PRELIMINARY DESIGN REPORT
FOR THE ZIVELI BULK WATER SUPPLY PROJECT

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February 2017
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ABBREVIATIONS

COW  City Of Windhoek  
WML  WML Consulting Engineers (Pty) Ltd.  
NAD  Namibian Dollar  
SABS  South African Bureau of Standards  
SANS  South African National Standard  
ISO  International Organisation for Standardisation  
lpcd  litres per capita per day  
Mio.  Million  
NAD  Namibia Dollar  
PS  Pump station  
PSP  Public standpost for water supply to the inhabitants of informal settlements  
SADC  Southern African Development Community  
ToR  Terms of Reference  
UfW  Unaccounted-for Water  
VSD  Variable Speed Drive (of a pump)  
OD  Outside Diameter  
ND  Nominal Diameter  
hv  Head loss
1 INTRODUCTION

WML Consulting Engineers (Pty) Ltd. has been appointed by Square Foot Developments to prepare a preliminary design for the potable water supply line to the Ziveli Development.

2 DESIGN OBJECTIVE

A potable water supply line shall be designed to convey drinking water from the reservoir at Luipertsvalley via the Auas Mountains to the Ziveli Development.

The pipeline shall be constructed by the Developer of the Ziveli Development and it is understood that the intention is that it shall eventually be taken over by the City of Windhoek.

The pipeline shall be designed in such a way that not only the water demands of the Ziveli development can be met, but also to cater for the anticipated (future) supply of the Utisig Military Base and a number of adjacent plots to the Ziveli Development (Aris Area).

3 DESIGN CHALLENGES

A number of challenges exist for the design of the intended pipeline. The rough and rocky terrain over the mountain requires careful planning of the pipeline route in order to allow for access during construction and later for maintenance of the pipeline.

In addition, the geodetic height differences between the starting point and the highest point near the Uitsig Military Base is in access of 250m which limits the choice of pipe materials in order to withstand the required pumping pressures. An optimum solution between pump capacities, material constraints and construction cost is thus essential.

4 PIPELINE ROUTE

A number of different route options have been discussed and investigated. For the purpose of this report and preliminary design, one specific preferred route by the Developer has been investigated.

The route starts at the existing concrete reservoir near the Luipertsvalley Military Base from where it follows an existing gravel road and later along the western side of the shooting range on a slight ascending slope. After the shooting range, the pipe joins an existing track up to the top of the mountain over steep and rocky terrain.

It is envisaged to construct a ground reservoir on the highest point of the pipeline route to function as a pressure break and intermediate storage. From this reservoir water will gravitate downwards towards the new reservoir at Ziveli and the other planned offtakes.
A layout of the proposed pipeline route and an elevation profile with the most prominent points are shown below.
5 DESIGN PARAMETERS

5.1 Water Demand

The water demand for the pipeline was established based on figures obtained from town planners and the developer. In addition provision has been made for a future take off of the Uitsig Military Base.

The average daily water demand was thus established as shown in the table below:

<table>
<thead>
<tr>
<th>Type Area</th>
<th>Quantity (units)</th>
<th>persons per unit</th>
<th>l/c/d</th>
<th>l/unit/d</th>
<th>Total PE</th>
<th>Total Consumption (l/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot 5</td>
<td>26</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>104</td>
<td>15,600</td>
</tr>
<tr>
<td>Ziveli</td>
<td>311</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>1244</td>
<td>186,600</td>
</tr>
<tr>
<td>Plot 9</td>
<td>16</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>64</td>
<td>9,600</td>
</tr>
<tr>
<td>Plot 10</td>
<td>28</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>112</td>
<td>16,800</td>
</tr>
<tr>
<td>Plot 11</td>
<td>26</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>104</td>
<td>15,600</td>
</tr>
<tr>
<td>Plot 12</td>
<td>28</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>112</td>
<td>16,800</td>
</tr>
<tr>
<td>Plot 13</td>
<td>28</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>112</td>
<td>16,800</td>
</tr>
<tr>
<td>Plot 15</td>
<td>28</td>
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<td>600</td>
<td>112</td>
<td>16,800</td>
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<td>26</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>104</td>
<td>15,600</td>
</tr>
<tr>
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<td>26</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>104</td>
<td>15,600</td>
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<td>4</td>
<td>150</td>
<td>600</td>
<td>116</td>
<td>17,400</td>
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<tr>
<td>Harmony</td>
<td>45</td>
<td>4</td>
<td>150</td>
<td>600</td>
<td>180</td>
<td>27,000</td>
</tr>
<tr>
<td>Uitsig Military Base</td>
<td>1</td>
<td>100</td>
<td>100</td>
<td>10000</td>
<td>100</td>
<td>10,000</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>618</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>2568</strong></td>
<td><strong>380,200</strong></td>
</tr>
</tbody>
</table>

