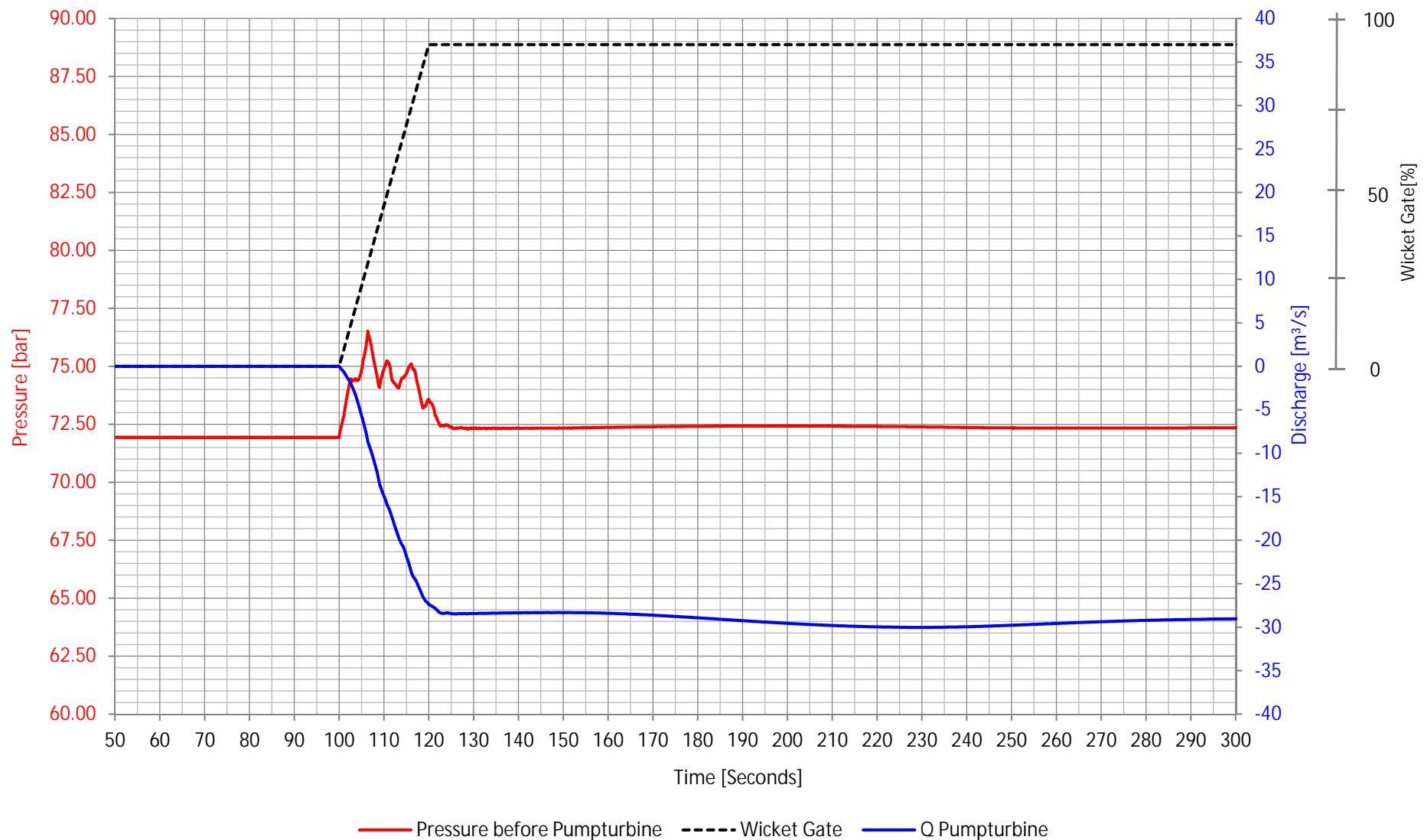
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Load Case 2b



