A Technical Appraisal of the Auki Water Supply System

Malaita Island, Solomon Islands

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLES

1. Introduction

1.1. General

Auki is a township in the Malaita Province of the Solomon Islands with a population of about 4,000 people. It is the seat of the administration for the Malaita Province and the only major settlement on the island. Water supply problems were and are very common in Auki and some efforts have been made to improve the situation. Though water hours are still imposed in Auki the situation has been substantially improved when the Solomon Islands Water Authority assumed responsibility for the water supply from the province government.

Figure 1 gives an overview on the location of Malaita Island.

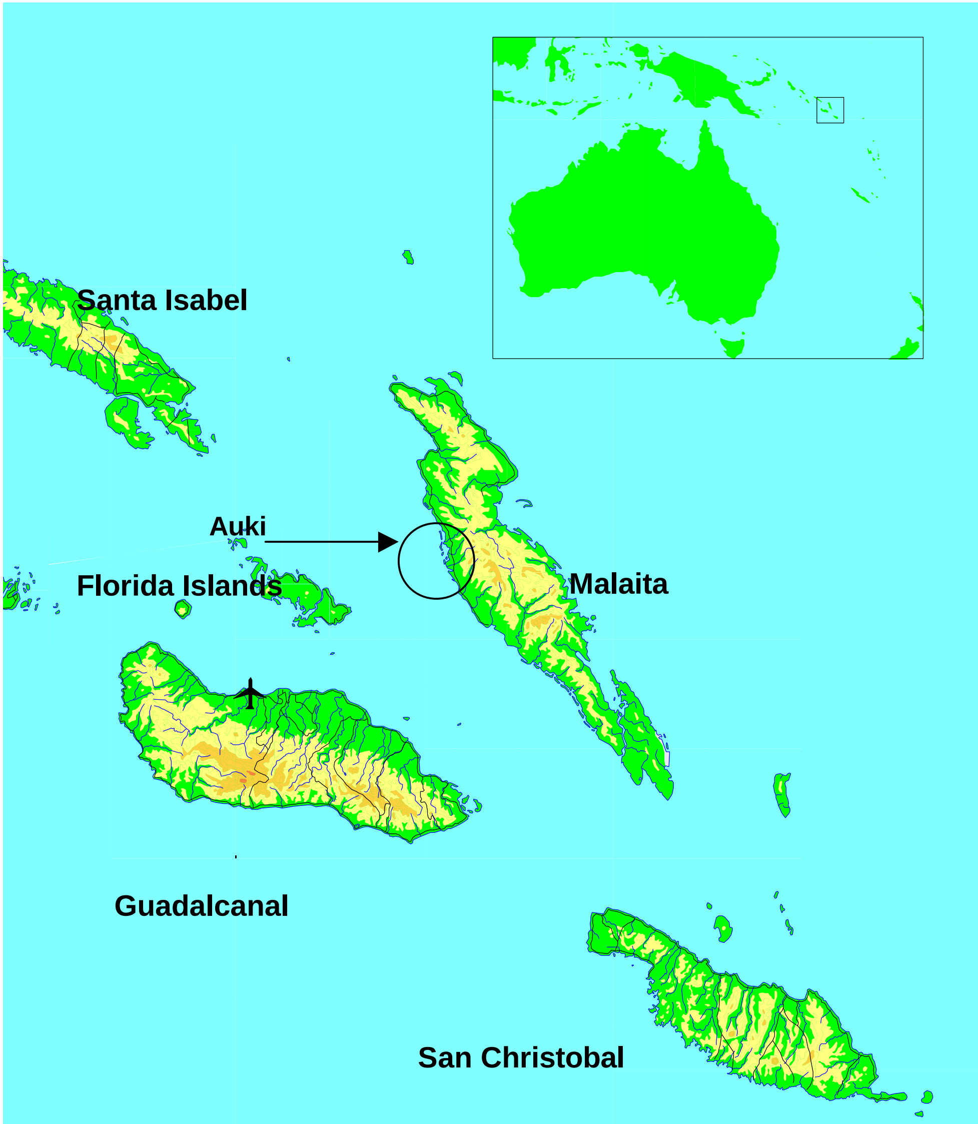

Figure 1: Location of Malaita Island in the Solomon Islands Group

1.2. Scope of the Trip and the Report

This report is part of SOPAC's technical assistance to the Solomon Islands, in this particular case to the Solomon Islands Water Authority (SIWA). All relevant data was collected during a field trip to the Solomon Islands from the 19th to 30th of May 1998. The author together with Mr Lemuel Siosi, Design and Planning Engineer for SIWA visited Malaita Province on 27th and 28th May.

The scope of this report is to describe and analyse the Auki water supply system and recommend improvements to the current operation as well as rehabilitation measures. It will be used as basis for a broader analysis of the water supply system applying distribution network modelling. It is also meant to provide some examples and training on how analysis of small water-distribution systems can be carried out.

The trip provided on-site training for SIWA staff in pipe-flow measurements, to be followed up by a four-week attachment of SIWA's Design and Planning Engineer, Lemuel Siosi, to SOPAC Water Resources Unit to further investigate the Auki water supply system and develop a strategy for its rehabilitation.

2. Acknowledgement

The author wishes to thank SIWA staff for their strong commitment to the project and in particular, Donald Makini, General Manager and John Waki, Operations and Maintenance Engineer. Mr Lemuel Siosi deserves special thanks for his dedication to the work during the field trip to Auki.

The Government of Taiwan, the United Nations Development Programme and SOPAC, through its regular budget, funded this project.

3. Summary

The Auki Water Supply System was investigated for SIWA on the 27th and 28th of May. Significant data was gathered by using a portable flowmeter and questioning the system operator. However, data such as the number of people served and diurnal consumption patterns could not be collected due to time constraints.

The existing water supply system is divided into two pressure zones with it's major components given in Table 1.

Analysis carried out by comparing pump performance curves and pipe resistance curves confirmed that the installed pumps and rising mains are undersized. Investigations carried out at the main source show that only a portion of the available water is being captured. The loss through leakage at the intake is of the same magnitude as the current abstraction rate of 7 l/s showing the potential for future upgrading of the source. However, at present the installed pump capacity and rising mains impede higher abstraction and supply rates.

Rehabilitation of the scheme is imminent but should be subject to a broader analysis by modelling the entire distribution system. This investigation should be carried out as a training project for SIWA's Design and Planning Engineer under the supervision of SOPAC. Nevertheless, some features which should be considered for the rehabilitation are recorded.