Total expected population: 2568 (PE)

Total Expected average daily water demand: \( \approx 381.00 \) (m\(^3\)/day)

The existing water reservoir at Luipertsvalley has a storage capacity of 2678m³.

The CoW has been contacted to confirm the availability of the required 381 m³/d. However, the CoW is currently not able to enter the SCADA system to verify current demands and can thus not confirm the required availability at this stage.

For the purpose of this report it has thus been assumed that the required average daily demand of 381 m³/d can be provided by the CoW from the reservoir at Luipertsvalley. Should this assumption be proven wrong, an additional ground reservoir next to the existing concrete reservoir would have to be constructed or other alternatives investigated.

5.2 Design Flow

According to the “Guidelines for Human Settlement Planning and Design” published by CSIR in 2000, the design flow for water mains to reservoirs shall be minimum 1.5 x annual average daily demand (chapter 9, page 28).

Thus, the design flow has been established from the demand figures given above as follows:
• Design Flow Gravity Line SECTION A (Reservoir Luipertsvalley to new pumpstation):  
  1.5 x 381 m³/d = 571.5 m³/d = 7.94 l/s (20hrs gravity feed during pumping hours)

• Design Flow Pumpline SECTION B (new pumpstation to new reservoir on top of mountain):  
  1.5 x 381 m³/d = 571.5 m³/d = 7.94 l/s (20hrs pumping)

• Design Flow Gravity Line SECTION C (New reservoir on top of mountain to Ziveli):  
  1.5 x 371 m³/d = 556.5 m³/d = 6.44 l/s (24hrs gravity flow)

As later shown in the preliminary design, a possible reduction of pumping hours was investigated. It was found that a reductions of pump hours below 20 hours would increase the velocity and thus friction losses in such a way that this would economically not be feasible.

As previously mentioned, the above calculated design flows are based on the 1.5 x annual average daily demand as suggested by the “Red Book”. Should the CoW however allow for a reduced design flow equal to the annual average daily demand, the design flows for the identified Sections A to C would be as follows:

• Section A: 5.29 l/s (20hrs gravity feed during pumping hours)  
• Section B: 5.29 l/s (20hrs pumping)  
• Section C: 4.29 l/s (24hrs gravity flow)

An alternative design for such possible reduction in design flow has also been carried out and the calculations are attached in Annexure B.

### 5.3 Discharge Pressure

In general, a minimum discharge pressure of 1.5bar has been assumed in the design. The maximum discharge pressure shall not exceed 7 bar.

No allowance in discharge pressure has been made to reach the Uitsig Base directly from the pumpline. The planned site for the intermediate reservoir near the Uitsig Base is located about 30m below the base itself and an additional height of about 45m would be required to reach the based plus discharge into an elevated tank. It was considered uneconomical to include this additional height into the design as it would increase the already high pumping pressures and required pipe classes. In case of the Uitsig Base intending to draw water from the new supply scheme, a separate pump installation and pipeline from the new intermediate reservoir (storage for Uitsig Base considered) would have to be installed by the military base themselves.
As for the gravity line, high discharge pressures are expected alone due to the high difference in altitude between the intermediate reservoir on the mountain and the take of points in the valley. A pressure reducing valve will therefore have to be installed to reduce the discharge pressures below 7 bar at a strategic determined point.

6 PIPE MATERIALS

First and foremost it is the high pressure which limits the choice of pipeline material.

HDPE and uPVC pipes are available up to 20 bar working pressure, which is insufficient looking alone at the geodetic height differences to be overcome.

In consideration of the rocky terrain, the most economical solution would be laying the pipe above ground over long sections of the pipe alignment. This would however not be possible with uPVC pipes due to their vulnerability towards UV light.

Ductile Iron pipes or Galvanized Mild Steel pipes would be the logical options. While DI pipes are extremely expensive, GMS pipes could be the preferred option here.