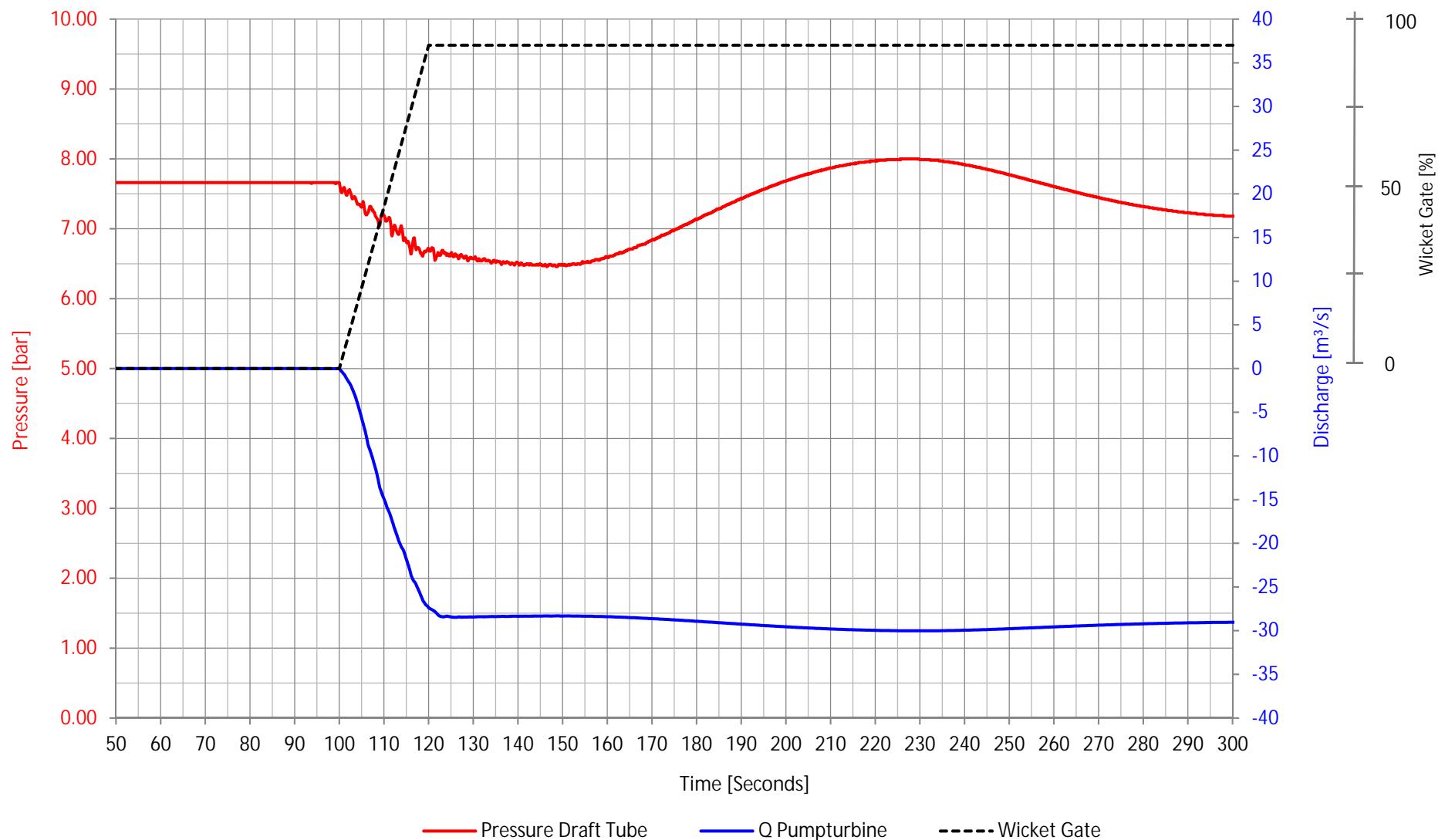
PSPP Manara 220 MW

Load Case 2c



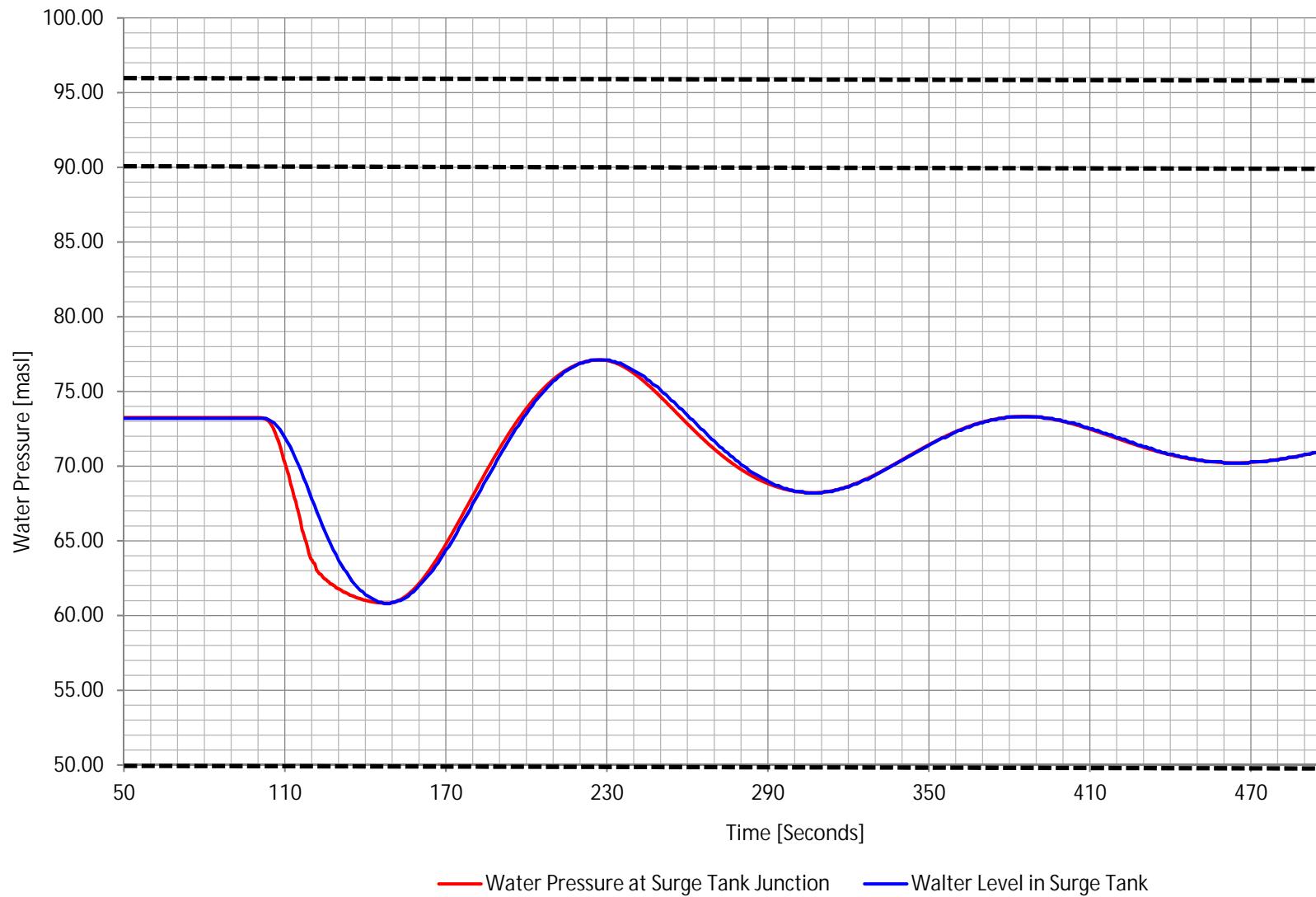
PSPP Manara 220 MW

Load Case 2c



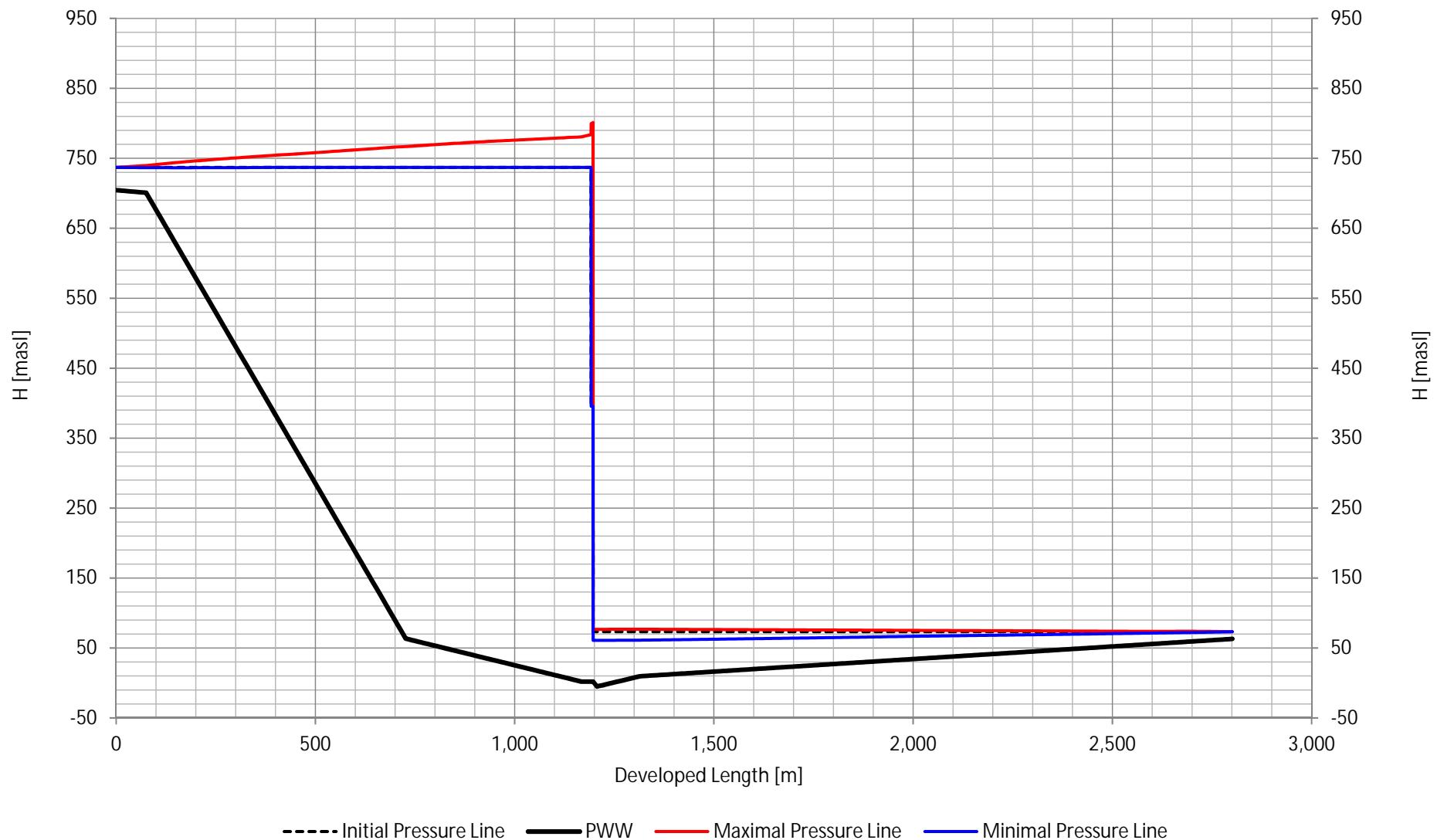
PSPP Manara 220 MW

Load Case 2c



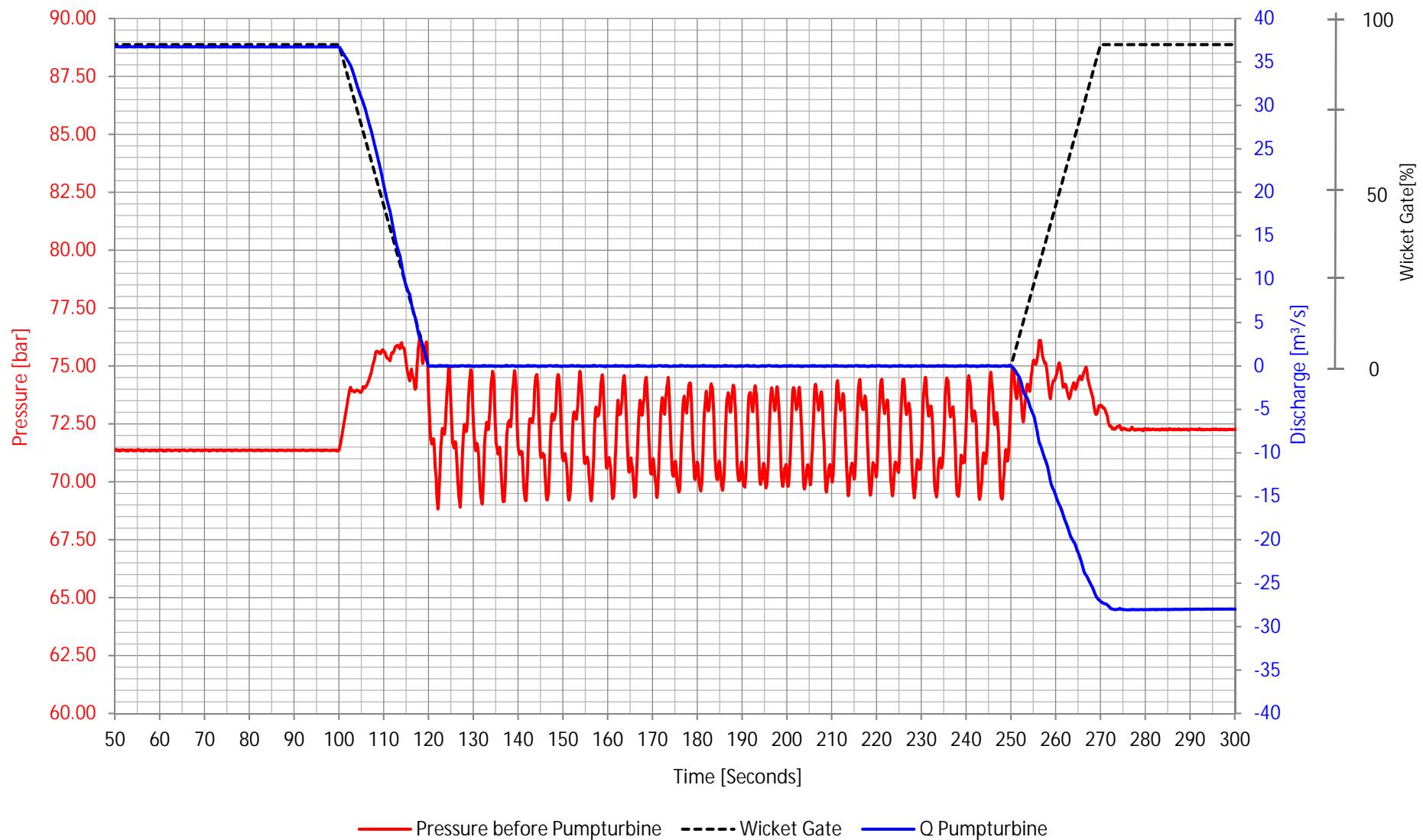
PSPP Manara 220 MW

Load Case 2c



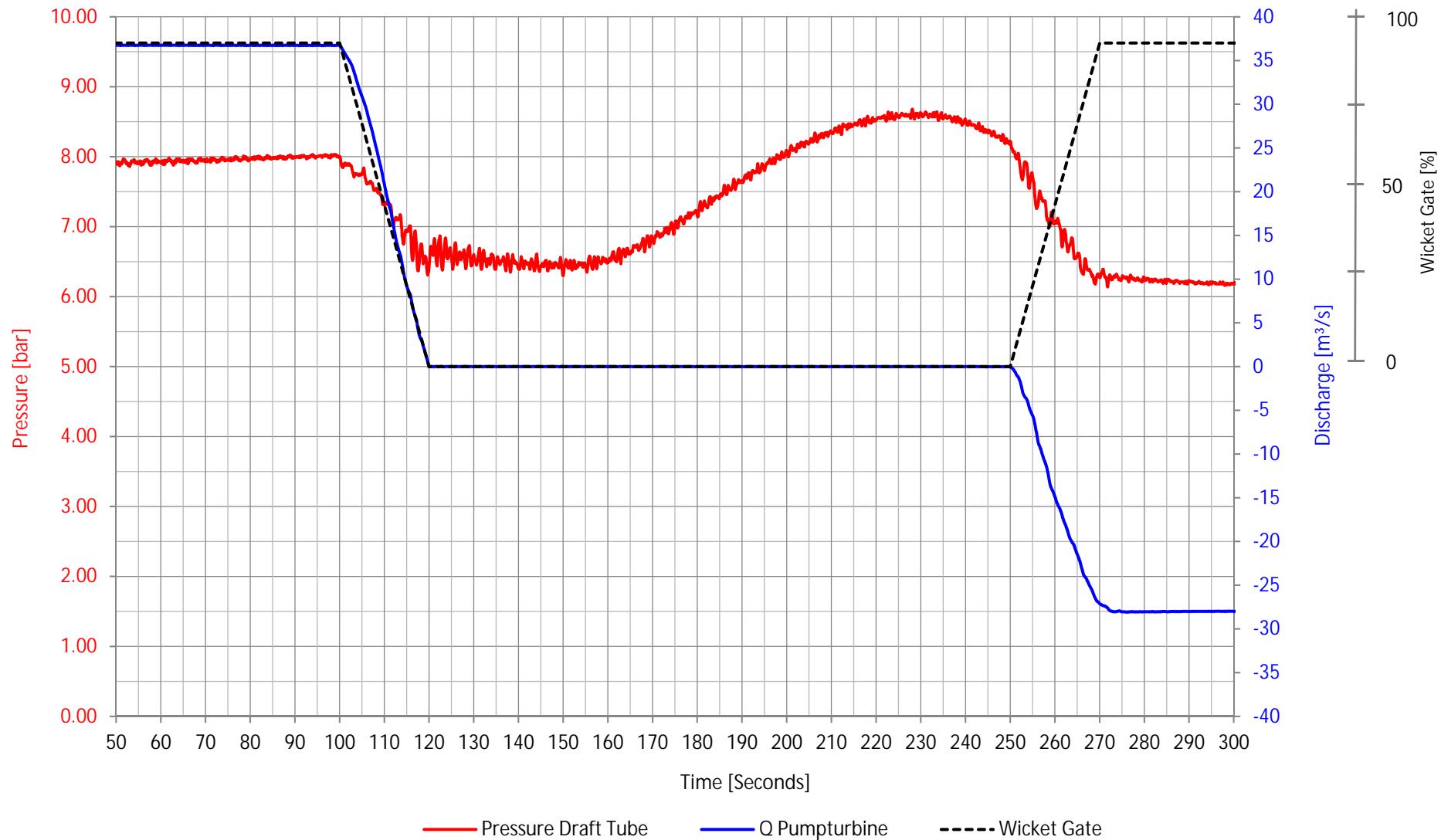
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Load Case 3b