Table 1: Asset description and their operation for the Auki Water Supply System

<table>
<tr><th></th><th>Item</th><th colspan="2">Flow or Volume</th><th>Description/ Operation</th></tr>
<tr><td rowspan="3">Kwaibala Source</td><td>Kwaibala Spring Source</td><td colspan="2">7 l/s</td><td>Spring source ,source captured through a box allowing significant leakage, sustainable flow rate > 12 l/s</td></tr>
<tr><td>11 kW Pump</td><td>4.9 l/s</td><td rowspan="2">Both pumps parallel 7 l/s</td><td>Southern Cross, unknown model, operated 24 hours a day</td></tr>
<tr><td>7.5 kW Pump</td><td>5.5 l/s</td><td>Southern Cross, Impeller 192mm, 2900 rpm, operated 24 hours a day</td></tr>
<tr><td rowspan="5">Gallery</td><td>Gallery Source</td><td colspan="2">max 4.8 l/s</td><td>unsustainable flow rate, operated at irregular intervals</td></tr>
<tr><td>Storage Tank</td><td colspan="2">Inflow Volume
2.5 l/s 180 m^3</td><td>Circular metal construction, d = 9.8 m, h = 2.4 m, feeding low-level distribution system at a rate of 6 l/s during water hours</td></tr>
<tr><td>Storage Tank</td><td colspan="2">4.5 l/s - 180 m^3</td><td>Circular metal construction, d = 9.8 m, h = 2.4 m, used exclusively as intermediate storage for the high-level tank</td></tr>
<tr><td>11 kW Pump</td><td>4.8 l/s</td><td rowspan="2">Both pumps parallel 7 l/s</td><td>Southern Cross, Impeller 215mm, 2900 rpm, operated at irregular intervals</td></tr>
<tr><td>15 kW Pump</td><td>6.7 l/s</td><td>Southern Cross, operated at regular intervals approx. 16 hours per day</td></tr>
<tr><td>High Level</td><td>Storage Tank</td><td colspan="2">Inflow Volume
6.7 l/s - 180 m^3</td><td>Circular metal construction, d = 9.8 m, h = 2.4 m, feeding low-level distribution system at a rate of 6 l/s during water hours</td></tr>
</table>

4. Description and Analysis of the Auki Water Supply System

4.1. Distribution System

The Auki water supply system distributes untreated water to about 4,000 people from a main spring source located approximately one kilometre southwards from the main centre. The Pacific Island Handbook (1992) describes Auki as "a township with modern offices and housing, a district hospital, schools, a shopping centre, harbour facilities for coastal ships, yards for boat building etc." From the point of view of a water supplier it is important to state that houses are scattered over a wide area which requires relatively long mains and distribution pipes considering the number of people supplied with water.

SIWA assumed responsibility for the Auki water supply system from the Province Administration in 1995 and since then the water supply has been gradually improved to provide a reliable supply. However, the poor status of the distribution system and limited financial and management resources constrain the water supply to 10 hours per day.

The entire system has been mapped and the information on hardware such as pipe diameters, fitting, tank location and pump location have been entered into a Geographical Information System (GIS). The data stored is partly erroneous and has not been kept up to date. All information gathered during the field trip to Auki has been used to update the database.

By using a portable ultrasonic flowmeter[1] and reading in-line meter records the abstraction rate at the main source could be determined to be about 7 l/s. The central accounting system in Honiara lists 333 connections out of 269 as domestic (184 metered, 85 un-metered) out of one serves over 1000 people through associated standpipes and 64 as commercial (21 metered, 43 un-metered) connections. This is inconsistent with the information obtained in Auki stating that over 400 official connections exist . However, assuming a population served of about 4,000 people the daily consumption rate would be about 150 litres per day per person (l/p/d); for a population of 5,000 would still yield 120 l/p/d. Both values are significantly less than the design consumption rate of 215 l/p/d SIWA which usually applies to the design of urban water supply systems.

Figure 2 shows a schematic drawing of the Auki water supply system. The major components are the main source with its two associated 7.5 kW and 11 kW pumps and two 80 mm supply mains pumping into the two low-level tanks. Parts of the two mains were supposed to have been replaced by a new 100 mm PVC main laid in 1995. However, due to the poor quality of the work, the new main could never be commissioned.

[1] All measurements were taken using a Portaflow 300 ultrasonic flowmeter with a 2 MHz sensor manufactured by MICRONICS Ltd., UK.