The following materials and pressure classes were found available on the local market:

<table>
<thead>
<tr>
<th>Pipe material</th>
<th>Available Diameter</th>
<th>Max. working Pressure [bar]</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>from [mm] to [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>uPVC</td>
<td>50 to 315</td>
<td>20</td>
<td>low</td>
</tr>
<tr>
<td>HDPE</td>
<td>16 to 160</td>
<td>20</td>
<td>low</td>
</tr>
<tr>
<td>DI</td>
<td>80 to 1200</td>
<td>20</td>
<td>very high</td>
</tr>
<tr>
<td>GMS medium duty</td>
<td>15 to 150</td>
<td>16</td>
<td>high</td>
</tr>
<tr>
<td>GMS heavy duty</td>
<td>15 to 150</td>
<td>25/30*</td>
<td>high</td>
</tr>
</tbody>
</table>

* 30 bar can be special ordered

Considering above, the design would be based on an optimum combination of pipe materials, considering the required pressure class, soil conditions and material cost.

While the preliminary design covered under this report considers one pipe material per section (as described below), the detail design should focus to differentiate on lower possible pressure classes of the chosen material in each section. So can possibly in Section B and Section C a large portion of heavy duty pipes be replaced by medium duty pipes. Also the possible use of uPVC or HDPE pipes after the pressure reducing valve in Section C should be investigated in the detail design, considering the then available survey data and details on the presence of hard rock.
7 PIPELINE SYSTEM AND FUNCTIONS

The deciding factors of high water pressure, hard rock conditions and economic considerations have led to the following pipeline system:

7.1 Section A (Exist. Reservoir to Pump Station)

Water shall be drawn from the existing ground level reservoir at Luipertsvalley and gravitated in an uPVC pipe to a point as high as possible but still providing sufficient supply security via gravitation, where an in-line booster station shall be constructed.

This uPVC pipe section shall be constructed underground, as the soil conditions in the lower laying areas are not as hard to motivate an above ground installation.

In addition a lower pressure class can be used in the gravity section, avoiding higher capital cost compared to a pump installation directly at the reservoir.

This pipe section must however be adequately designed for hydraulic purposes to ensure gravitation to the pump station and also to avoid flow velocities in access of 2m/s in pumping conditions.

7.2 Section B (Pump Station to Intermediate Reservoir)

The water shall be pumped by the inline booster station up to the intermediate reservoir near the Uitsig Military Base.

This section consist mainly of steep and rocky terrain and an above ground installation is therefore preferred. Due to above ground installation and high water pressures, the pipe material in this section was chosen to be GMS.

There is a possibility that some sections (especially just after the pump station) might be feasible to construct underground with a different pipe material (uPVC, HDPE). This would however have to be verified during the detail design. For concept design purposes however, the whole section was assumed to be constructed above ground with GMS pipes.

The intermediate reservoir would be constructed at a suitable place below the Uitsig Military Base (see image below).

Although the Uitsig Base should also be served in future from this pipeline, the supply pressure at the reservoir was chosen to be just sufficient to fill the reservoir (1 bar). The Uitsig Military Base would have to install an additional booster pump from the reservoir to overcome the about 30m in height difference to the base plus an additional 15m for a possible future elevated reservoir.

The intermediate tank would be constructed from pre-stressed steel on a concrete foundation. (typical Abeco ground tank installation)
7.3 **Section C (Intermediate Reservoir to Ziveli)**

From the Intermediate reservoir a gravity line should be provided down to the final reservoir at the Ziveli Development.

The pipeline would join the existing surfaced road just below the military base and follow its alignment all the way to the erf boundary of the Ziveli development. Although some sections might be possible as an underground installation (to be verified during the detail design), an above ground installation with GMS pipes has been assumed for the concept design. From route investigations and experiences during the road construction the evidence of hard rock can be assumed almost throughout this section. An above ground installation is thus the more likely option and was therefore chosen as the basis for the concept design. Nevertheless, this will have to be confirmed during the detail design, as especially towards the end of the section softer ground could be expected.

The height difference from the intermediate reservoir to the Ziveli reservoir is in its extremes as much as 170m, resulting in high static pressures. The pipe material has thus (and due to above ground installations) been chosen to be GMS.

In order to supply the identified take off points towards the end of the pipeline with a discharge pressure not exceeding 7 bar, a pressure reducing valve will be required.