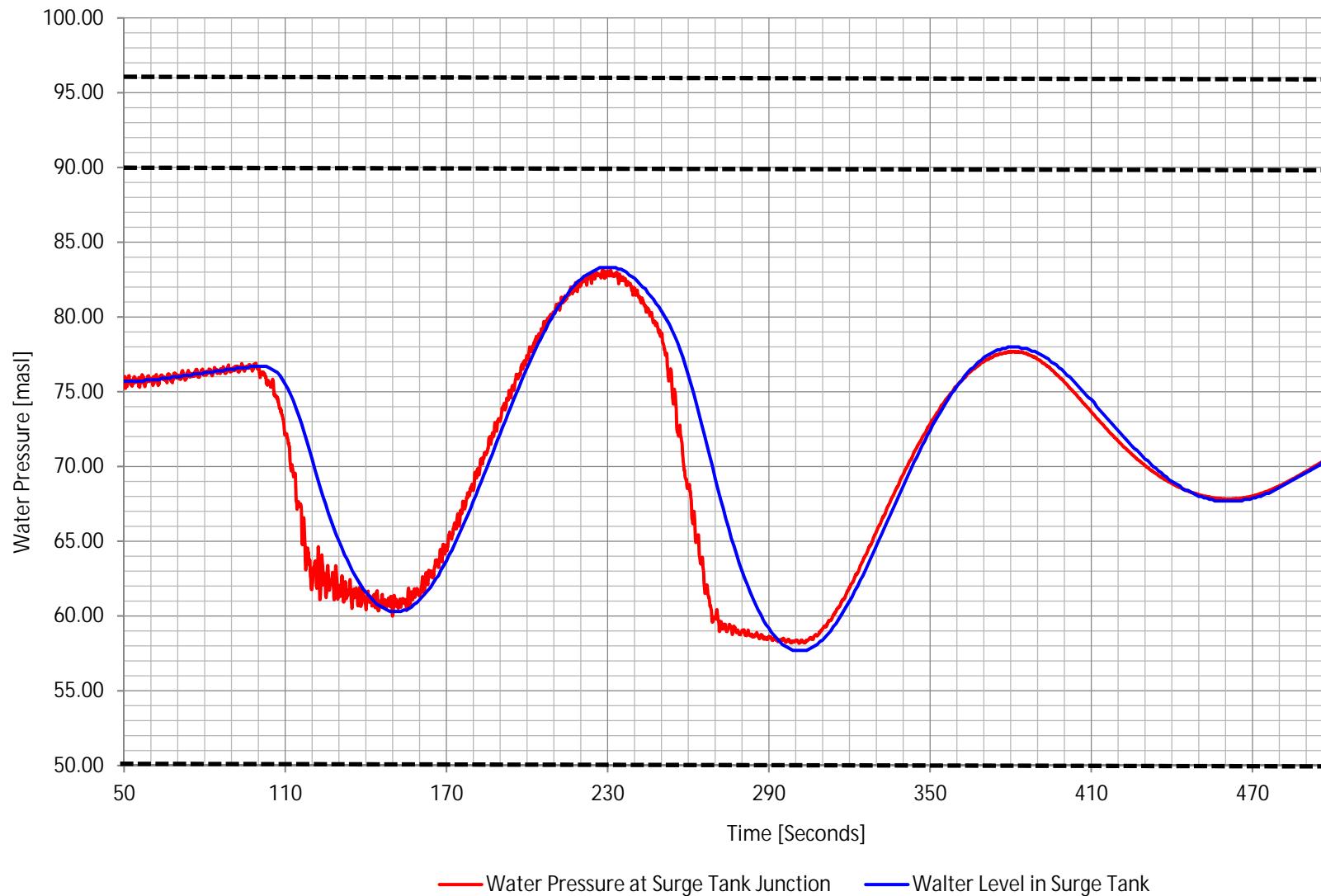
PSPP Manara 220 MW

Load Case 3b



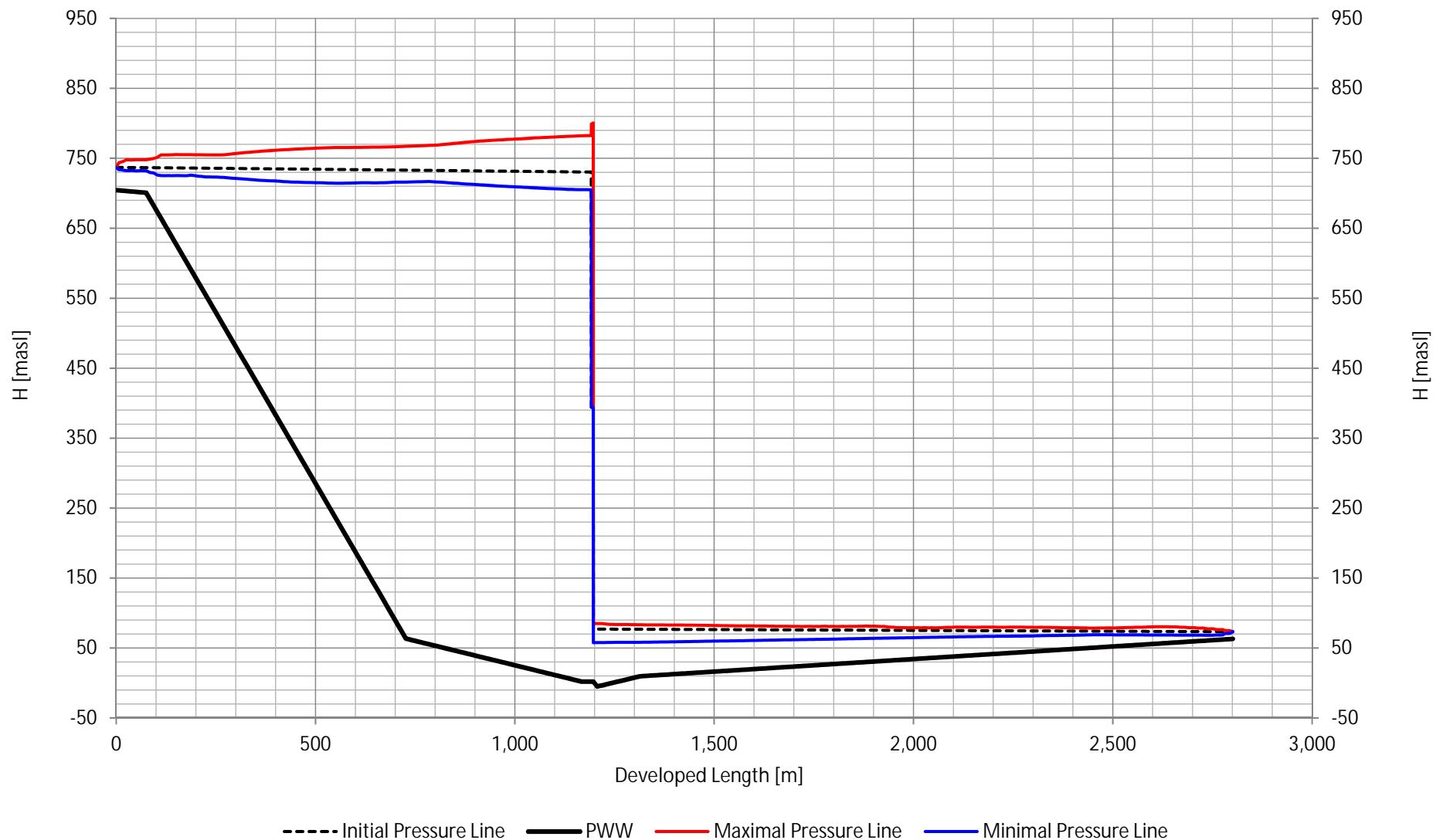
PSPP Manara 220 MW

Load Case 3b



PSPP Manara 220 MW

Load Case 3b

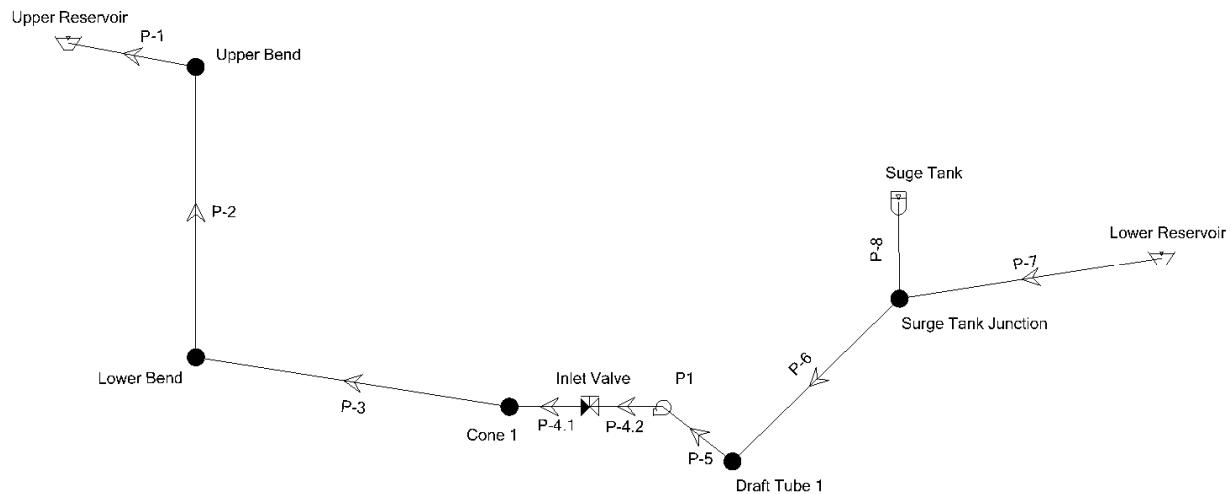


ANNEX C: TRANSIENT CALCULATION 2

Upper reservoir: MOL 712.50 masl

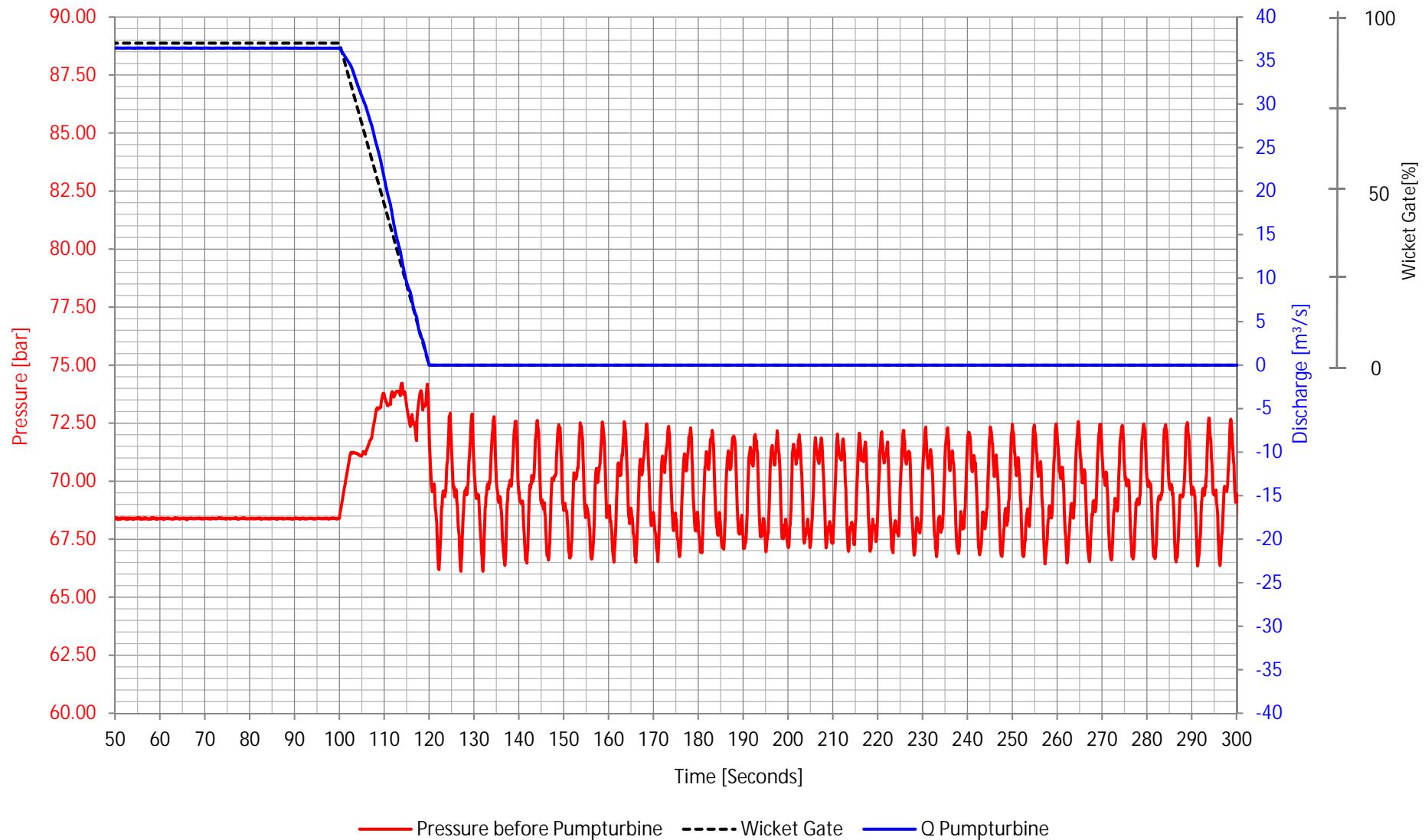
Lower reservoir: FSL 80.70 masl

Model for the transient calculation



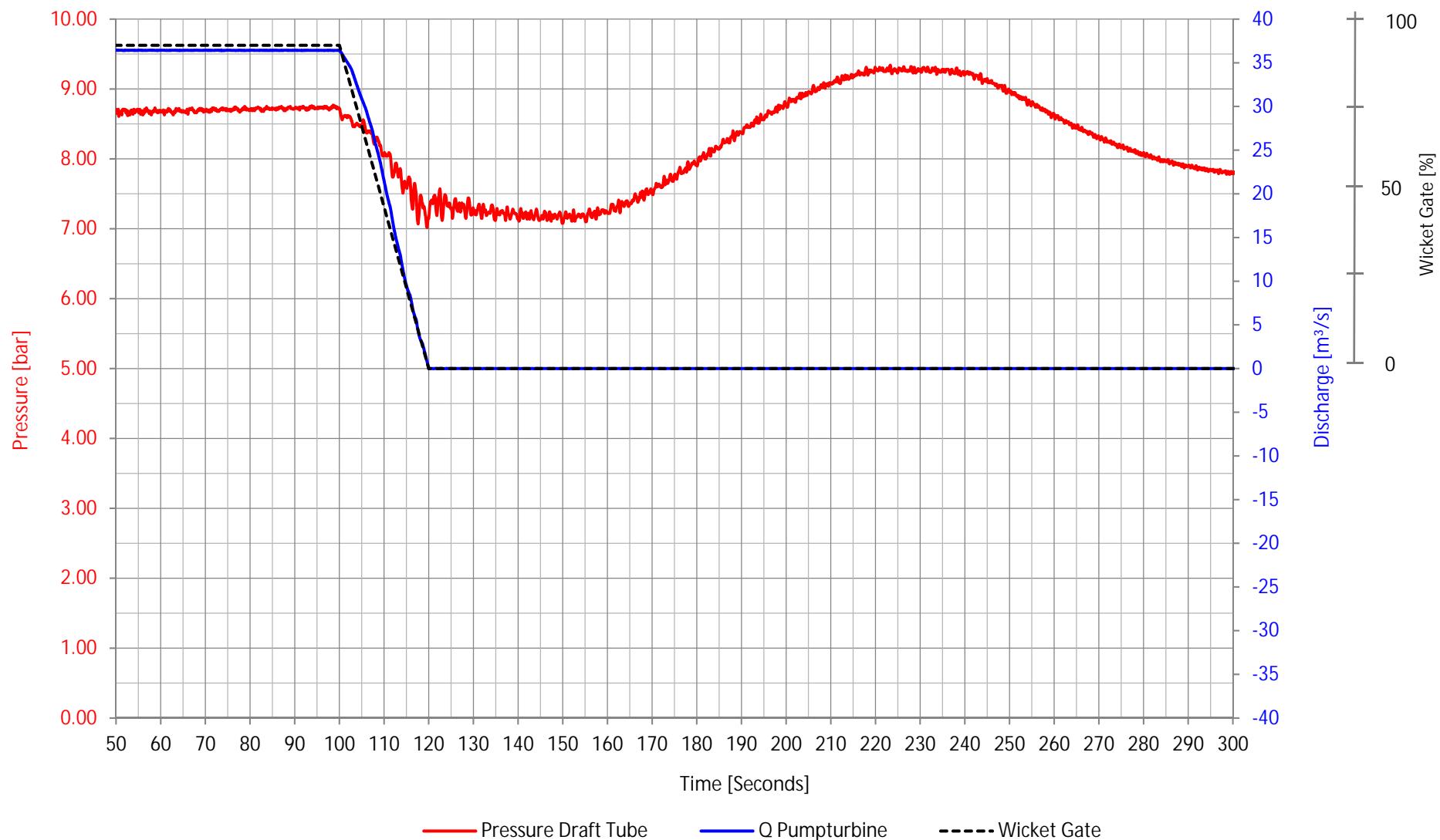
PSPP Manara 220 MW

Load Case 1a



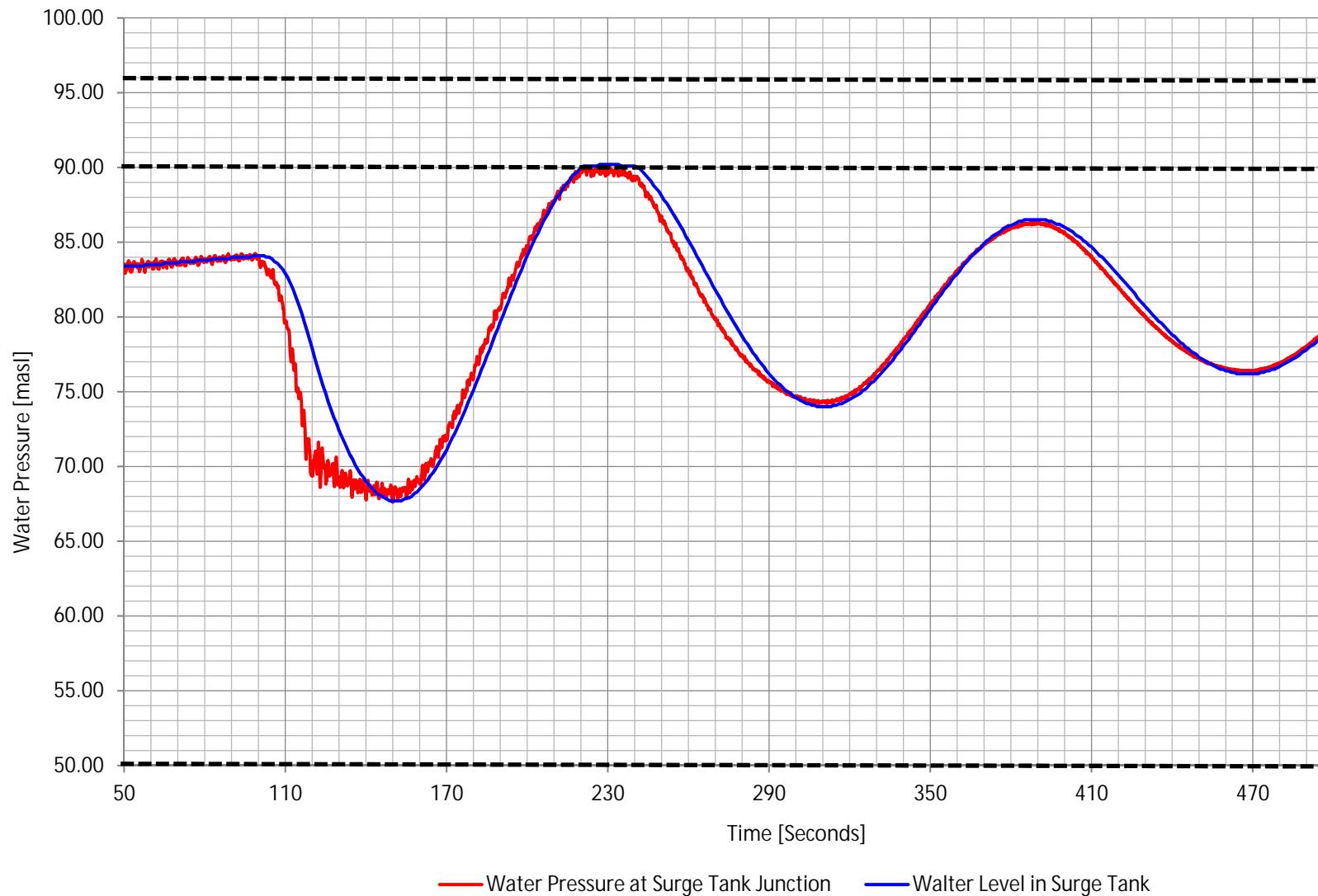
PSPP Manara 220 MW