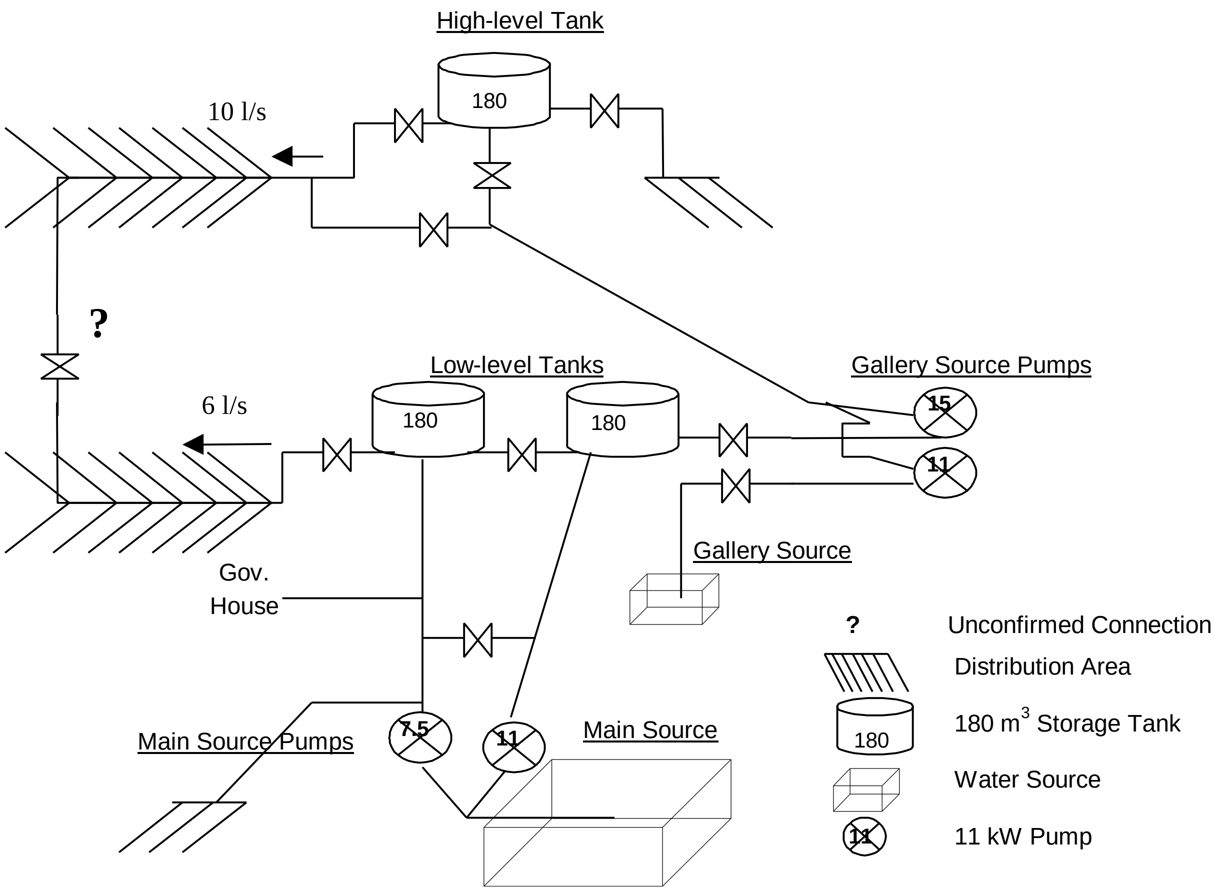

Figure 2: Schematic drawing of the present Auki water supply system with its major components

The interconnection between both pipes and the connection of the Province Governor's house was determined through pipe flow measurements at the low-level tanks and the main source. The original plan doesn't contain this information.

At the gallery two tanks are being filled from the main source, but only one delivers water to the low-level distribution system at a constant flow rate of about 6 l/s. The other tank is used as an intermediate reservoir to pump water into the high-level tank. The interconnecting valve between the two tanks is normally closed. The operator decides on the basis of his personal "as matters stand assessment" whether to open it or not.

From the second gallery tank (intermediate tank) water is pumped using a 15 kW pump into the high level tank from where the water is reticulated into the system at a constant flow rate of about 10 l/s. The second 11 kW pump at the gallery operates on stand-by and pumps water from the gallery source into the high-level tank. Both pumps sometimes pump directly into the high-level distribution system depending on the operator's assessment of the situation. summarises the major elevations, distances and pipe specifications for the Auki Water Supply System.

Table 2: Major elevations, distances and pipe specifications for the Auki Water Supply System

<table>
<tr><th>Location</th><th>Elevation</th><th>Straight Line Distance</th><th>Pipe Length</th><th>Pipe Diameter</th><th>Pipe Material</th></tr>
<tr><td></td><td>[m]</td><td>[m]</td><td>[m]</td><td>[mm]</td><td></td></tr>
<tr><td rowspan="2">Main Source (Kwaibala)</td><td rowspan="2">15.3</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">15</td><td rowspan="2">15</td><td rowspan="2">200, 80</td><td rowspan="2">PVC, Cast Iron</td></tr>
<tr><td rowspan="2">Pumps at Main Source</td><td rowspan="2">16.8</td></tr>
<tr><td rowspan="2">1000</td><td rowspan="2">1800</td><td rowspan="2">80</td><td rowspan="2">PVC</td></tr>
<tr><td rowspan="2">Storage Tanks at Gallery</td><td rowspan="2">48.8</td></tr>
<tr><td rowspan="2">20</td><td rowspan="2">20</td><td rowspan="2">80</td><td rowspan="2">Cast Iron</td></tr>
<tr><td rowspan="2">Pumps at Gallery</td><td rowspan="2">45.4</td></tr>
<tr><td rowspan="2">500</td><td rowspan="2">650</td><td rowspan="2">80</td><td rowspan="2">PVC</td></tr>
<tr><td rowspan="2">High-level Tank</td><td rowspan="2">85.6</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

The constant flow rates into the two distribution systems can be explained in terms of the restricted imposed water hours. It is very likely that consumers in Auki keep most of their taps open in order to get the biggest share possible if water is flowing into the systems. It could be observed that many households store water during the water hours impeding a correct reflection of the diurnal water consumption patterns in Auki. The question mark beside the interconnecting valve in Figure 2 between the low-level and high-level distribution system indicates that it is not known whether the interconnection exists at all and whether a trade off between the two systems is possible. However, experience shows that connections between presumably separated pressure zones exist in many water supply systems.

4.2. Water Sources

4.2.1. Main Source (Kwaibala Source)

The main water source for the water supply is a kind of spring catchment southeast of the main township. Seepage and partly artesian groundwater is impounded by an artificial basin constructed initially from bare rocks plaster mounted to a retaining wall and in 1985 rehabilitated by a concrete structure (Figure 3).

The spring intake is founded on Alluvium while the steep slope and the major parts of the catchment area consist of fractured limestone. A full understanding of the hydrological mechanism creating the spring could not be gained but it seems that perched watertables in the limestone combined with a permeable fault running from west to east provide the water influx. Though no indications of imminent geo-hazards could be found further geological and hydrogeological investigations to assess the long term availability and the sustainable abstraction rate of this water source would be very desirable.

It appears that the idea behind this structure is that the springwater should be captured within the structure (Basin 1) so that some reservoir is being created from which the water flows into Basin 2 through an inlet and is then is abstracted by a 200 mm PVC suction pipe. Basins 2 and 3 are structures that were constructed as part of the 1985 rehabilitation and were intended to limit the leakage to a tolerable rate though neither structure penetrates deep enough into impermeable underground to avoid the leakage.

The springs shown in Figure 3 are spots were water enters Basin 1 and were discovered during dryer times when it ran dry. However, they do not seem to be the only source. Gravel spots on the bottom of Basin 1 indicate continuous influx in these parts and some surface water could also be observed entering Basin 1.

No measurements of the overall yield of the source are available. Water losses at the two indicated spots were estimated to be about 6 l/s, which is in the same range as the abstraction rate of between 6.6 l/s and 7.2 l/s. Hence, the yield at the time the source was inspected can be estimated to 12 l/s. Photographs of the intake structure have been attached as Appendix 1.