A strategic position has been determined in the concept design. Depending on the outcome of the investigations during the detail design if an underground installation could be possible in the lower areas, the final position of the pressure reducing valve might be shifted in order to allow a more inexpensive pipe material (uPVC) to be used in that circumstance.
The schematic section below highlights the described pipeline system and functions.

8 PRELIMINARY DESIGN CALCULATIONS

Hydraulic calculations have been carried out with Civil Designer Software and by hand calculations using Darcy’s friction factor equation and the Colebrook-White equation.

According to the road construction the evidence of hard...rAnnexure A, the major results are summarized below:

8.1 Section A (Exist. Reservoir to Pump Station)

Pipe: uPVC 160mm PN9

Evaluation of pumping/water flow hours:
24hrs: Q = 6.61 l/s, v= 0.38 m/s, head loss = 1.67 m
20hrs: Q = 7.94 l/s, v= 0.46 m/s, head loss = 2.30 m
16hrs: Q = 9.92 l/s, v= 0.57 m/s, head loss = 3.60 m

Thus a water flow of 20 hrs has been assumed for the design (in connection with the pumping hours of Section B below)

Q = 7.94 l/s (20hrs water flow)

v = 0.46 m/s

head loss = 2.30m

Pressure at Pump Station = 1.17 bar → Selection o.k

8.2 Section B (Pump Station to Intermediate Reservoir)

Pipe: GMS 100mm Heavy Duty

Evaluation of pumping/water flow hours:
Thus 20 hrs for pumping has been assumed for the design.

Q = 7.94 l/s (20hrs water flow)
\( v = 0.94 \text{ m/s} \)
head loss  = 20.90m

Required Pump Pressure = 27 bar

Discharge Pressure at Intermediate Reservoir = 1.45 bar → Selection o.k

8.3 Section C (Intermediate Reservoir to Ziveli)

Pipe: GMS 80mm Heavy Duty

Q = 6.44 l/s (24hrs gravity flow)
\( v = 1.29 \text{ m/s} \)
head loss  = 88.01m

Discharge Pressure at Ziveli Reservoir = 6.96 bar → Pressure sufficient, however to be reduced.

Pressure reducing valve at km 5+930, reducing by 5 bar from 10.36 to 5.36 bar. This results in discharge pressures at the offtakes between 4.5 and 5.4 bar. The reduced discharge pressure at the Ziveli Reservoir is then 1.96 bar.

8.4 Alternative Hydraulic Design

As mentioned under 5.2 above, an alternative hydraulic design was carried out for a reduced design flow equal to the annual average daily demand, as the perception was gained that the CoW might be willing to accept such reduced design flow.

The calculations for this alternative design are attached in Annexure B.
9 PROPOSED PIPELINE DESIGN

9.1 Proposed Design

As mentioned under Based on the above design calculation and system descriptions, the following pipeline system is proposed:

Section A (Exist. Reservoir to Pump Station)
  uPVC 160mm PN9
  Length = 1470 m; Q = 7.94 l/s, v = 0.46 m/s

Section B (Pump Station to Intermediate Reservoir)
  GMS 100mm Heavy Duty
  Length = 2210 m; Q = 7.94 l/s, v = 0.94 m/s, pump pressure = 27 bar

Section C (Intermediate Reservoir to Ziveli)
  GMS 80mm Heavy Duty
  Length = 3590 m; Q = 6.44 l/s, v = 1.29 m/s

An overview of the proposed system is shown in the graphic overleaf.
9.2 **Alternative Hydraulic Design**

The alternative design with a reduced design flow results in an expected decrease of pipe diameters as summarized below:

- **Section A (Exist. Reservoir to Pump Station)**
  - uPVC 110mm PN9
  - Length = 1470 m; Q = 5.29 l/s, v = 0.64 m/s

- **Section B (Pump Station to Intermediate Reservoir)**
  - GMS 80mm Heavy Duty
  - Length = 2210 m; Q = 5.29 l/s, v = 1.06 m/s, pump pressure = 28.5 bar

- **Section C (Intermediate Reservoir to Zivel)**
  - GMS 65mm Heavy Duty
  - Length = 3590 m; Q = 4.29 l/s, v = 1.20 m/s

An overview of the alternative system is shown in the graphic overleaf.
ANNEXURE A