Load Case 1a



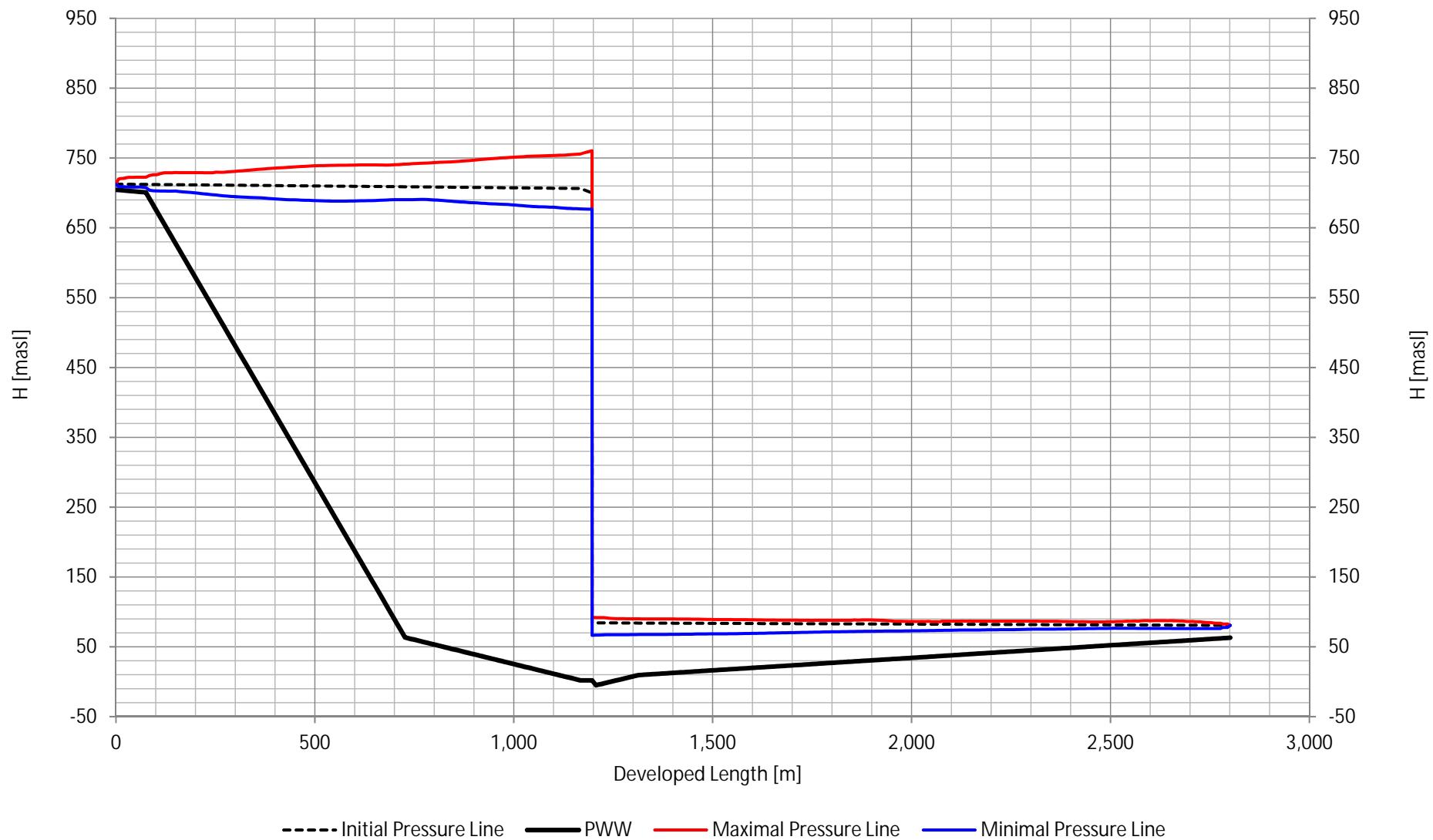
PSPP Manara 220 MW

Load Case 1a



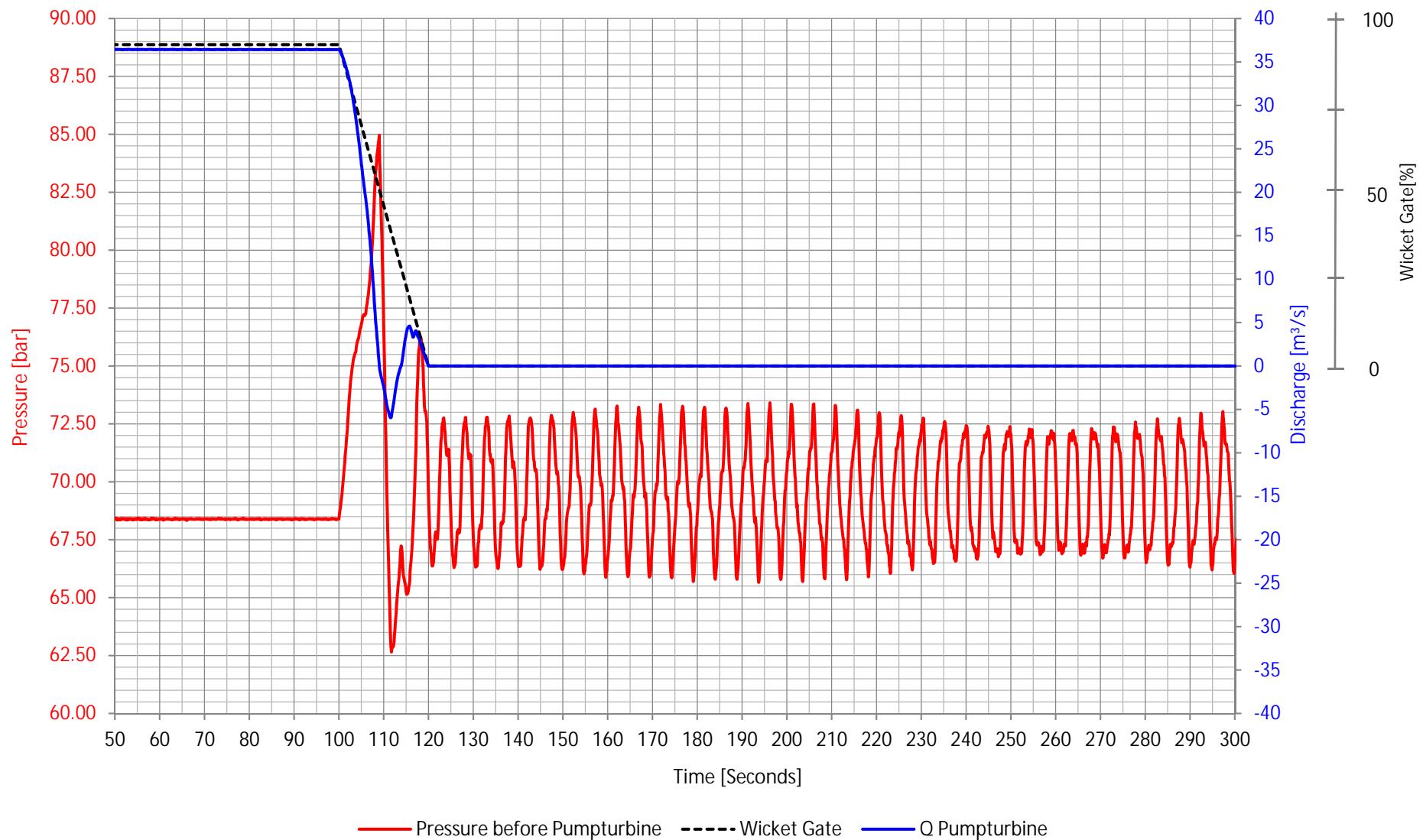
PSPP Manara 220 MW

Load Case 1a



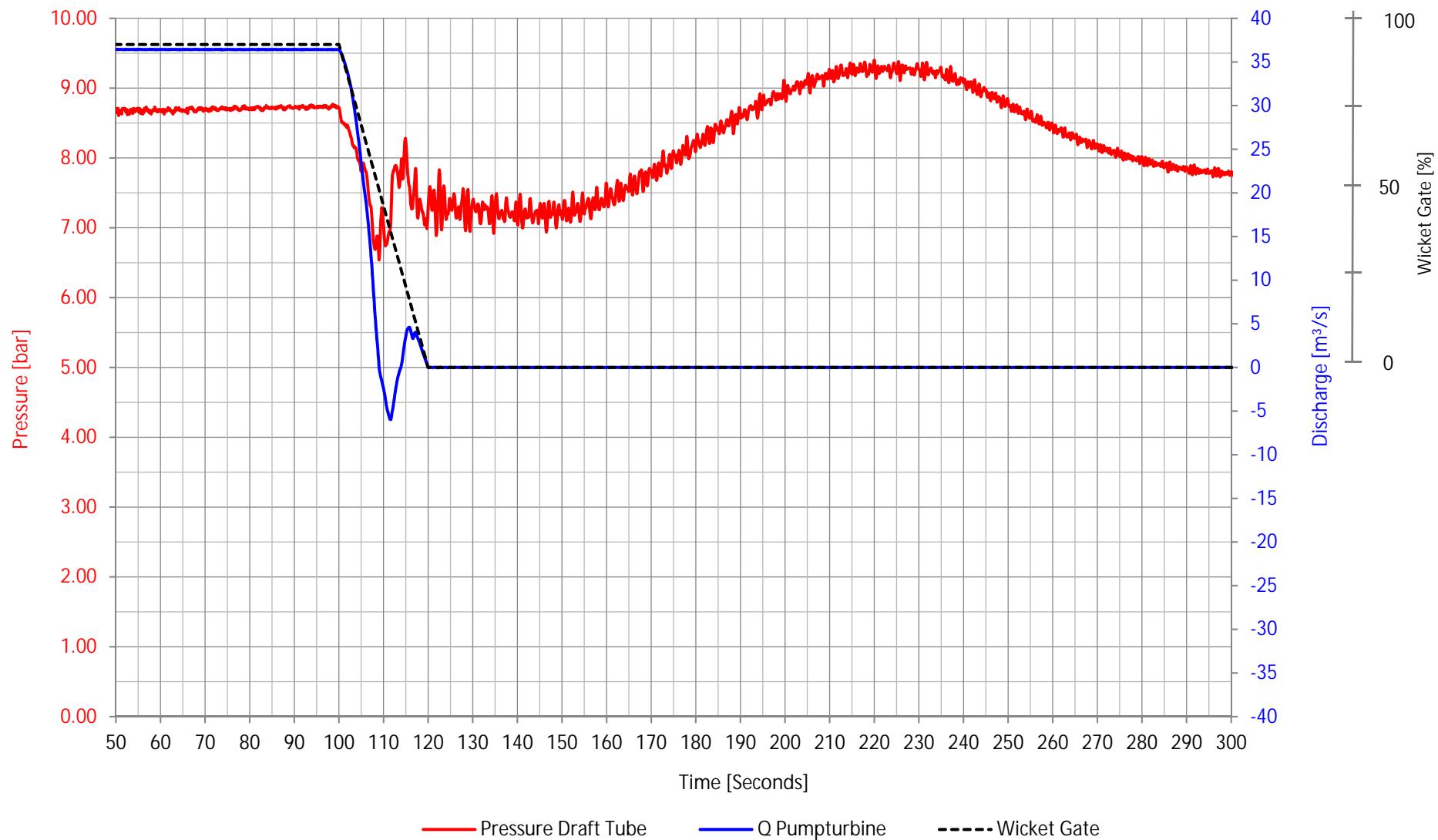
PSPP Manara 220 MW

Load Case 1b



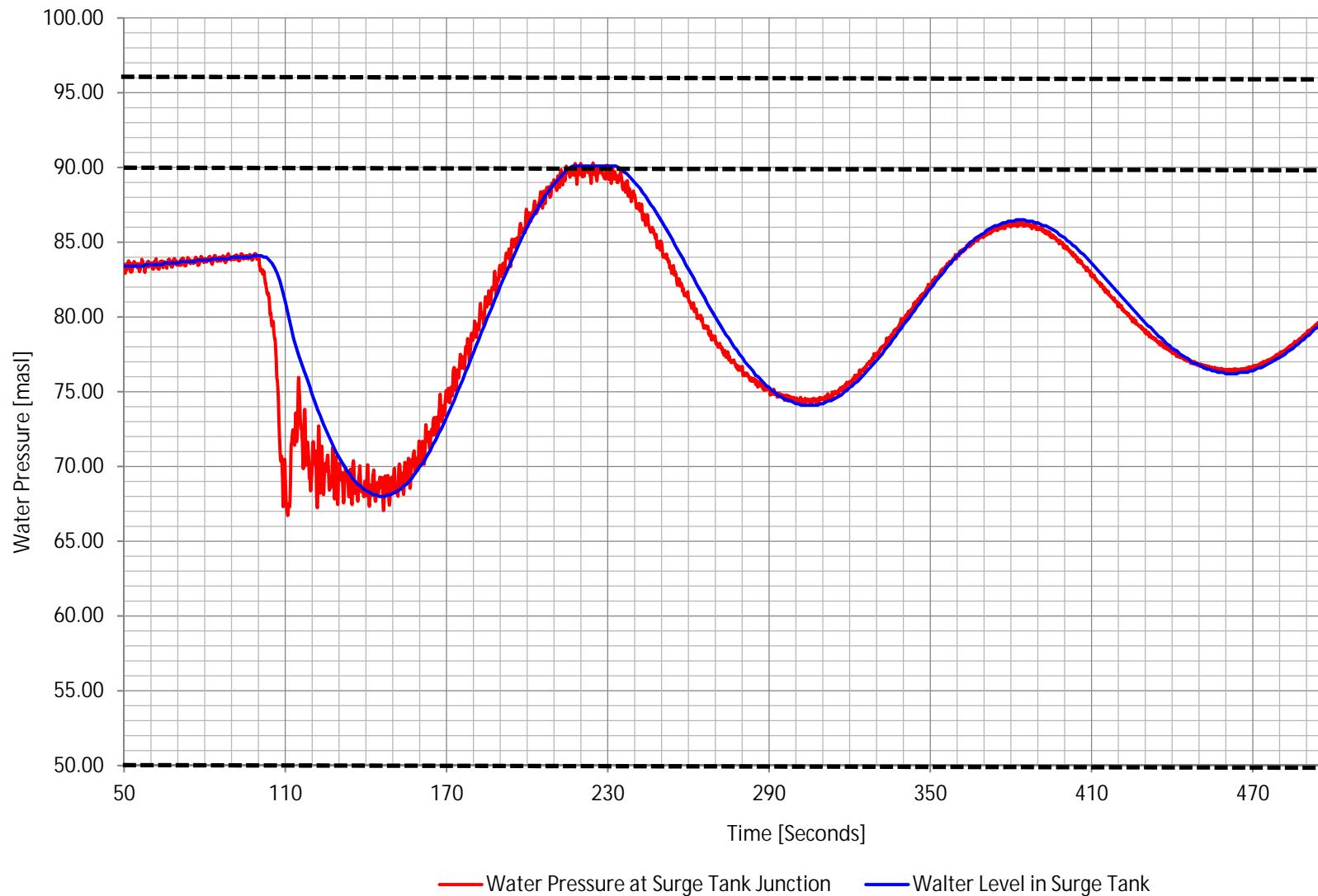
PSPP Manara 220 MW

Load Case 1b



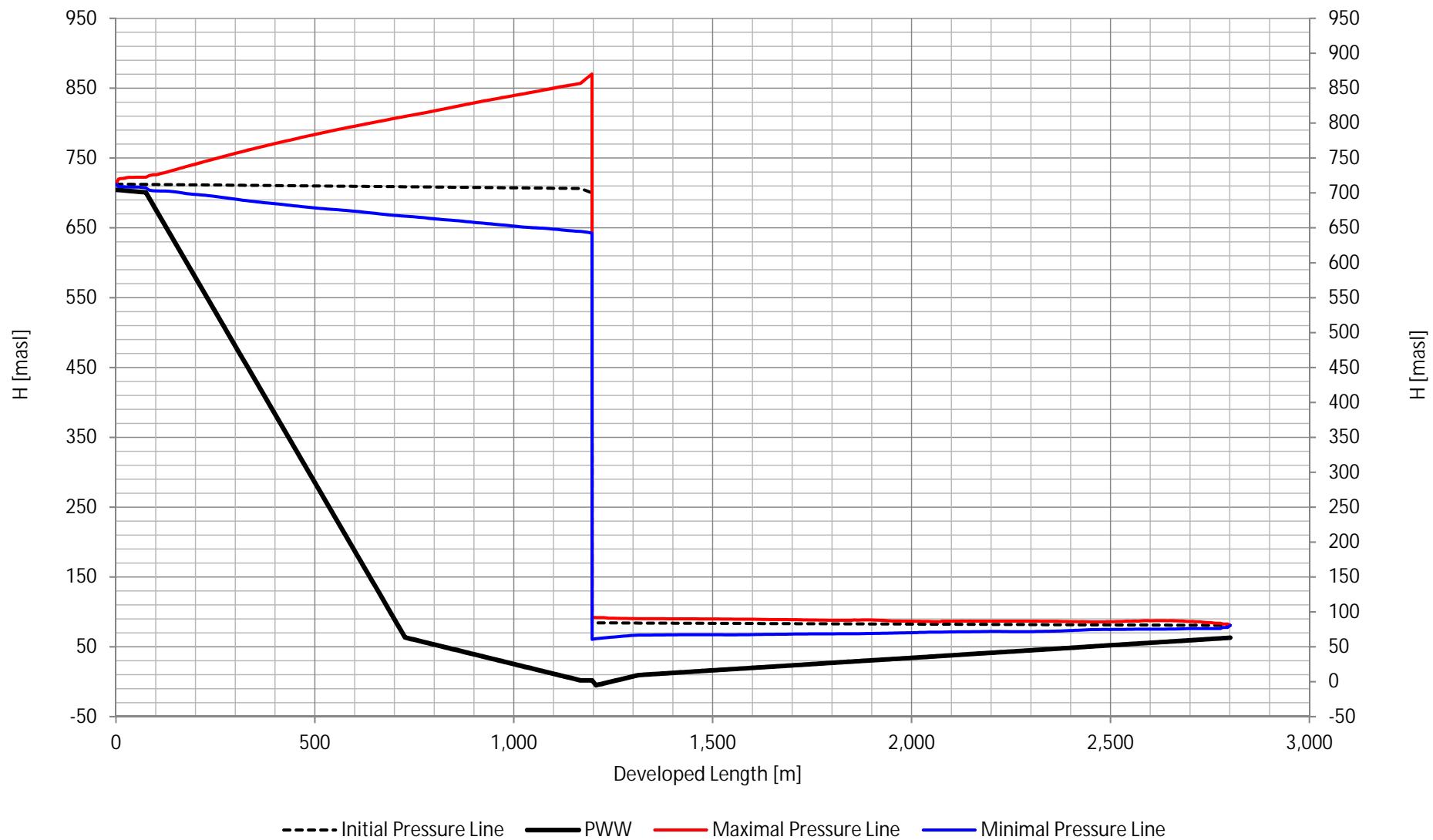
PSPP Manara 220 MW

Load Case 1b



PSPP Manara 220 MW

Load Case 1b



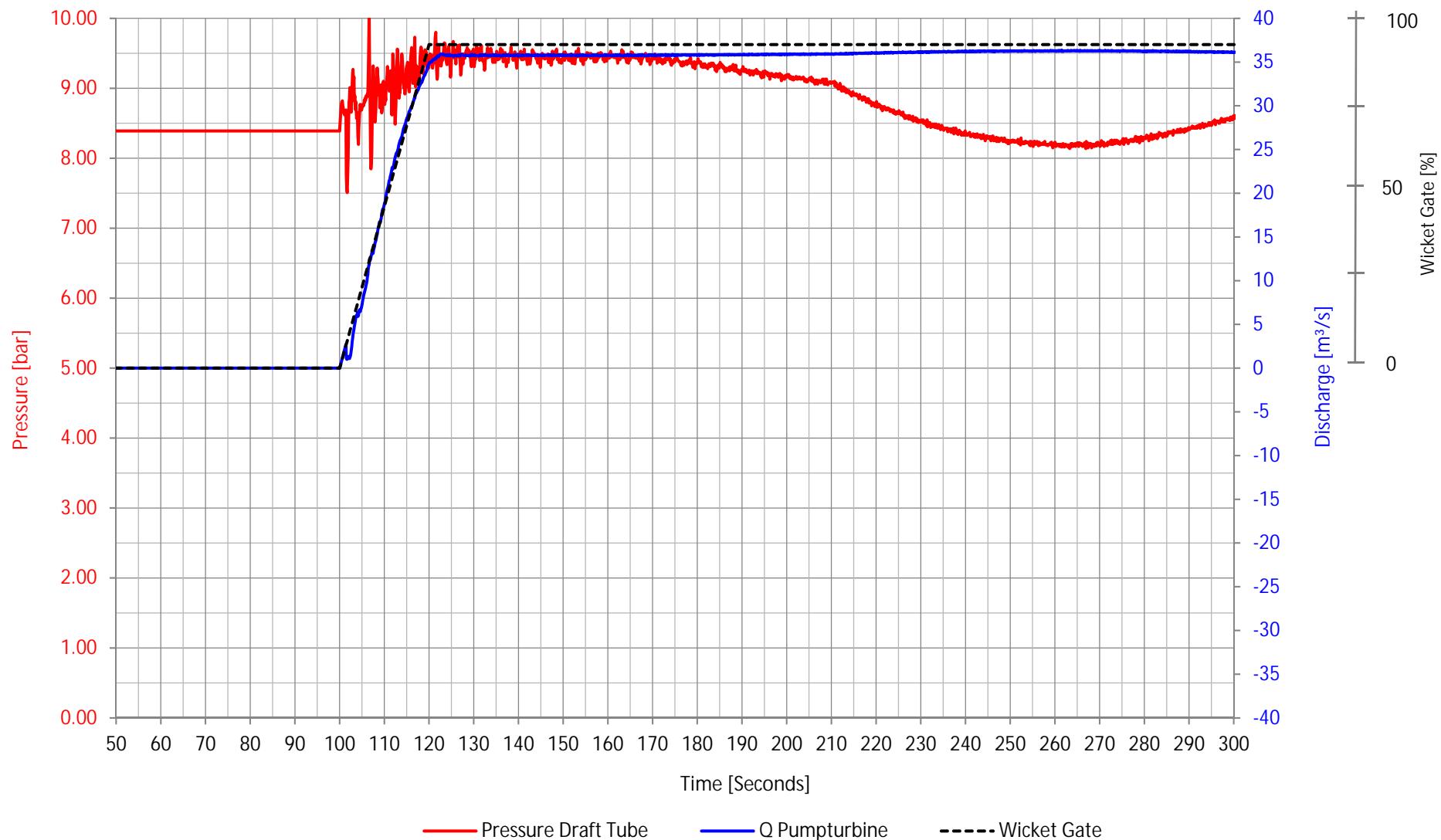
PSPP Manara 220 MW

Load Case 1c



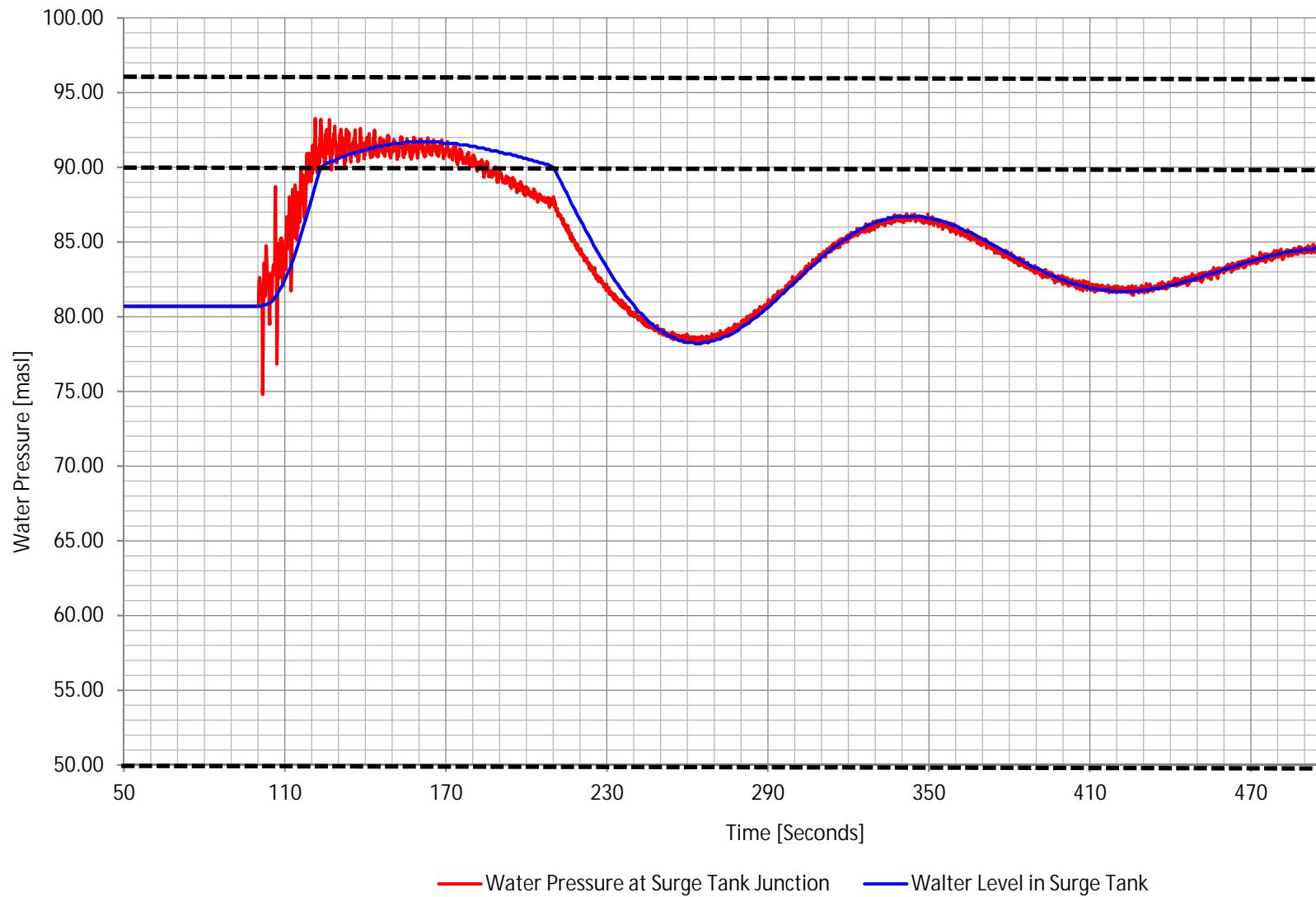