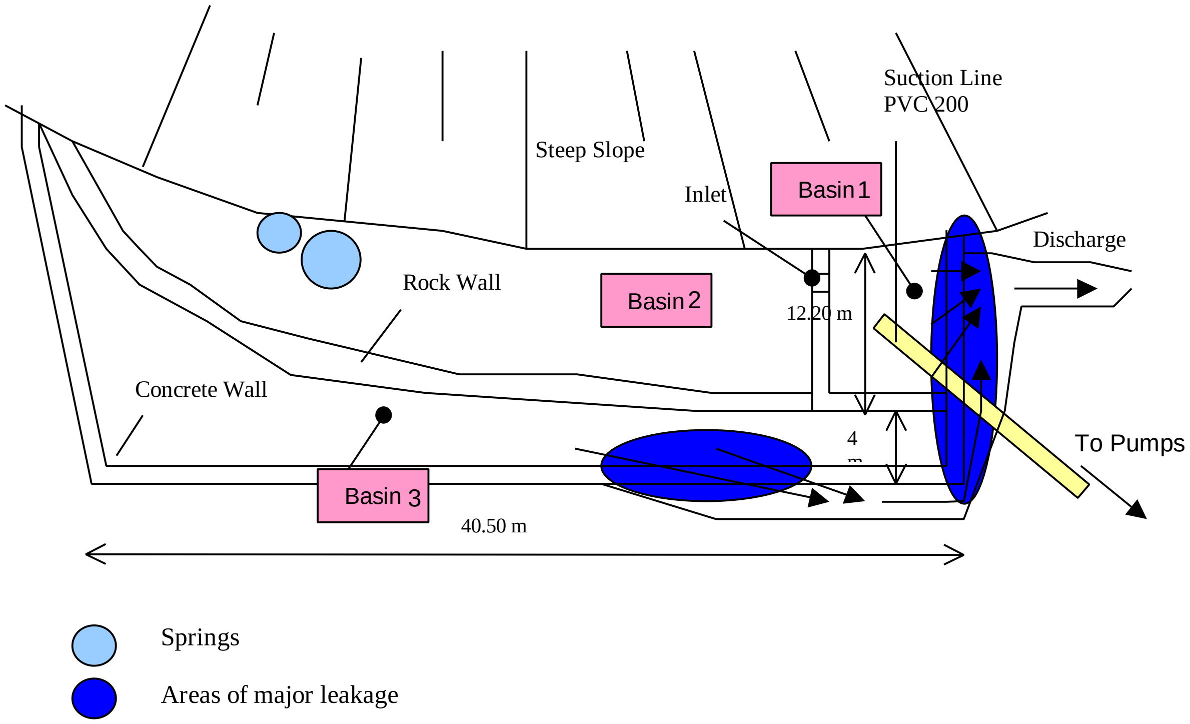

Figure 3: Sketch of the main source for the Auki water supply system

During dryer periods the spring tends to run dry mainly due to the high losses. As a response Basin 1 had been partly deepened to allow the suction pipe penetrating deeper into the basin and making a greater water body available for pumping. This measure can be seen only as a provisional rehabilitation. The entire intake is in very poor condition and needs upgrading and rehabilitation. Solutions will be discussed in section 5.0.

4.2.2. Gallery Source

The second source for the Auki water supply system is another artesian spring located beneath the two low-level tanks and the Auki Power Station at about 45 m amsl. It is used to pump only into the high-level tank. From what could be seen during the inspection the spring is being captured through a simple 1-m wide and 2-m long perforated concrete box. Presumably water enters the box through the bottom. The water is clear and didn't smell although doubts about the water quality may be justified due to the closeness of the source to the Power Station with lots of diesel spillage on the same compound.

No measurements of the overall yield of the source are available. At the time of inspection, about 4.8 l/s were abstracted from the gallery source and the water level was falling. Therefore the sustainable abstraction rate is smaller than the measured pump rate.

4.3. Pumps and Storage Tanks

4.3.1. Main Source Pumps and Storage Tanks

Figure 4 shows a schematic drawing of the pumping arrangements at the main source with averaged flow rates. Both pumps, sharing a PVC 200 mm suction line of about 20 m, pump against a static head of about 35.5 m into the storage tanks at the gallery. At the moment the standard operation is to have both pumps pumping 24 hours a day. Measurements taken at the pressure side of the pumps give flow rates of 4.4 l/s for the 7.5 kW pump and about 2.8 l/s for the 11 kW pump indicating that headloss for the bigger pump is much higher than for the smaller pump. summarises the measurements at the Kwaibala Source.

In order to confirm this result a test of the pump performance was carried out running one pump at a time. The 11 kW pump generated a flow rate of about 4.9 l/s while the 7.5 kW pump generated a flow of 5.5 l/s. Assuming that interconnecting pipe no 4 in Figure 4 was open at the time, hence allowing the flow to separate and to use both pipes, the major headloss occurs in pipe no 3. It is also possible to infer from the measurements that while both pumps were operating, headloss in pipe no 6 is higher than in pipe no 5. The practical use of this information is that, if maintenance work is carried out it should first focus on those two pipes. The pump performance test for the main source pumps has been attached as Figure A2.1 and a computed analysis (in Appendix 2) of the pumps with conventional methods has been attached as Figures A2.2 to A2.4.

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[2] Consolidated means in this context that the different pumping rates measured have been made consistent.