Preliminary Design Calculations

Hydraulic Design - SECTION A (Exist. Reservoir to Pumpstation)

- \( H_{\text{geo Start}} = 1819 \text{ MSL} \)
- \( H_{\text{geo End}} = 1805 \text{ MSL} \)
- Preset Pressure [bar]: 0 (reservoir empty)
- \( \Delta H_{\text{geo}} = 14 \text{ m} \)
- \( L [\text{m}] = 1470 \)
- Duration of water flow = 20 hrs
- \( Q [\text{m}^3/\text{day}] = 571.5 = 0.007938 \text{ m}^3/\text{s} = 7.94 \text{ l/s} \)
- Pipe D [mm] = 148.88 (internal diameter) (160mm uPVC, PNG)
- \( k [\text{mm}] = 0.1 \)
- \( A [\text{m}^2] = 0.0174086 \)
- Water in pipeline: 25.6 \( \text{m}^3 \)
- \( v [\text{m/s}] = \frac{Q}{A} = 0.4559541 \)

Friction Losses:

- \( \text{RE} = \frac{v \cdot D}{v} = 6.79 \cdot 10^4 > 2320 \) turbulent flow
- \( \varepsilon = \frac{k}{D} = 6.72 \cdot 10^{-4} \)
- \( \lambda = 0.022 \) (from Nomogram)
- \( \zeta_{wv} = \frac{\lambda}{D} \cdot L = 217 \)
- \( nv = \zeta_{wv} \cdot \left( \frac{v^2}{2g} \right) = 2.30 [\text{m}] \)
- Water pressure at End of Pipeline: 11.70 mWS

Water Pressure:

- at Chainage [m]: 350 (low point) \( h_{\text{geo}} = 1777 \text{ MSL} \)
  - \( p = 5376.1 \text{ Pa} \)
  - Actual pressure = 4.15 bar
  - pressure ok
- at Chainage [m]: 1470 (PS) \( h_{\text{geo}} = 1805 \text{ MSL} \)
  - \( p = 22579.6 \text{ Pa} \)
  - Actual pressure = 1.17 bar
  - pressure ok
Hydraulic Design - SECTION B (Pumpstation to Intermediate Reservoir)

\[
\begin{align*}
H_{\text{geo}} \text{ Start} & = 1806 \text{ MSL} & \text{H}_{\text{geo}} \text{ End} & = 2040 \text{ MSL} \\
\text{Preset Pressure [bar]} & = 27 & \Delta H_{\text{geo}} & = -235 \text{ m} \\
L [\text{m}] & = 2210 & \text{duration of water flow} & = 20 \text{ hrs} \\
Q [\text{m}^3/\text{day}] & = 571.5 & = 0.007938 \text{ m}^3/\text{s} & = 7.94 \text{ l/s} \\
\text{Pipe D [mm]} & = 103.9 (\text{internal diameter}) & (100\text{mm GMS, heavy duty}) \\
k [\text{mm}] & = 0.1 \\
A [\text{m}^2] & = 0.0084786 & \text{Water in pipeline} & = 18.7 \text{ m}^3 \\
\nu [\text{m/s}] & = Q / A & = 0.9361873
\end{align*}
\]

Friction Losses:

\[
\begin{align*}
\text{RE} &= (\nu \times D) / \nu = 9.73E+04 > 2320 & \bullet \text{ turbulent flow} \\
\varepsilon &= k / D = 9.62E-04 \\
\lambda &= 0.022 \text{ (from Nomogram)} \\
\zeta_{hv} &= \lambda / D^4 L = 468 \\
hv &= \zeta_{hv} \times (\nu^2 / 2g) = 20.90 \text{ [m]} & \text{Water pressure at End of Pipeline:} & 14.10 \text{ mWS} \\
& & \bullet & 1.41 \text{ bar}
\end{align*}
\]