PSPP Manara 220 MW

Load Case 1c



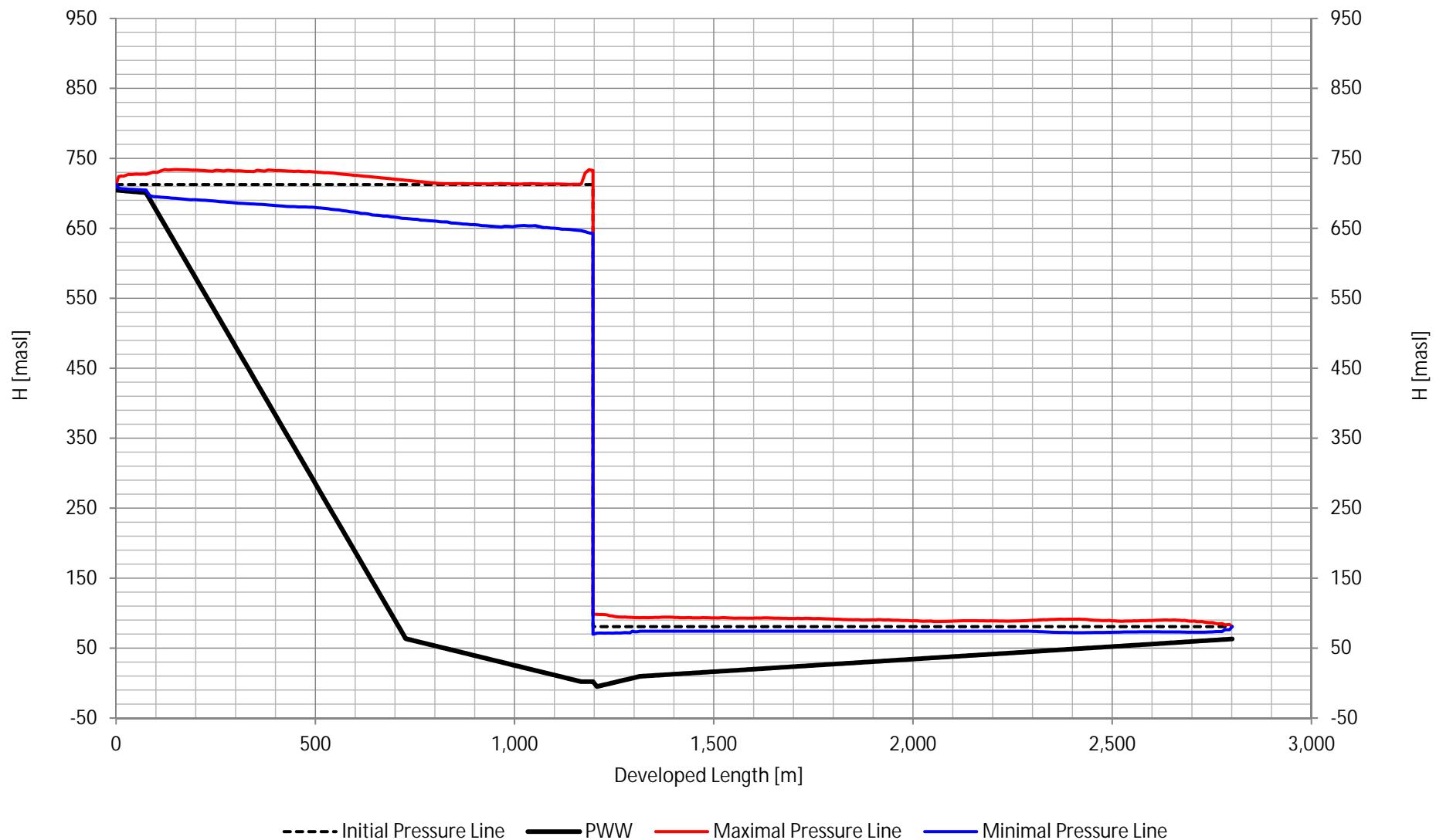
PSPP Manara 220 MW

Load Case 1c



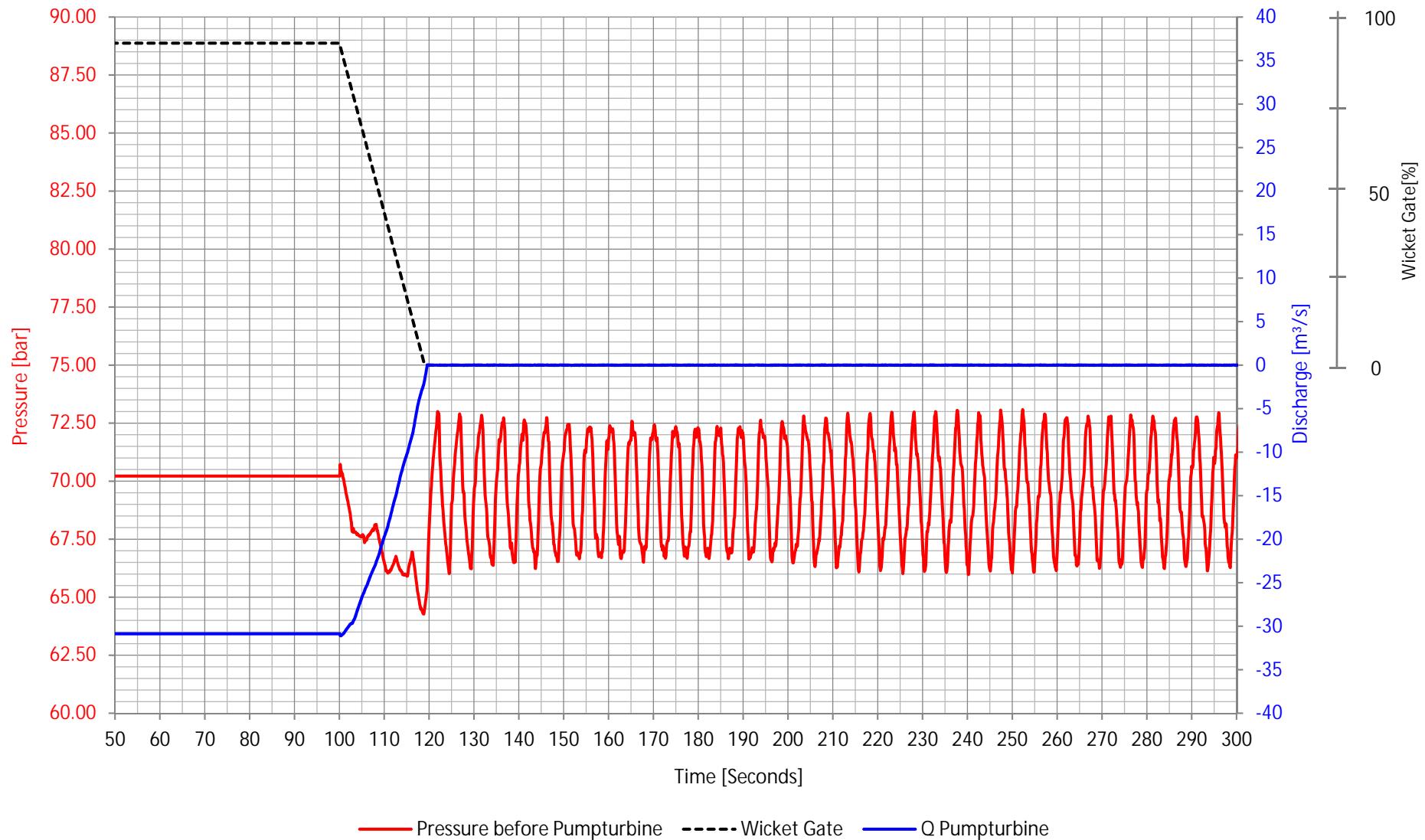
PSPP Manara 220 MW

Load Case 1c



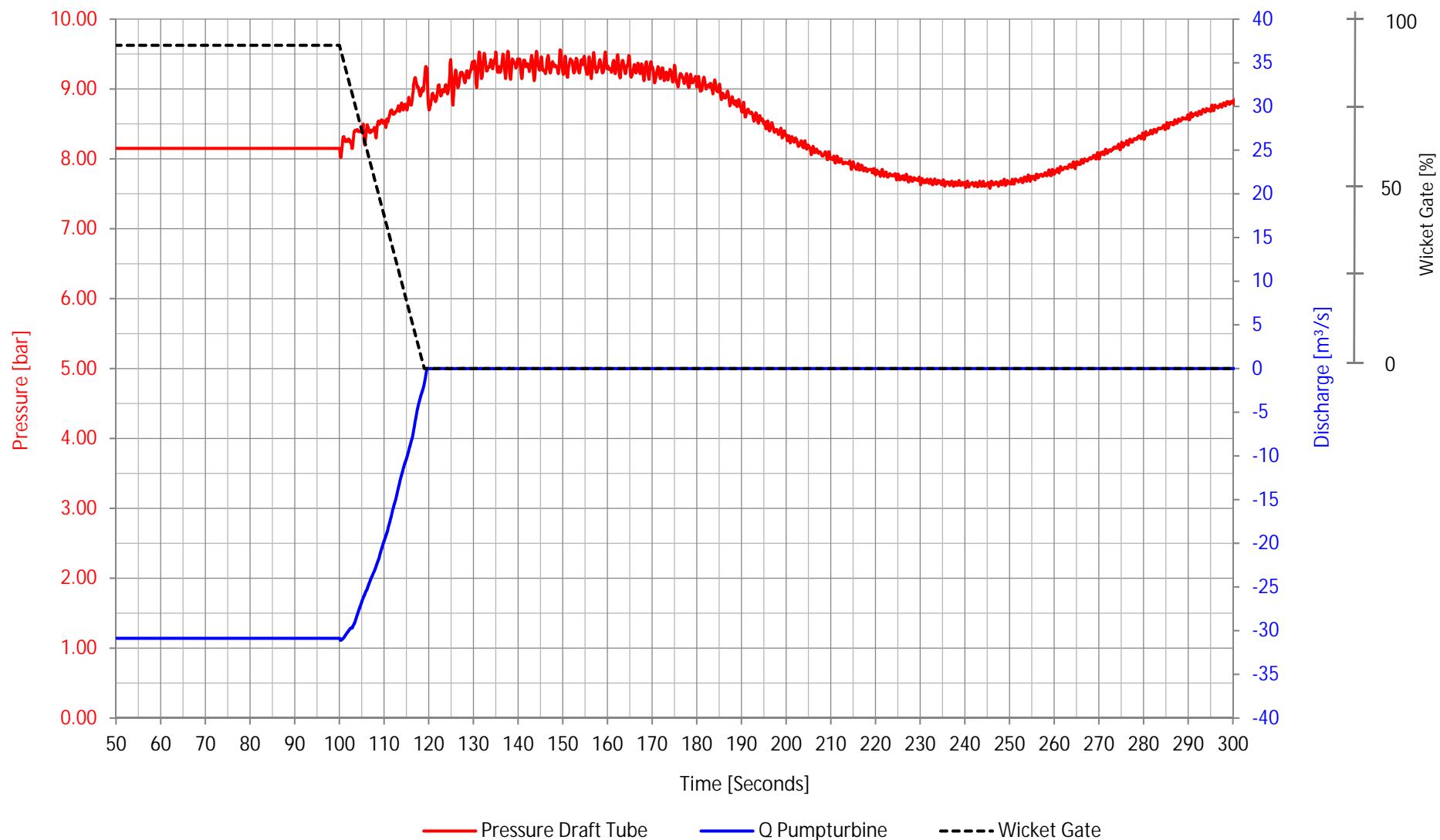
PSPP Manara 220 MW

Load Case 2a



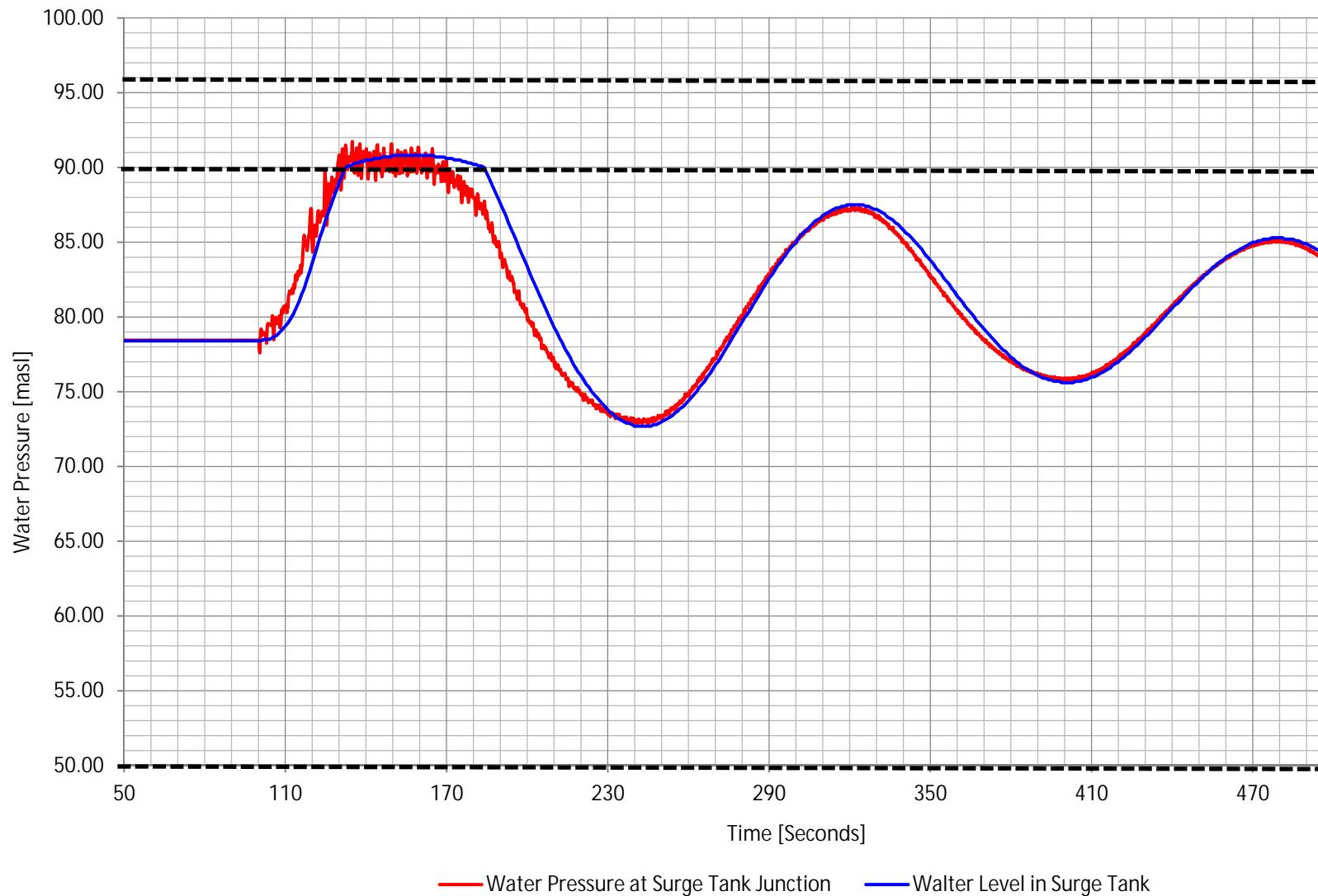
PSPP Manara 220 MW

Load Case 2a



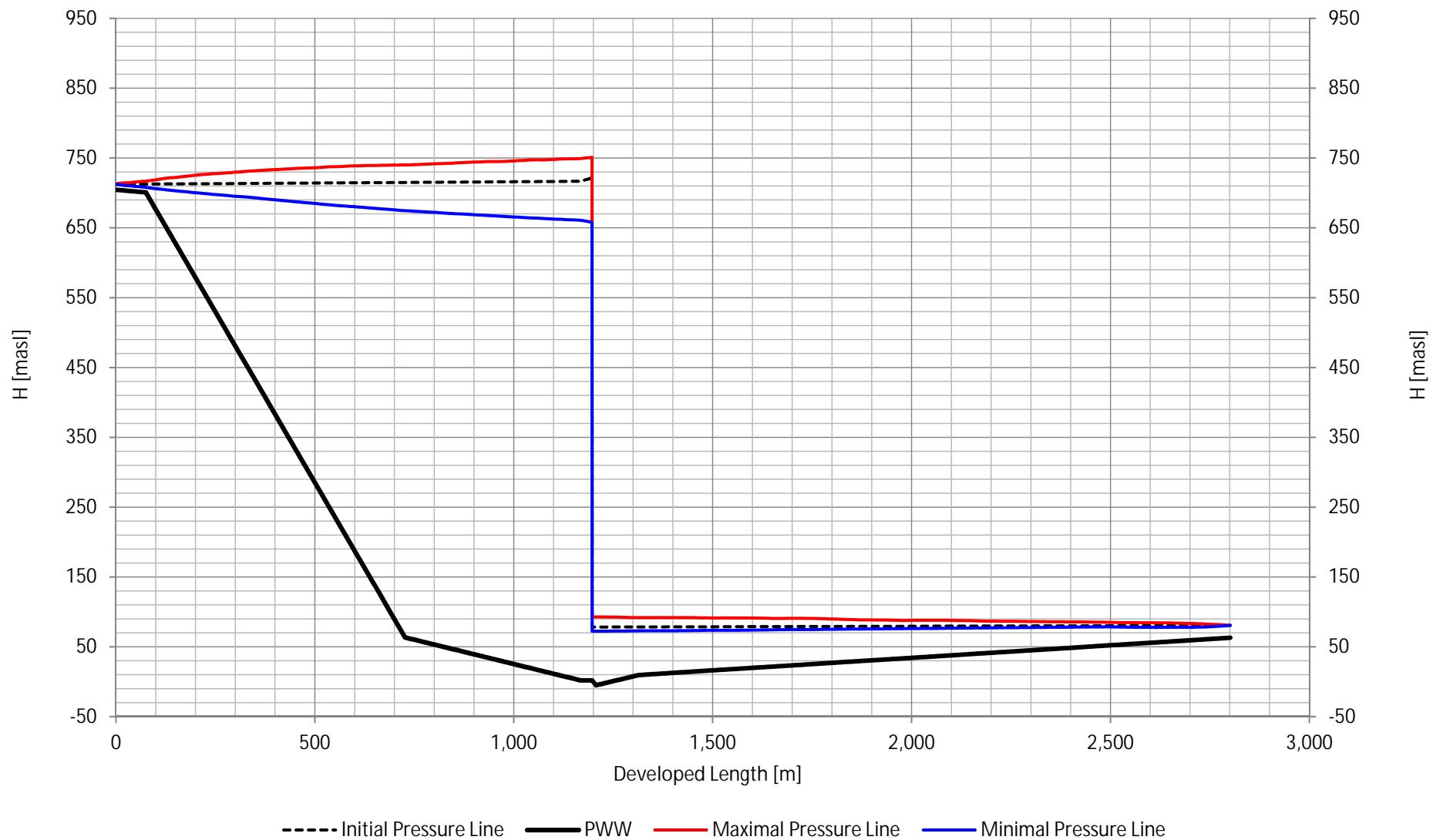
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Load Case 2a



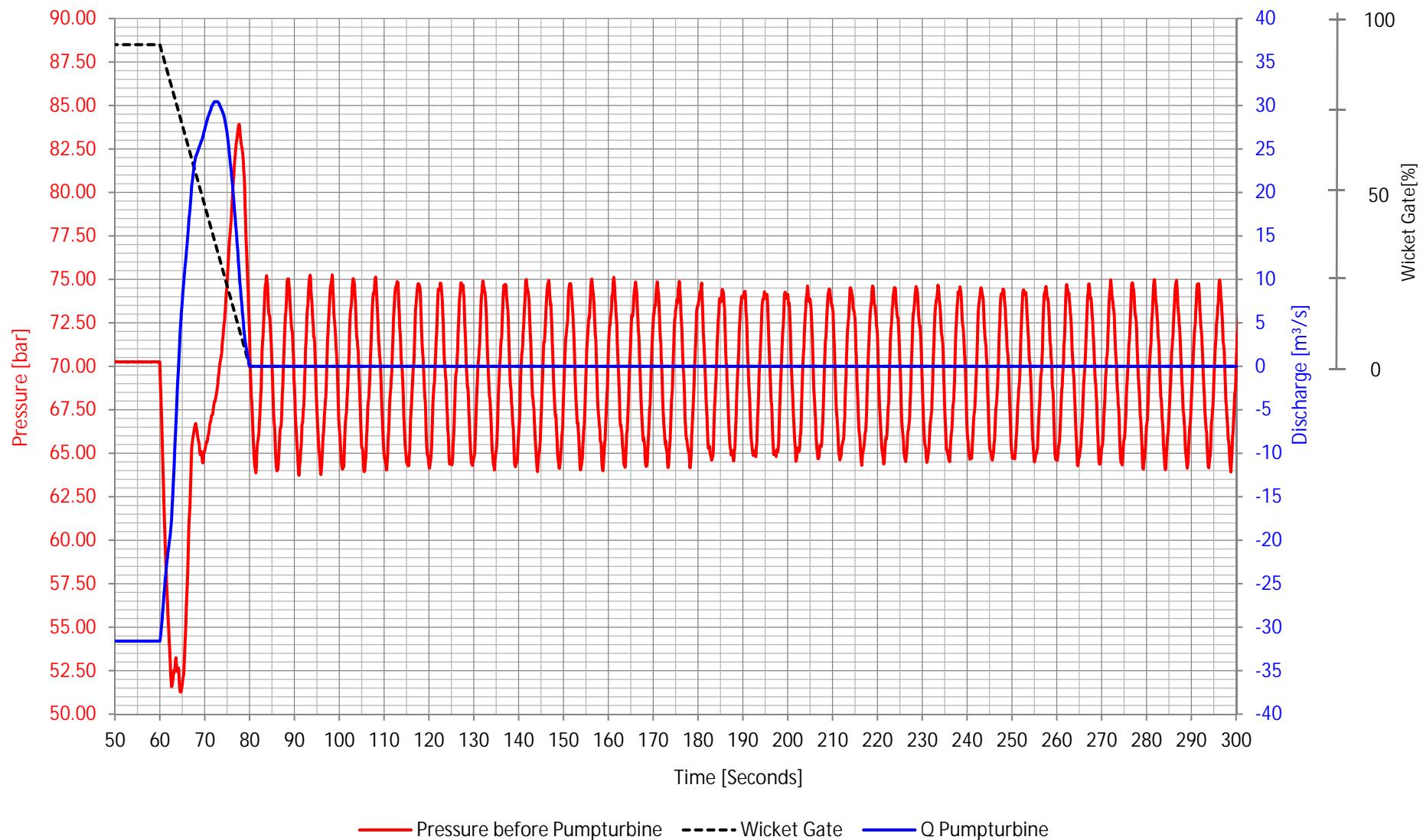
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Load Case 2a