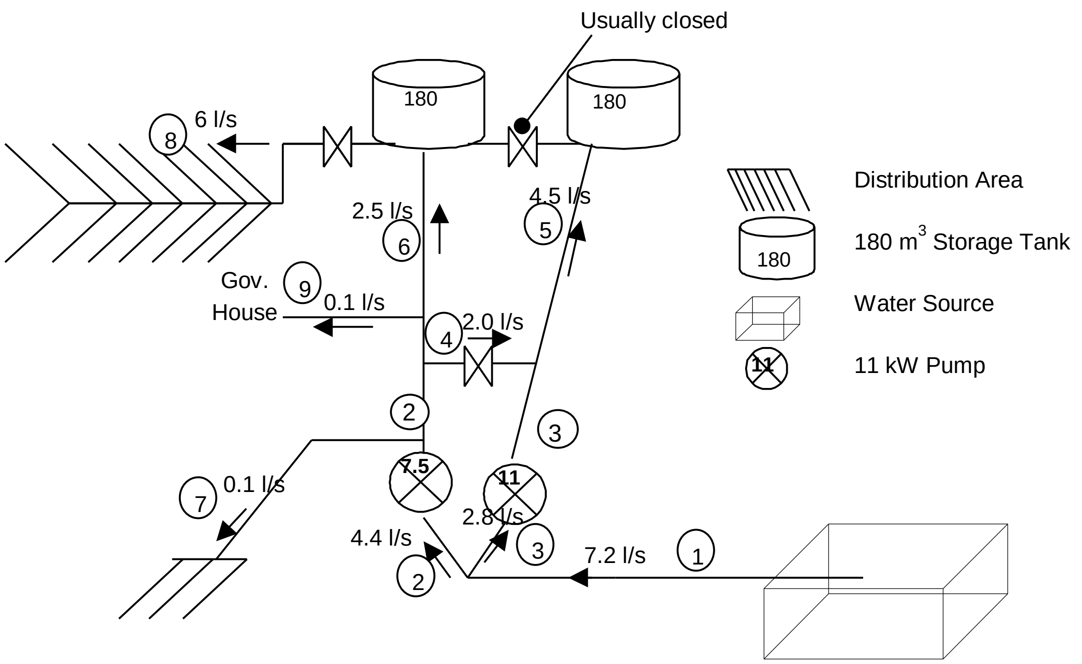

Figure 4: Schematic drawing of the pumping arrangements from the main source

Table 3: Summary of the measurements for the pumping arrangement at the main source

Pipe No.	Material	Diameter	Flow Rate	Comments
	[-]	[mm]	[l/s]	
1	PVC	200	6.6 -7.2	Measured at various times
2	Cast Iron	79	3.8 - 4.4	Measured at the pressure end of the pipe
3	Cast Iron	79	2.4 - 3.0	Measured at the pressure end of the pipe
4	PVC	80 (?)	2.0	Estimated, pipe could not be located and unearthed
5	PVC	80	2.5	Measured at the tank inlet
6	PVC	80	4.5	Measured at the tank inlet
7	PVC	25	0.1	Estimated
8	PVC	100	6.0 - 6.1	Measured, flow rate almost constant
9	PVC	25	0.1	Estimated

Another important result of the test refers to the flow rates entering the storage tanks. With the present operation routine using both pumps simultaneously 24 hours per day, water is abstracted from the main source at a rate of 7 l/s resulting in a daily production of about 605 m^3. Out of this 2.5 l/s or 216 m^3/d of water is entering the storage tank feeding the low-level distribution area and 4.5 l/s or 389 m^3/d entering the second tank to be pumped further into the high-level tank leaving the low-level area with only 35 % of the daily production.

Figure A2.5 shows the inflow-outflow analysis for the low-level storage tank applying the measured inflow rate of 2.5 l/s and a constant outflow rate during water hours of 6 l/s. Water hours (when water is available) are applied from 6.00 AM to 9.00 AM, 11.00 AM to 1.00 PM and 3.00 PM to 8.00 PM. Figure A2.6 shows the same analysis for a 12-day period.

The outflow divided by the inflow times the daily water hours or 6 / 2.5 * 10 = 24 [hours] gives the required pumping time, which is in this special case 24 hours. In other words, the pumps have to run 24 hours per day to supply 216 m^3 at a flow rate of 6 l/s for ten hours a day. That leaves no space for any optimisation of the present configuration.

It can be further derived from Appendix 2.6 and 2.7 that the maximum volume in the tank, or the fluctuating water body is about 90 m^3 (or 50 % of the available storage capacity) or 42 % of the daily water consumption of that particular zone.

4.3.2. Gallery Pumps and Storage Tanks

Figure 5 shows a schematic drawing of the pumping arrangements at the gallery source. There are two pumps installed using the same 80 mm PVC pressure line. The smaller one, a 11 kW Southern Cross centrifugal pump, pumps water from the gallery source into the high-level tank and the larger, a 15 kW pump, pumps water from the second storage tank at the gallery into the high-level tank. Both pump against a static head of about 36.8 m. At the moment the standard operation is using the 15 kW pump until the high-level tank is filled up. From time to time, depending on the operator's judgement, the 11 kW pump supplements water from the gallery source. If there is enough water available in the second tank at the gallery and the high level tank is already full, both pumps can be used to pump directly into the distribution system.

Considering the different pumping options from the gallery a pumping test was carried out to assess pump performance. Measurements taken at the pressure side of the pumps while pumping into the high-level tank gave flow rates of 4.8 l/s for the 11 kW pump and 6.7 l/s for the 15 kW pump. Using both pumps at the same time gave a flow rate of 7 l/s. When pumping into the distribution system the 11 kW pump pumped 7.4 l/s and the 15 kW pump 9.2 l/s reflecting the lower total pump head. Both pumps together can force 11.7 l/s into the distribution system. Bold and underlined figures in Figure 5 indicate pumping into the distribution system. The pump performance test for the gallery source pumps are attached as Figure A3.1 in Appendix 3.

An analysis similar to the one for the Kwaibala pumps was carried out. Again, since the exact specification was unknown a set of curves has been produced. The computed curves in Figure A3.2: Pipe and Pump Analysis for the gallery pumps pumping into the high level tank for a 15 kW/ 194 mm pump, a 11 kW/ 205 mm and their parallel pumping match the pipe resistance curve for a 650 m long pipe with a roughness of k = 0.6 mm for the measured flow rate of 7 l/s. The total head for the parallel pumping configuration is about 69.5 m or 73 % of the static head and a flow rate of 7 l/s and 67.8 m or 69% of the static head for the 15 kW/ 194 mm pump at a flow rate of 6.8 l/s.