Water Pressure:

\[
\begin{align*}
\text{at Chainage [m]} &= 470 \text{ (at road)} & \rho &= 43611.4 \text{ Pa} & \bullet & 0.44 \text{ bar} \\
\text{h}_{\text{geo}} &= 1832 \text{ MSL} & \text{actual pressure} &= 23.86 \text{ bar} & \text{pressure ok} \\
\text{at Chainage [m]} &= 1500 \text{ (high point)} & \rho &= 136185.5 \text{ Pa} & \bullet & 1.39 \text{ bar} \\
\text{h}_{\text{geo}} &= 1993 \text{ MSL} & \text{actual pressure} &= 6.81 \text{ bar} & \text{pressure ok} \\
\text{at Chainage [m]} &= 2210 \text{ (Int. Res.)} & \rho &= 205068.6 \text{ Pa} & \bullet & 2.05 \text{ bar} \\
\text{h}_{\text{geo}} &= 2040 \text{ MSL} & \text{actual pressure} &= 1.45 \text{ bar} & \text{pressure ok}
\end{align*}
\]
Hydraulic Design - SECTION C (Gravityline Reservoir to End)

\[ H_{geo} \text{ Start } = 2043.6 \text{ MSL} \quad H_{geo} \text{ End } = 1899 \text{ MSL} \]

\[ \text{Preset Pressure [bar]} = 0.5 \quad \text{H}_{geo} = 144.6 \text{ m} \]

\[ L \text{ [m]} = 3590 \quad \text{duration of water flow} = 24 \text{ hrs} \]

\[ Q \text{ [m}^3/\text{day]} = 556.5 = 0.000441 \text{ m}^3/\text{s} = 0.644 \text{ l/s} \]

\[ \text{Pipe D [mm]} = 79.7 \text{ (internal diameter)} \quad \text{(80mm GMS, heavy duty)} \]

\[ k [\text{mm}] = 0.1 \]

\[ A [\text{m}^2] = 0.0049899 \quad \text{Water in pipeline: } 17.0 \text{ m}^3 \]

\[ \nu [\text{m/s}] = \frac{Q}{A} = 1.2910555 \]

Friction Losses:

\[ RE = \frac{(\nu \times D)}{\nu} = 1.03 \times 10^5 > 2320 \quad \bullet \text{ turbulent flow} \]

\[ e = k / D = 1.25 \times 10^{-3} \]

\[ \lambda = 0.023 \text{ (from Nomogram)} \]

\[ \zeta_{fr} = \frac{\nu^2}{2g} = 1036 \]

\[ hv = \zeta_{fr} \times (\frac{v^2}{2g}) = 88.01 \text{ [m]} \quad \text{Water pressure at End of Pipeline: } 61.59 \text{ mWS} \]

\[ \text{at Chaiage [m]} \]

\[ h_{geo} = 2257 \quad \upsilon = 542826.3 \text{ Pa} \quad 5.43 \text{ bar} \]

\[ \text{actual pressure} = 10.35 \text{ bar} \quad \text{reduced pressure} = 5.35 \text{ bar} \]

\[ \text{pressure ok} \]

\[ h_{geo} = 2306 \quad \upsilon = 554611.2 \text{ Pa} \quad 5.55 \text{ bar} \]

\[ \text{actual pressure} = 10.33 \text{ bar} \quad \text{reduced pressure} = 5.33 \text{ bar} \]

\[ \text{pressure ok} \]

\[ h_{geo} = 2657 \quad \upsilon = 639029.5 \text{ Pa} \quad 6.39 \text{ bar} \]

\[ \text{actual pressure} = 9.58 \text{ bar} \quad \text{reduced pressure} = 4.58 \text{ bar} \]

\[ \text{pressure ok} \]

\[ h_{geo} = 3021 \quad \upsilon = 726574.3 \text{ Pa} \quad 7.27 \text{ bar} \]

\[ \text{actual pressure} = 9.49 \text{ bar} \quad \text{reduced pressure} = 4.49 \text{ bar} \]

\[ \text{pressure ok} \]

\[ h_{geo} = 3590 \quad \upsilon = 863423.3 \text{ Pa} \quad 8.63 \text{ bar} \]

\[ \text{actual pressure} = 8.96 \text{ bar} \quad \text{reduced pressure} = 1.96 \text{ bar} \]

\[ \text{pressure ok} \]
Verlustbeiwert \( \lambda \) für \( 2320 < Re < \infty, 10^{-3} < k/d < 2 \cdot 10^{-1} \)
ANNEXURE B