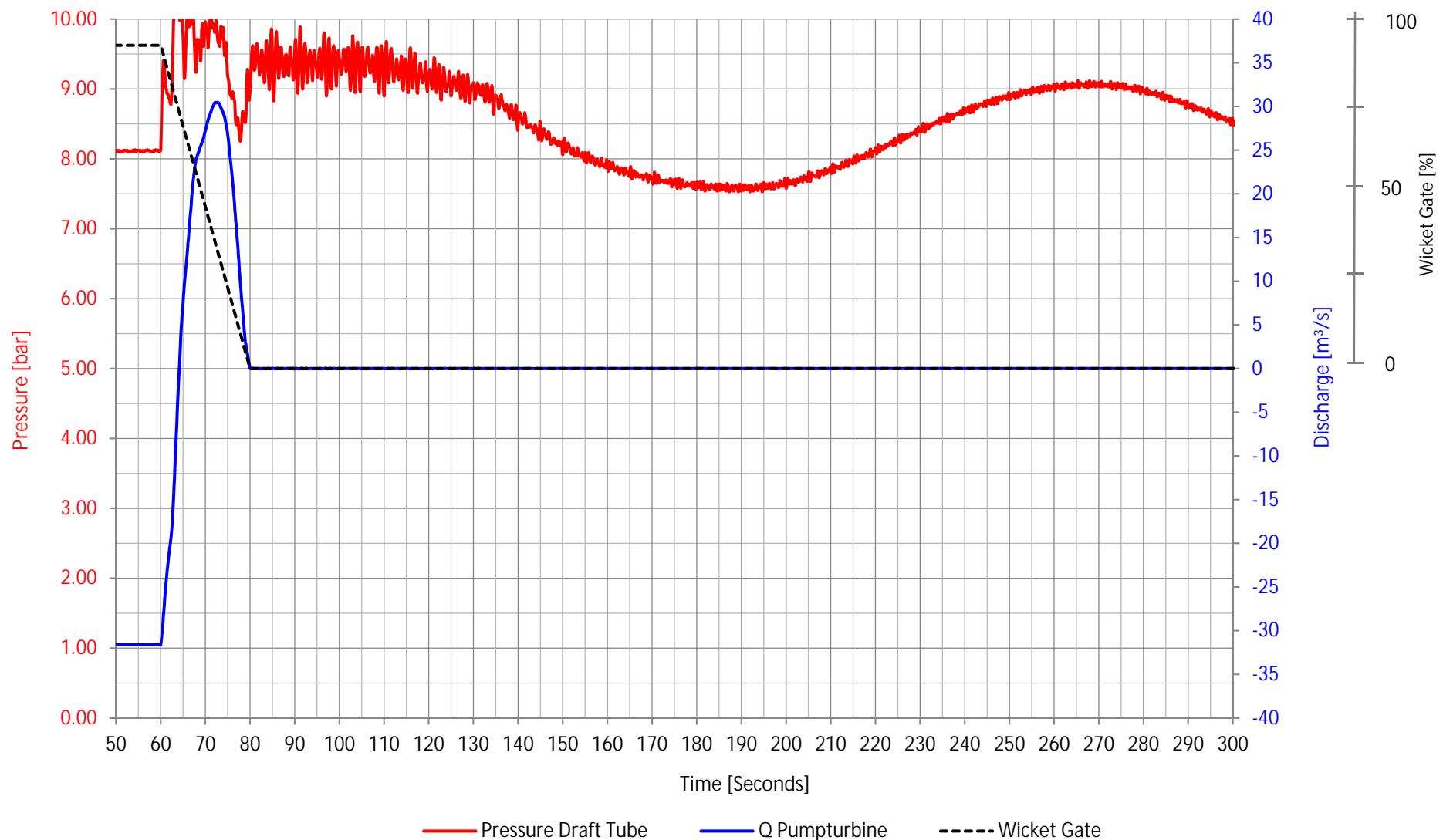
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Load Case 2b



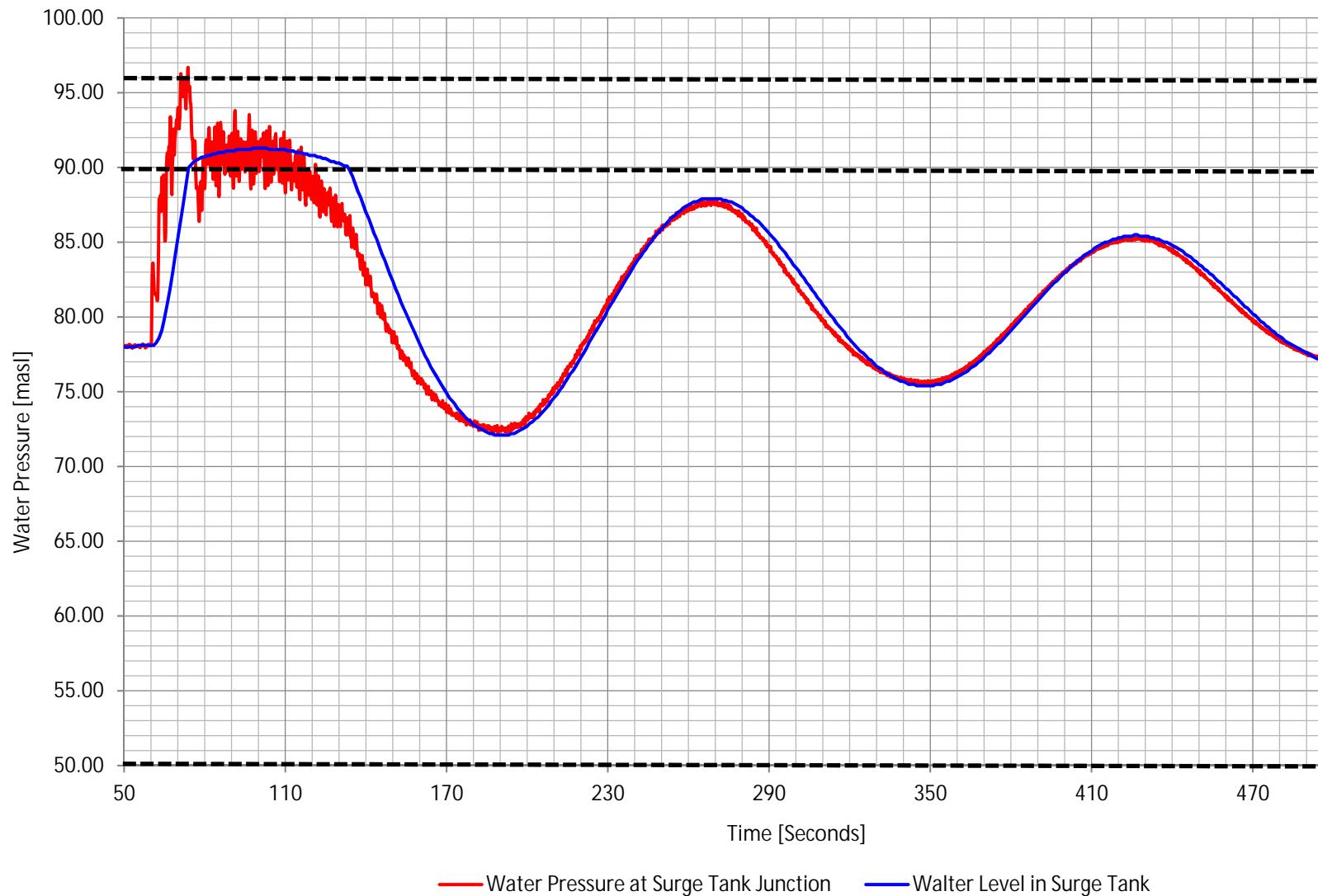
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Load Case 2b



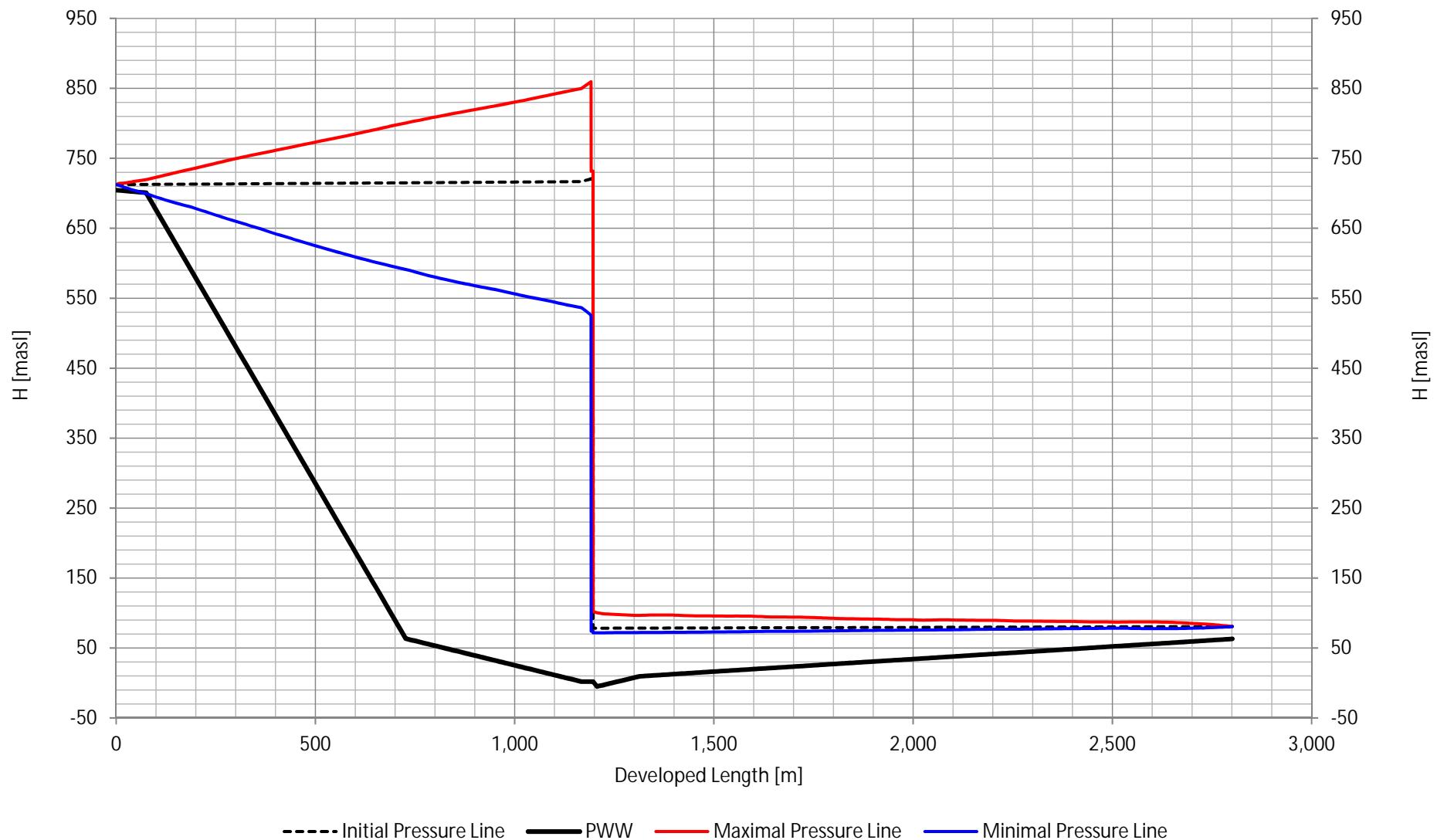
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Load Case 2b



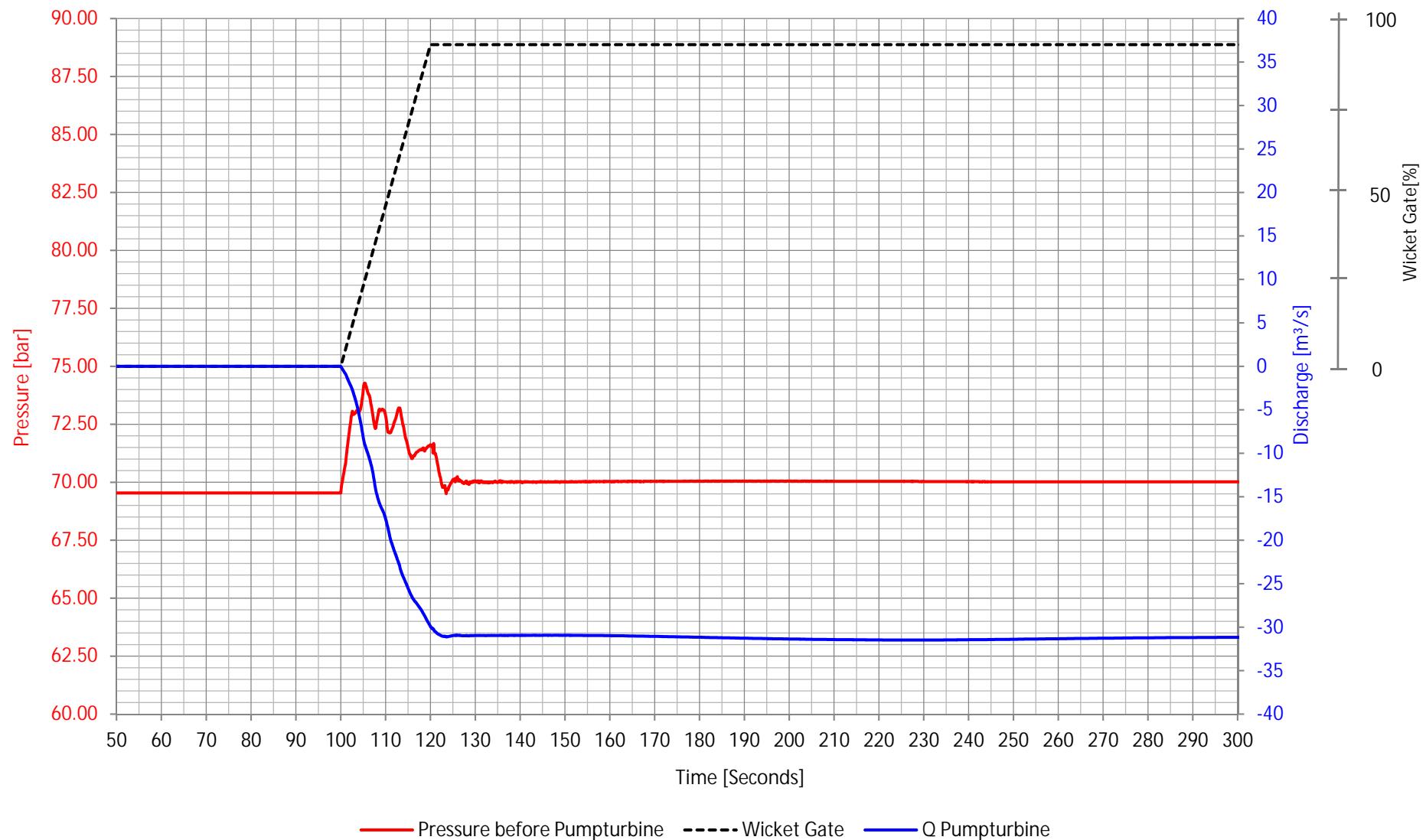
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Load Case 2b