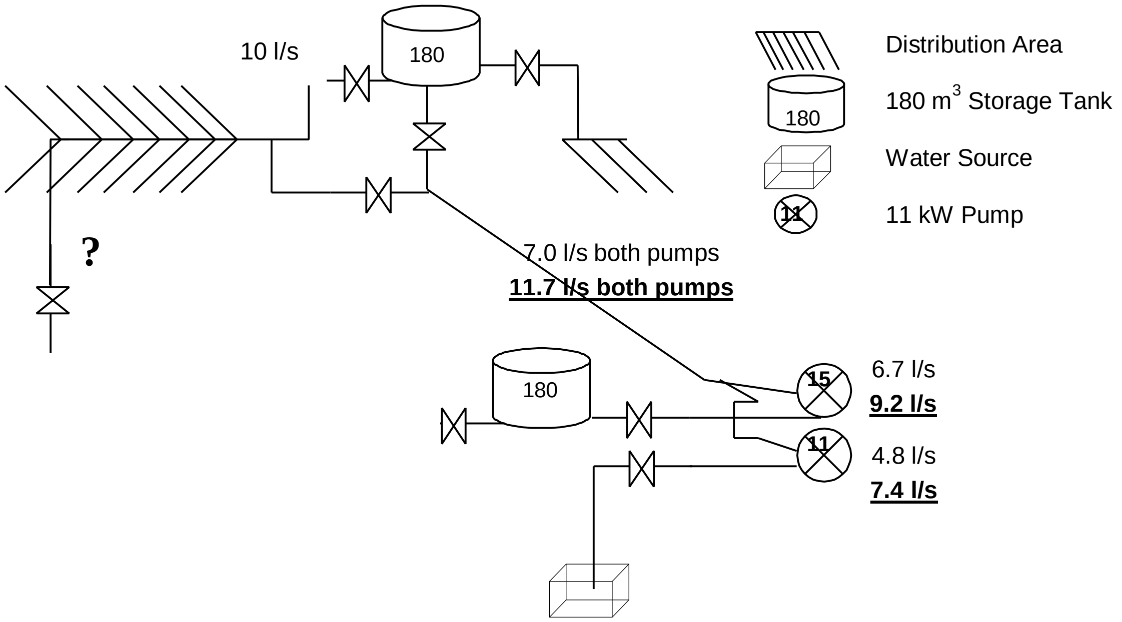

Figure 5: Schematic drawing of the pumping arrangements at the gallery source (bold figures indicate pumping directly into the distribution system)

The storage facilities related to the gallery pumps, intermediate tank and high-level tank, have been analysed and the characteristic curves are attached in Appendix 3 as Figure A3.3 and Figure A3.4.

Assuming a constant flow rate of 10 l/s (measured) into the distribution system 360 m^3/day is required to be boosted into the high-level tank. The two-tank system has been modelled for an inflow of 6.7 l/s into the high-level tank and an inflow of 4.5 l/s into the intermediate tank assuming that the regular operation at the gallery is using the 15 kW pump only.

Figure A3.3 (Appendix 3) displays one example of how the required pumping time of 14.9 hours (10/6.7*10 [hours]) can be distributed so that the full flow rate of 10 l/s is delivered during the imposed water hours. Please note that this result was achieved by assuming a pump operator (or a control switch) would shut the pump off and on if a certain condition is matched, e.g. a certain level in the tank. Possible variation of the pumping hours into the high-level tank can be also derived from Figure A3.3 (Appendix 3). The fluctuating water body for the high-level tank amounts to 120 m^3 or 33 % of the water reticulated into this particular pressure zone.

The graph in Figure A3.4 (Appendix 3) shows the tank simulation for the intermediate tank and has been computed using an inflow of 4.5 l/s from the Kwaibala source and an outflow of 6.7 l/s into the high-level tank. The required pumping time is 22.2 (6.7/4.5*14.9 [hours]) and the fluctuating water body for the intermediate tank amounts to 85 m^3 or 24 % of the water boosted into the high-level tank. This figure is high considering that the tank is used only to store water to boost it from the main source into the high-level tank. This reflects the difference in performance of the pumps.

The required pumping time of 22.2 hours is not consistent with the fact that at present water is being pumped up into the intermediate tank 24 hours a day. A likely explanation is that some of the excess water is used to prolong water hours for the high-level distribution system or that the measured flow rates used for the simulation were inaccurate.

Photographs of the facilities at the gallery have been attached as Photo A3.1 to A3.4 (Appendix 3).

4.4. Conclusions

The main components of the Auki water supply system have been described and analysed. Water hours are imposed even though 7 l/s or 605 m^3/day are abstracted from the Kwaibala spring source, which would allow a daily consumption rate of 120 litres per person, assuming 5000 people are to be served.

The nearly constant flow rates of 6 l/s into the low-level distribution system and 10 l/s into the high-level system during water hours imply that consumers try to store as much water as possible when water is available. Since it is unknown how many people are being served water in each of the two pressure zones more information needs to be collected before a final decision on the upgrading of the system can be made.

However, based on the information gathered and derived through its analysis major upgrading is necessary. The applied analysis of the spring itself and the pumping and storage facilities identify the leakage and the undersized pumping system (rising main pipes and pumps) at the Kwaibala source as the main reasons for the relative water shortage (or water hours)[3]. Both pumping arrangements investigated don't indicate that the pumps perform particularly badly. They are simply undersized. The rehabilitation of the spring has to be accompanied by the upgrading of the pumps at Kwaibala source and/or the rising mains. A general and holistic analysis of the entire distribution system through network modelling is necessary. At this stage there is not enough information to undertake this kind of investigation[4].

5. Recommendations

5.1. General

An efficient upgrading of the system should be based on further recommendation derived from a water distribution network model. SIWA's Design and Planning Engineer should develop such a model. The work can be supervised and backstopped by SOPAC's Water Resources Unit. Work should start as soon as possible.

In order to develop such a model more data need to be collected on the existing population, the population growth and diurnal consumption patterns. The existing database needs to be

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[3] Note that water shortage refers to the desired consumption rate of 215 l/p/d only.

[4] A simple model has been created for the system shown in Figure 2 using the described data. The results comply with the conclusions given in Chapter 4.

updated with consumer data and checked regularly. A clear picture of consumption for the two pressure zones needs to be gained. Upgrading and rehabilitation of the system should include the Kwaibala Source, pumps and rising mains as well as the rising main to high level tank.

The present proposal to upgrade the system by building a new high-level tank being pumped directly from the Kwaibala source can not be assessed without more data, i.e. topographical and population data. **No decision should be made on this suggestion without having developed a strategy to upgrade the system to avoid poor investments.**

Water conservation measures as carried out by SIWA in Honiara should be applied to Auki. SIWA management should discuss how to overcome the current behaviour of storing water during water hours. A gradual transition into regular service could be reached by reducing flow rates released into the distribution system by partly closing valves and extending water hours accordingly. This could indicate to consumers that major changes are upcoming and hording-behaviour is no longer necessary.