Alternative Preliminary Design Calculations for reduced design flow

**Alternative Hydraulic Design - SECTION A (Exist. Reservoir to Pumpstation)**

\[
\begin{align*}
H_{geo} \text{ Start} & = 1819 \text{ MSL} & H_{geo} \text{ End} & = 1806 \text{ MSL} \\
\text{Preset Pressure [bar]} & = 0 \text{ (reservoir empty)} & \nabla H_{geo} & = 14 \text{ m} \\
L [m] & = 1470 & \text{duration of water flow} & = 20 \text{ hrs} \\
Q [m}^3/\text{day}] & = 381 \quad = \quad 0.005292 \text{ m}^3/\text{s} & = \quad 5.29 \text{ l/s} \\
\text{Pipe Dia [mm]} & = 102.38 \text{ (internal diameter)} & \text{(110mm uPVC, PN8)} \\
k [\text{mm}] & = 0.1 \\
A [m^2] & = 0.0082291 & \text{Water in pipeline} & = 12.1 \text{ m}^3 \\
\nu [m/s] & = Q / A = 0.643046
\end{align*}
\]

**Friction Losses:**

\[
\begin{align*}
RE & = (\nu \times D) / \nu = 6.58 \times 10^4 \quad > \quad 2320 \quad \bullet \quad \text{turbulent flow} \\
\varepsilon & = k / D = 0.77 \times 10^{-4} \\
\lambda & = 0.023 \quad \text{(from Nomogram)} \\
\zeta_{hv} & = \lambda D^* L = 330 \\
hv & = \zeta_{hv} \times \left(\nu^2 / 2g\right) = 6.96 \text{ [m]} & \text{Water pressure at End of Pipeline:} \quad 7.04 \text{ mWS} \\
& & \bullet \quad 0.70 \text{ bar}
\end{align*}
\]

**Water Pressure:**

\[
\begin{align*}
\text{at Chainage [m]:} & \quad 350 \text{ (low point)} & q \ p & = 16260.0 \text{ Pa} \quad \bullet \quad 0.16 \text{ bar} \\
& & \text{actual pressure} & = 4.04 \text{ bar} \quad \text{pressure ok} \\
& \quad 1777 \text{ MSL} & \text{h}_{geo} & = \\
\text{at Chainage [m]:} & \quad 1479 \text{ (PS)} & q \ p & = 68291.9 \text{ Pa} \quad \bullet \quad 0.68 \text{ bar} \\
& & \text{actual pressure} & = 0.72 \text{ bar} \quad \text{pressure ok} \\
& \quad 1805 \text{ MSL} & \text{h}_{geo} & = 
\end{align*}
\]
**Alternative Hydraulic Design - SECTION B (Pumpstation to Intermediate Reservoir)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{geo}$ Start</td>
<td>1805 MSL</td>
</tr>
<tr>
<td>$H_{geo}$ End</td>
<td>2040 MSL</td>
</tr>
<tr>
<td>Preset Pressure [bar]</td>
<td>28.5</td>
</tr>
<tr>
<td>$\Delta H_{geo}$</td>
<td>-235 m</td>
</tr>
<tr>
<td>L [m]</td>
<td>2210</td>
</tr>
<tr>
<td>duration of water flow</td>
<td>20 hrs</td>
</tr>
<tr>
<td>$Q$ [m$^3$/day]</td>
<td>381</td>
</tr>
<tr>
<td>$Q$ [m$^3$/s]</td>
<td>0.005292 m$^3$/s</td>
</tr>
<tr>
<td>Pipe D [mm]</td>
<td>79.7 (internal diameter) (80mm GMS, heavy duty)</td>
</tr>
<tr>
<td>k [mm]</td>
<td>0.1</td>
</tr>
<tr>
<td>A [m$^2$]</td>
<td>0.0049880</td>
</tr>
<tr>
<td>Water in pipeline</td>
<td>11.0 m$^3$</td>
</tr>
<tr>
<td>$v$ [m/s] = $Q$ / $A$</td>
<td>1.0608838</td>
</tr>
</tbody>
</table>

**Friction Losses:**

- $RE = (v^*D) / v = 8.45 \times 10^4 > 2320 \bullet$ turbulent flow
- $\varepsilon = k / D = 1.25 \times 10^{-3}$
- $\lambda = 0.023$ (from Nomogram)
- $\zeta_{sh} = \lambda D^4L = 638$
- $hv = \zeta_{sh} * (v^2 / 2g) = 38.57$ [m] Water pressure at End of Pipeline: 13.43 mWS 1.34 bar