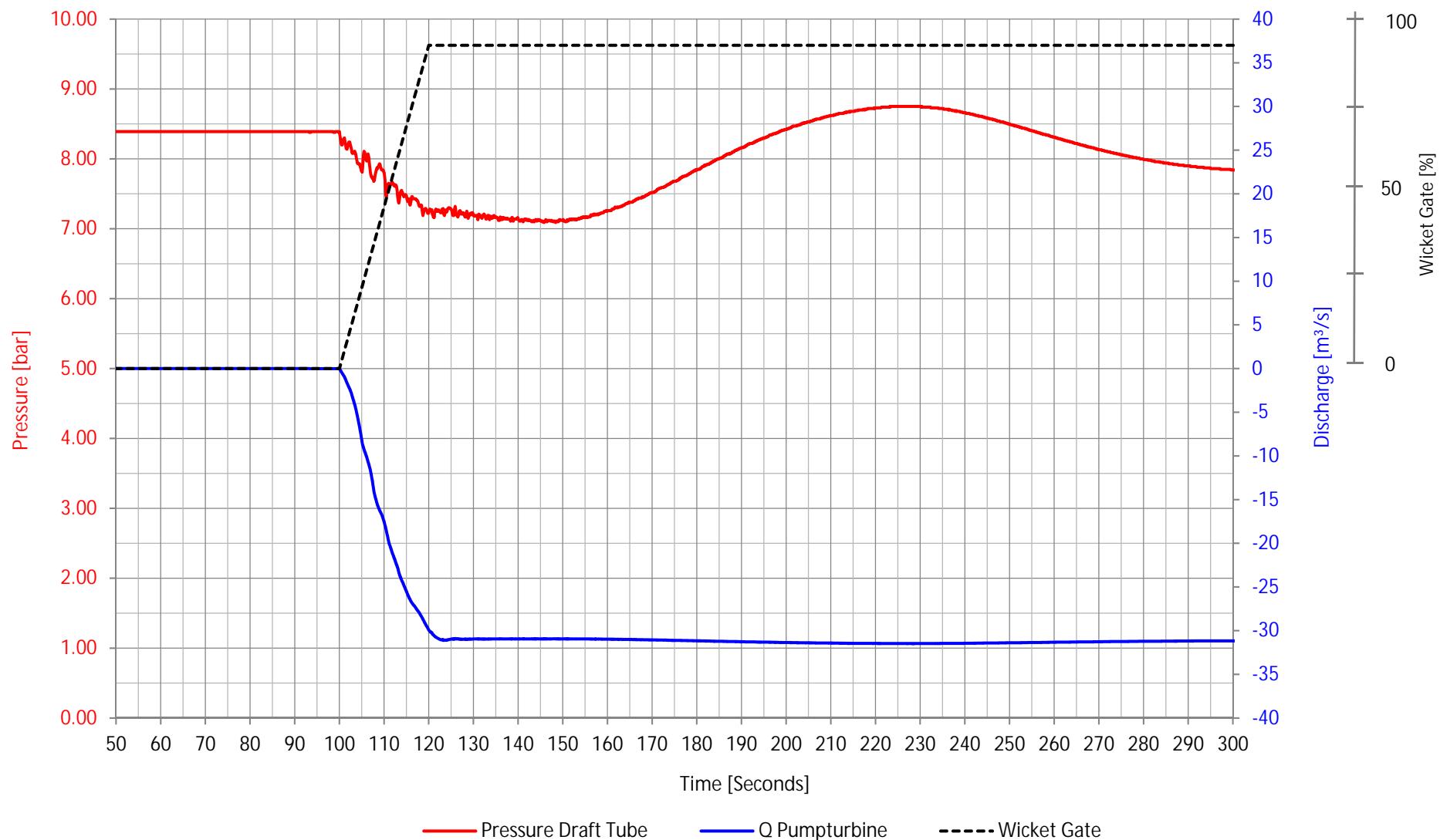
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Load Case 2c



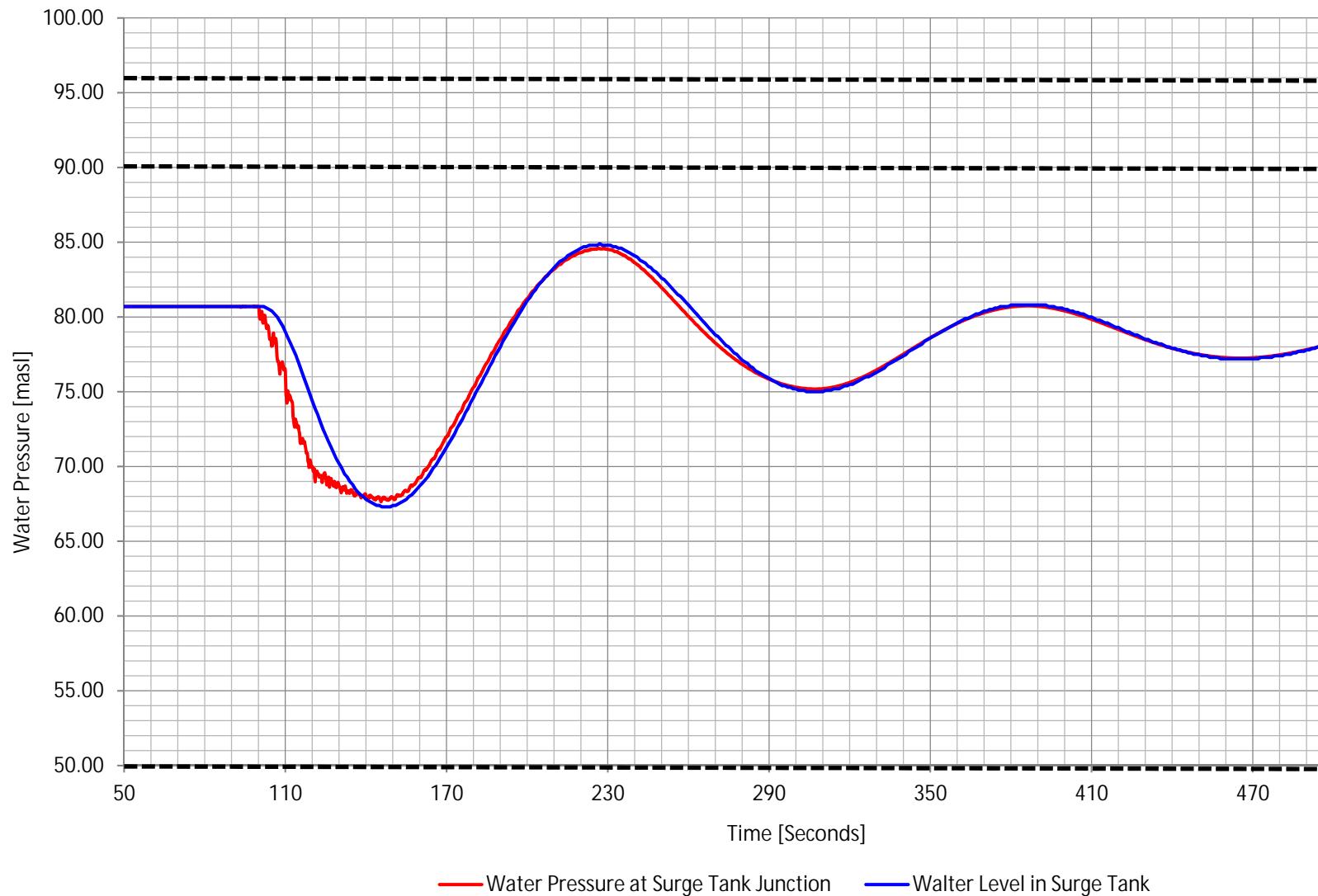
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Load Case 2c



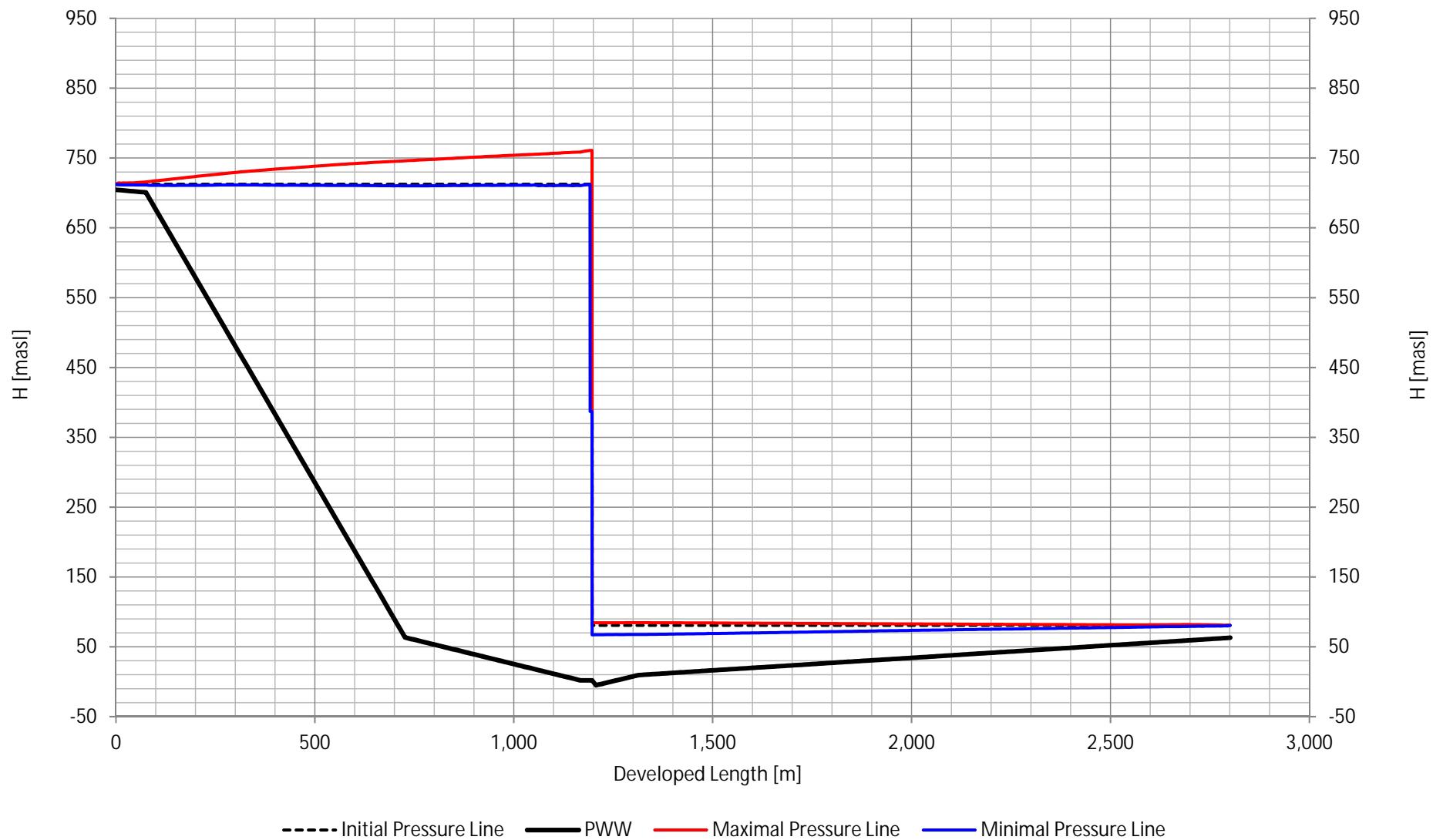
PSPP Manara 220 MW

Load Case 2c



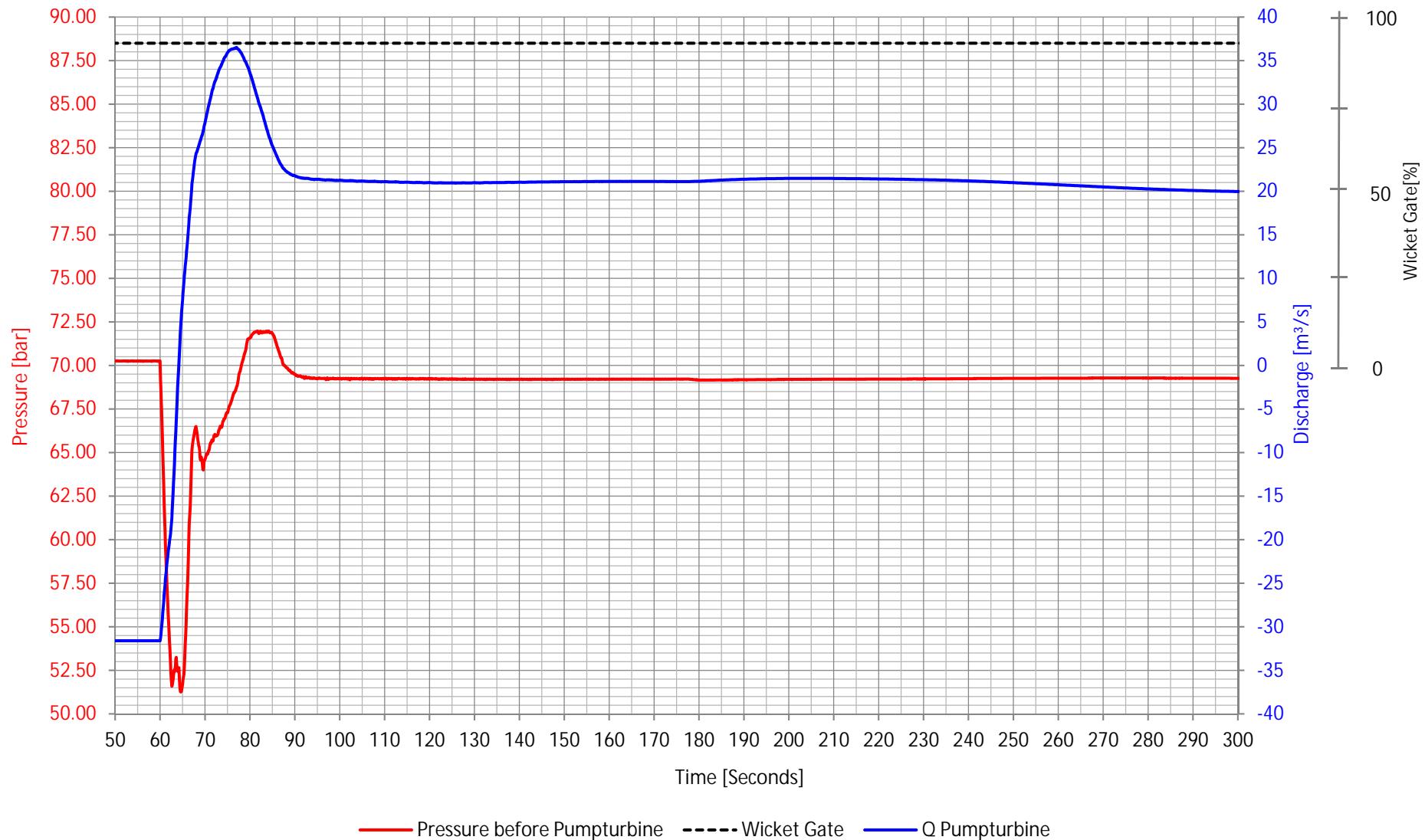
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Load Case 2c