5.2. Main Source

The main source could yield a sustainable rate of 12 l/s if the abstraction is done correctly. A major change in how water should be taken from the various springs and seepage is recommended. The proposal consists of four major steps:

- Deepening of Basin 1 using some kind of caisson fabricated from shaft-rings to be used as an open well.
- Excavating Basin 2 to a level where either impermeable ground is reached or the depth is considered sufficient (probably 1.0 m to 1.5 m).
- Laying slotted pipes into Basin 2 and Basin 1
- Building filter layers around the pipes and connect them to the shaft in Basin 1.

The described rehabilitation combines the principal of a filter gallery with that of an open slow (sand) filter (Figure 6).

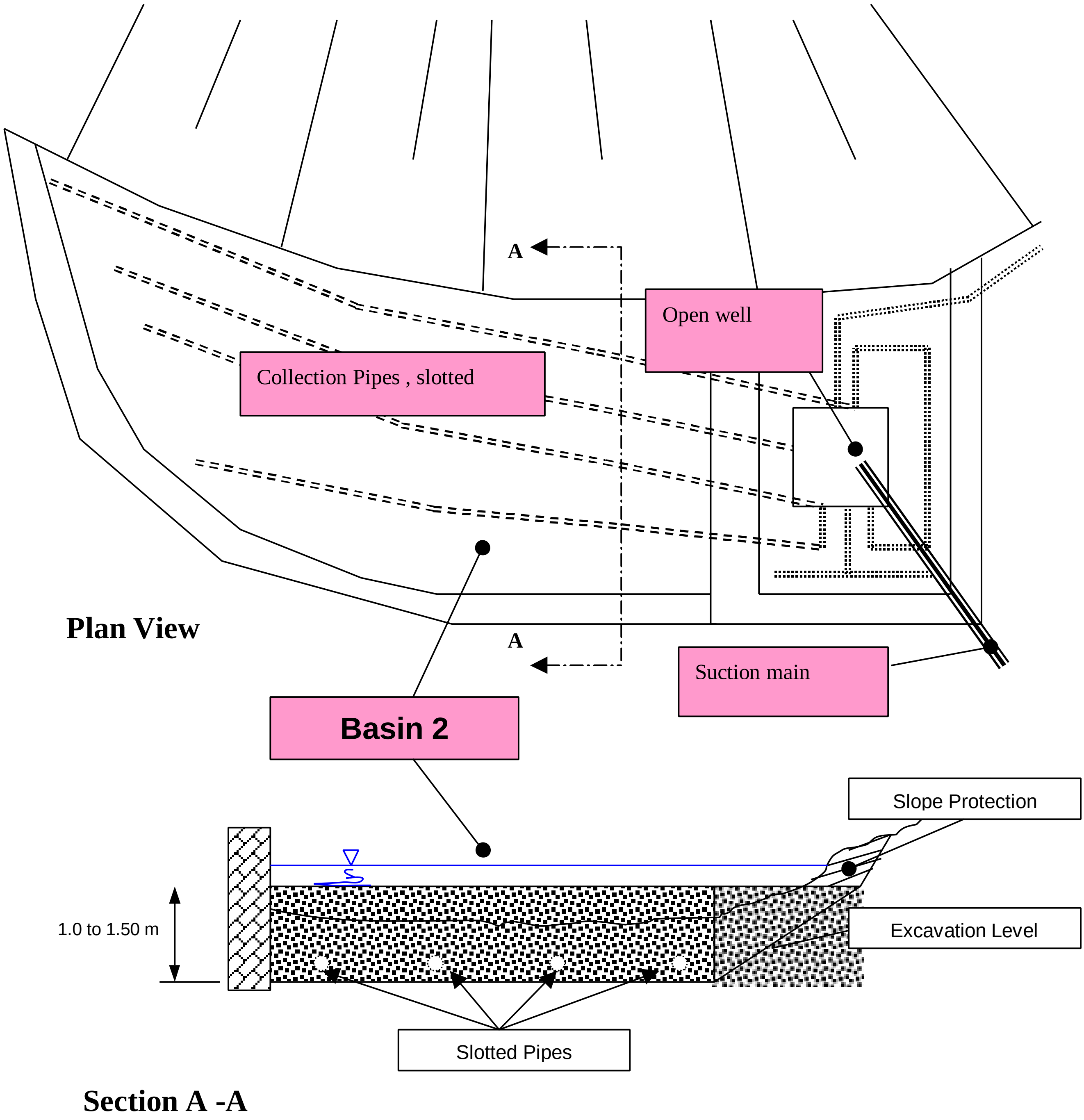

Figure 6: Proposed rehabilitation measure for the Kwaibala Source

5.3. Kwaibala Source Pumps and Mains

The pump and mains need upgrading, though exactly how should be determined in the development of the strategy plan. If SIWA was prepared to spend some money for an ad-hoc improvement of the system the 15 kW pump at the gallery could be relocated to the Kwaibala source. Based on the calculation presented in this report and on Figure A4.1 (Appendix 4) the pump could pump between 7.3 l/s and 8.5 l/s. Since that would not mean a significant change to the present rate of 7 l/s such a measure should be accompanied with the rehabilitation and commissioning of the already laid 100 mm PVC pipe. It should be noted in general that by changing the pump, no big increase in flow rate can be gained by increasing pump performance, due to the high resistance of the two 80 mm pipes.

As a general precaution against low pump performance the sharing of suction lines between pumps should be avoided.

5.4. Gallery Pumps

Some saving in pumping time could be gained by applying the pumping hours from the gallery into the high-level tank. Considering that a higher flow rate can be pumped into the distribution system than into the tank, some further pumping power could be saved by doing that. Saving would only materialise if the pump's speed is reduced when pumping into the system.

Water from the gallery, if used at all, should not be pumped directly into the high level tank but into the intermediate tank. If reconnecting the pump seems to be too costly the pump should run only if the other pump is not running. Parallel operation proved to be highly inefficient.

5.5. Distribution Network

The distribution network should be subject to a leak detection and control program.

Appendix 1: Kwaibala Water Source (Main Source)

Photo A1.1: Auki Kwaibala Source, View of Basin 1 and Basin 2.

Photo A1.2: Auki Kwaibala Source, View of retaining wall In Basin 1 and PVC 200mm suction pipe.

Photo A1.3: Auki Kwaibala Source, View of Basin 3 showing both new and old retaining structure.

Photo A1.4: Auki Kwaibala Source, View into Basin 1 showing the old suction pipe and gravel spots indicating water entry.

Photo A1.5: Auki Kwaibala Source, View into Basin 1 showing the new PVC 200mm suction sipe and gravel spots indicating water entry.