**Water Pressure:**

- at Chainage [m] 1470 (at road) $h_{geo} = 1832$ MSL $p = 76297.3$ Pa actual pressure = 25.04 bar pressure ok
- at Chainage [m] 1500 (high point) $h_{geo} = 1933$ MSL $p = 243502.1$ Pa actual pressure = 7.26 bar pressure ok
- at Chainage [m] 2210 (int. Res.) $h_{geo} = 2040$ MSL $p = 358759.7$ Pa actual pressure = 1.41 bar pressure ok
Alternative Hydraulic Design - SECTION C (Gravityline Reservoir to End)

\[ H_{geo \text{ Start}} = 2043.6 \text{ MSL} \quad H_{geo \text{ End}} = 1899 \text{ MSL} \quad (at \text{ inlet reservoir}) \quad (CL = 1893) \]

\[ \text{Preset Pressure [bar]}: \quad 0.5 \]

\[ L [m] = 3590 \quad \text{duration of water flow} = 24 \text{ hrs} \]

\[ Q [m^3/day] = 371 = 0.004294 \text{ m}^3/s = 4.29 \text{ l/s} \]

\[ \text{Pipe D [mm]} = 67.6 \text{ (internal diameter)} \quad (65mm \text{ GMS, heavy duty}) \]

\[ k [mm] = 0.1 \]

\[ A [m^2] = 0.0035891 \quad \text{Water in pipeline:} \quad 12.9 \text{ m}^3 \]

\[ v [m/s] = \frac{Q}{A} = 1.1964013 \]

Friction Losses:

\[ RE = \frac{v \cdot D}{v} = 8.09 \times 10^4 \quad > \quad 2320 \quad \ast \quad \text{turbulent flow} \]

\[ \epsilon = k / D = 1.48 \times 10^{-3} \]

\[ \lambda = 0.024 \quad (\text{from Nomogram}) \]

\[ \zeta_n = \lambda \cdot D \cdot L = 1275 \]

\[ h_v = \zeta_n \cdot \left( \frac{v^2}{2g} \right) = 92.99 \text{ [m]} \quad \text{Water pressure at End of Pipeline:} \quad 56.61 \text{ mWS} \quad 5.66 \text{ bar} \]

Water Pressure:

at Chainage [m]: 2257
\[ h_{geo} = 1890.85 \text{ MSL} \]
\[ \phi = 573462.1 \text{ Pa} \quad 5.73 \text{ bar} \quad \text{to be reduced} \]
\[ \text{actual pressure} = 10.04 \text{ bar} \quad \text{reduced pressure} = 5.04 \text{ bar} \quad \text{pressure ok} \]

at Chainage [m]: 2306
\[ h_{geo} = 1889.79 \text{ MSL} \]
\[ \phi = 585932.6 \text{ Pa} \quad 5.86 \text{ bar} \quad \text{to be reduced} \]
\[ \text{actual pressure} = 10.02 \text{ bar} \quad \text{reduced pressure} = 5.02 \text{ bar} \quad \text{pressure ok} \]

at Chainage [m]: 2657
\[ h_{geo} = 1888.94 \text{ MSL} \]
\[ \phi = 675118.3 \text{ Pa} \quad 6.75 \text{ bar} \quad \text{to be reduced} \]
\[ \text{actual pressure} = 9.21 \text{ bar} \quad \text{reduced pressure} = 4.21 \text{ bar} \quad \text{pressure ok} \]

at Chainage [m]: 3021
\[ h_{geo} = 1881.04 \text{ MSL} \]
\[ \phi = 767607.2 \text{ Pa} \quad 7.68 \text{ bar} \quad \text{to be reduced} \]
\[ \text{actual pressure} = 9.08 \text{ bar} \quad \text{reduced pressure} = 4.08 \text{ bar} \quad \text{pressure ok} \]

at Chainage [m]: 3590
\[ h_{geo} = 1802.7 \text{ MSL} \]
\[ \phi = 912164.7 \text{ Pa} \quad 9.12 \text{ bar} \quad \text{to be reduced} \]
\[ \text{actual pressure} = 6.47 \text{ bar} \quad \text{reduced pressure} = 1.47 \text{ bar} \quad \text{pressure ok} \]
Verlustbeiwert $\lambda$ für $2320 < \text{Re} < \infty$, $10^{-3} < k/d < 2 \cdot 10^{-1}$