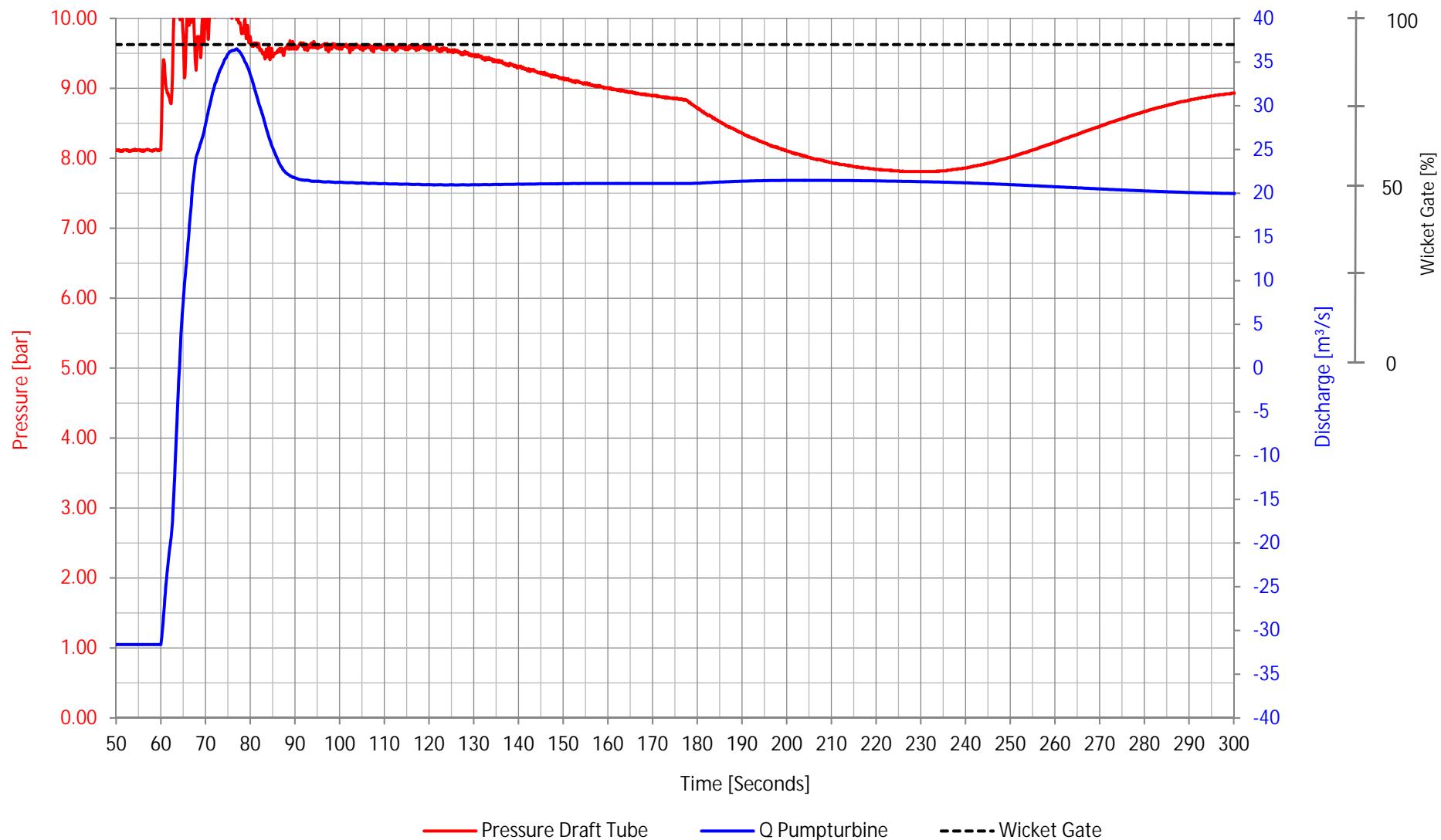
PSPP Manara 220 MW

Load Case 2d



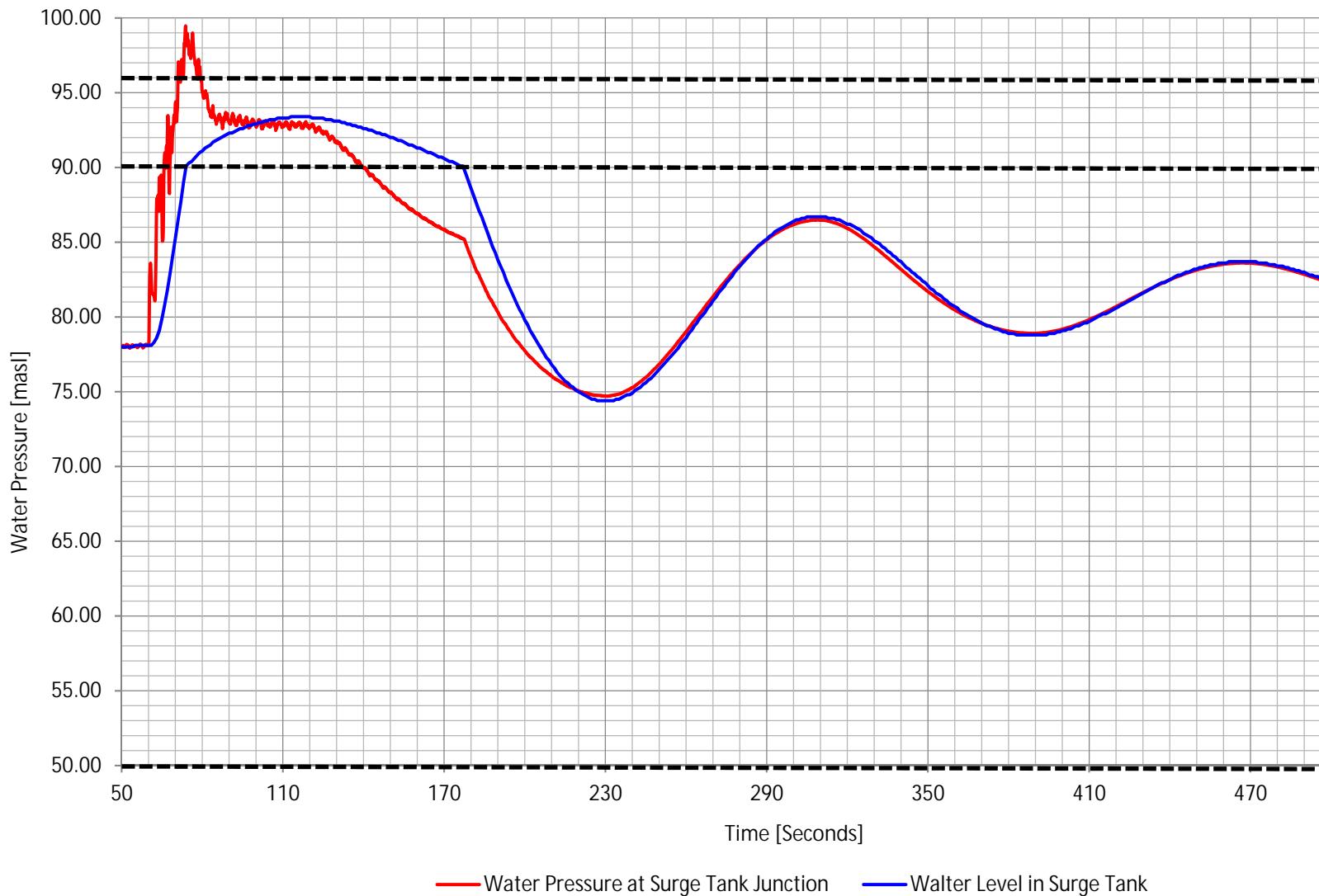
PSPP Manara 220 MW

Load Case 2d



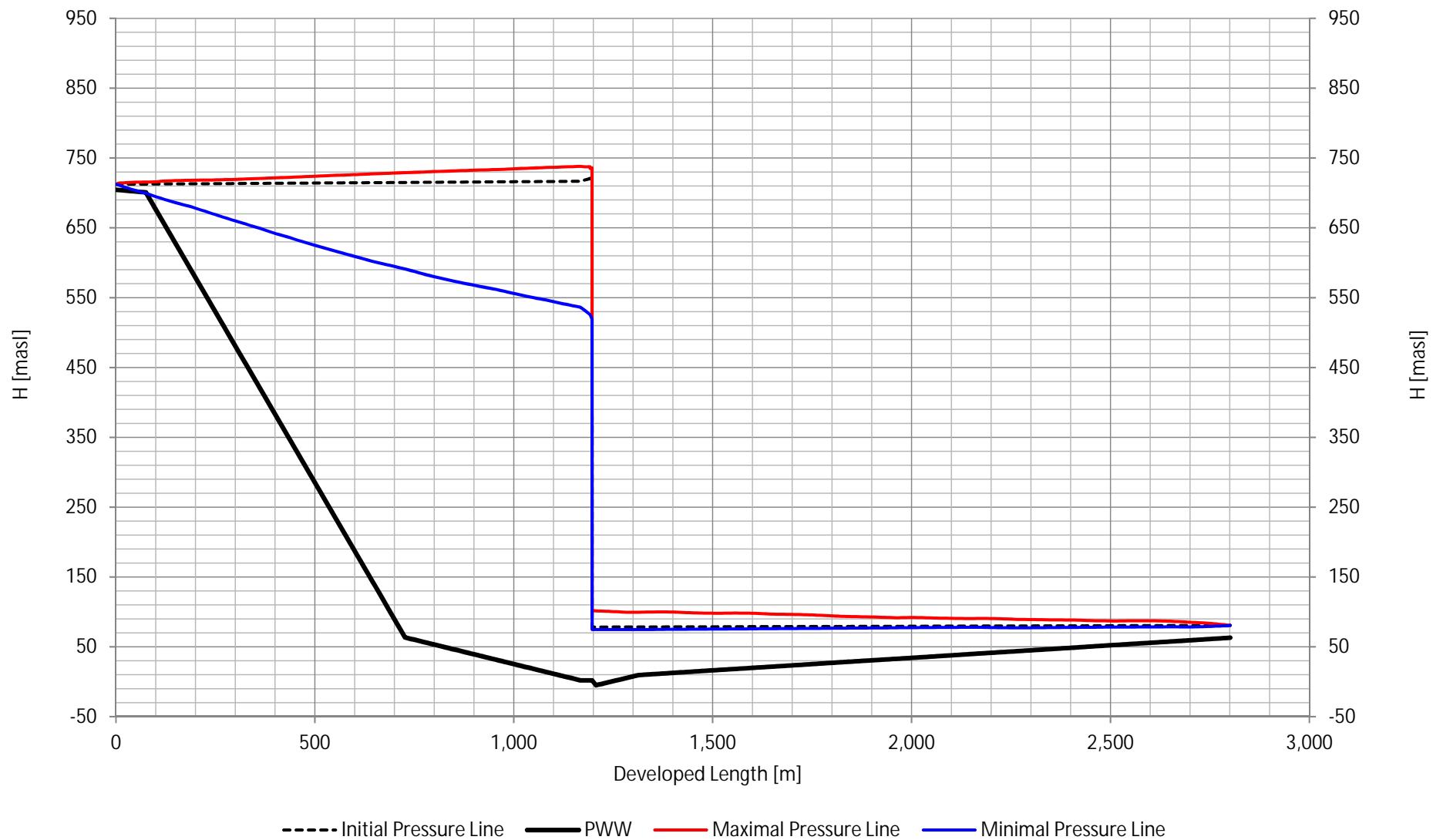
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Load Case 2d



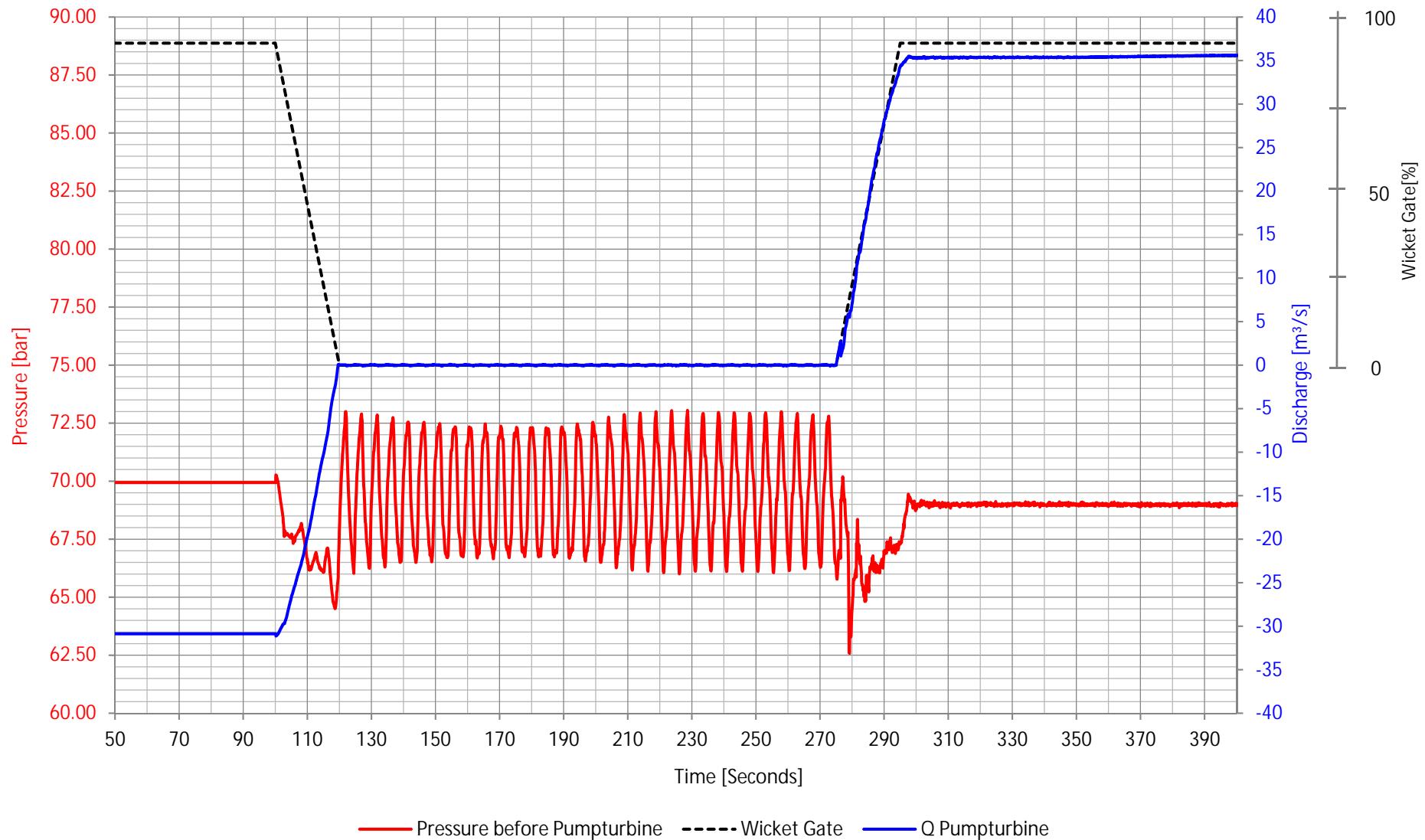
PSPP Manara 220 MW

Load Case 2d



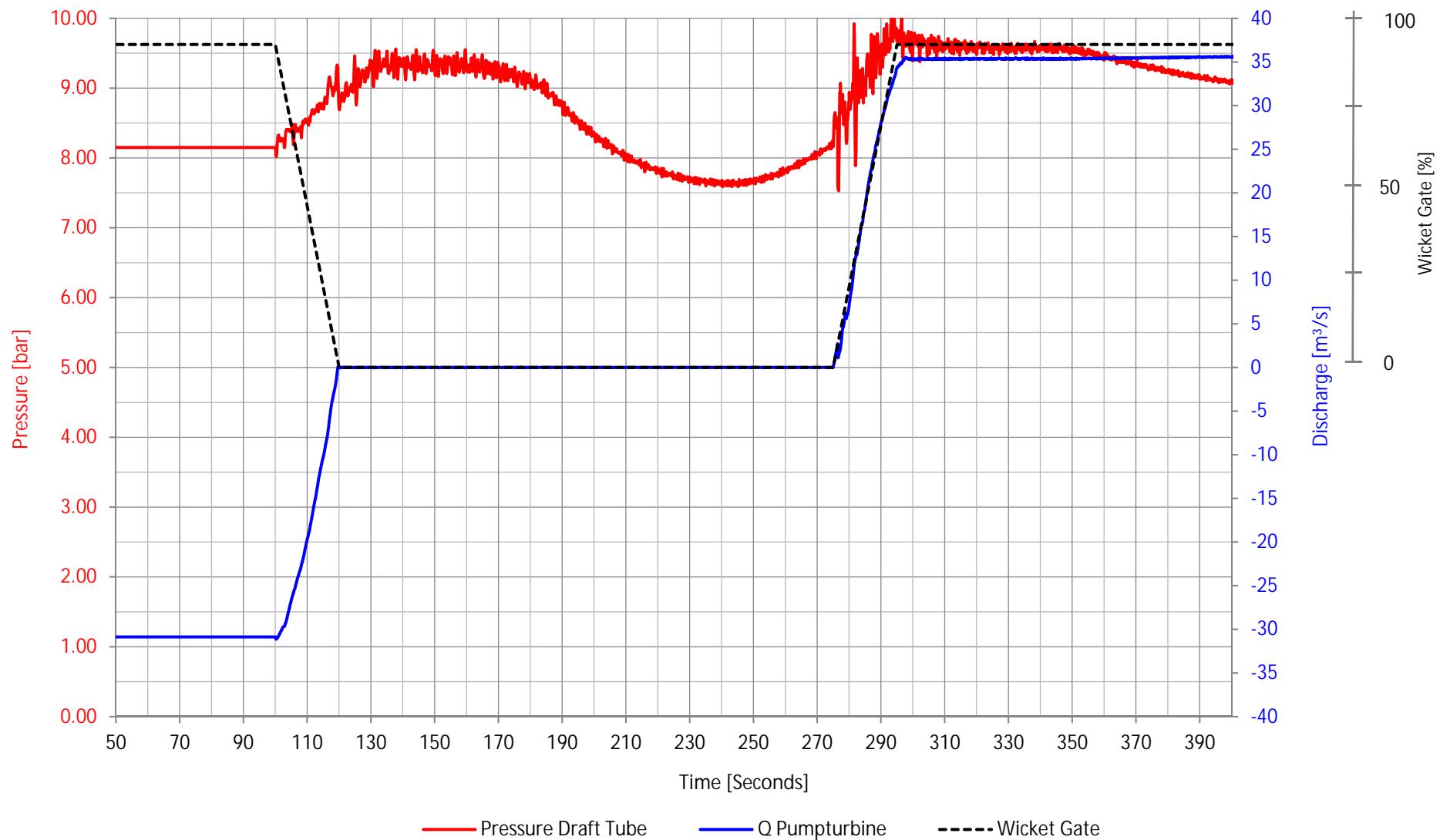
PSPP Manara 220 MW

Load Case 3a



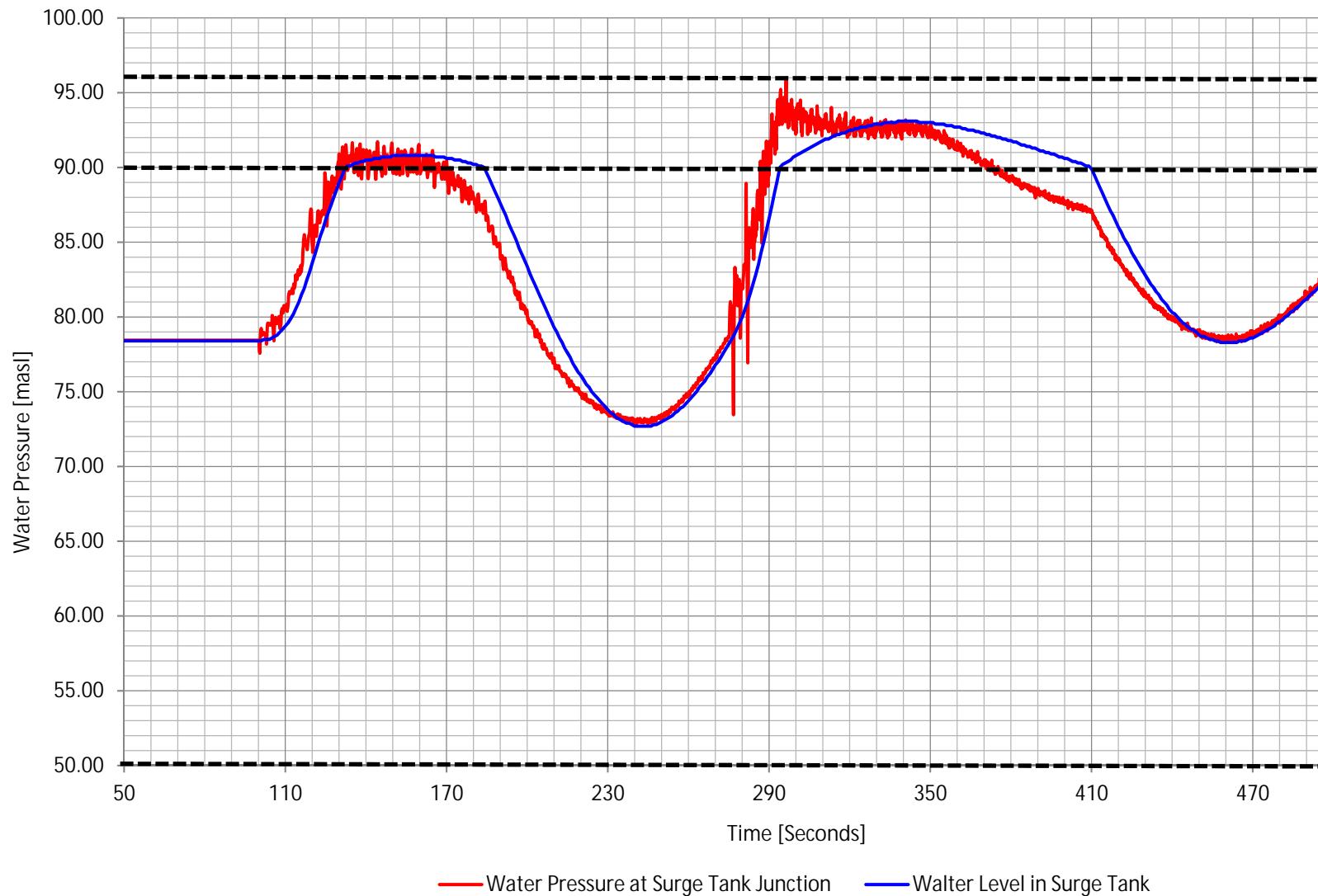
PSPP Manara 220 MW

Load Case 3a



PSPP Manara 220 MW

Load Case 3a



PSPP Manara 220 MW

Load Case 3a