Appendix 2: Kwaibala Source Pumps

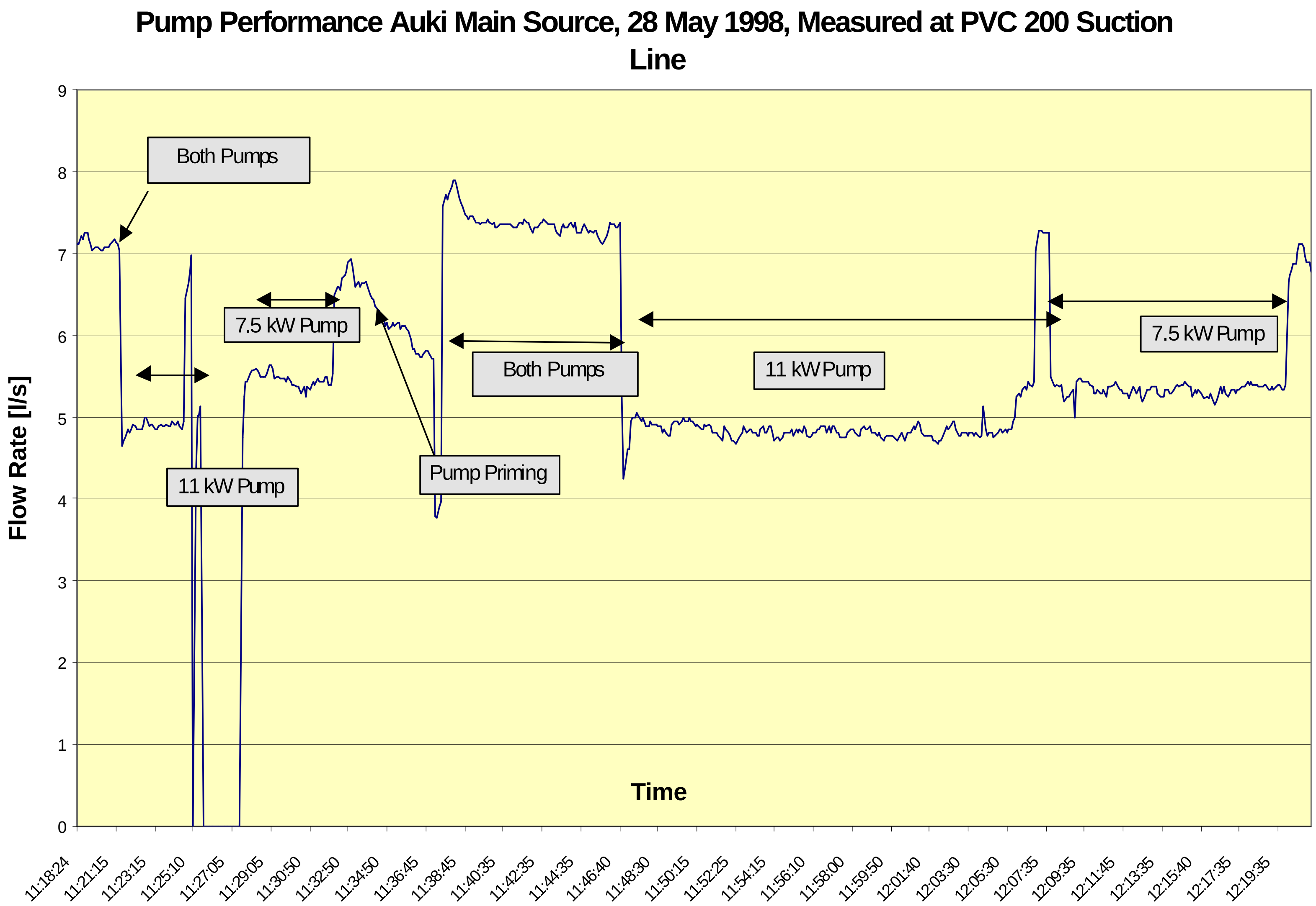

Figure A2.1: Pump Performace test at Kwaibala Source, 28 of May 1998

Simple Pump Analysis

In order to further assess the pump performance a set of calculations comparing different pump performance curves with a set of pipe resistance curves has been computed. The entire approach can be summarised as follows:

1. Display pump performance curves for the installed pumps over pipe resistance curves (length of pipe is 1800 m) in a standard way (Figure A2.2 and 2.3) and compare it with the measured results.

2. Exclude impossible or unlikely solutions.

3. Change variables of the displayed curves so that they match the measured results as well as possible (Figure A2.4).

The graphs in Figure A2.2 to A2.4 show pumping performance curves for an 11 kW and a 15kW Southern Cross pump. Since the exact specification, i.e. impeller size is not known, two different curves have been produced. .1 shows the configurations used for alternative pumping arrangements:

Table A5.1: Configuration of pumping arrangements

Pumping arrangement	Configuration
11 kW/ 205 mm impeller diameter and 7.5 kW/ 194 mm impeller diameter	1
11 kW/ 194 mm impeller diameter and 7.5 kW/ 194 mm impeller diameter	2
11 kW/ 205 mm impeller diameter	3
11 kW/ 194 mm impeller diameter	4
7.5 kW/ 194 mm impeller diameter	5

In Figure A2.2 Configurations 1 and 2 pump into two parallel 80 mm PVC pipes of 1800 m length. Since the actual state of the pipes is unknown, three different curves for three roughness factors k have been computed (dashed lines in the graph) in order to find a realistic k figure. The three upper pipe resistance curves have been added to enable a comparison between pumping into a two-pipe and a one-pipe system. The pinpointed flow rates of 4.45 l/s and 8.46 l/s indicate the level where the second (smaller) pump within each configuration begins to have an impact on the pumped flow rate.

The operation points for Configurations 1 and 2 have been marked where the measured flow rate of 7 l/s matches the pipe resistance curve for a pipe resistance of k = 1 mm with Configuration 1 and k =0.4 mm with Configuration 2.

Figure A2.3 shows the same pipe curves but now with the pump performance curves of Configurations 3, 4 and 5. The measured operation points have again been highlighted for the measured flow rates of 4.9 l/s (measured for the 11 kW pump) and 5.5 l/s (measured for the 7.5 kW pump). Both operation points are for flow rates considerably less than those indicated by the intersection of the pipe and pump performance curves which indicate flow rates of 7 l/s for Configuration 3, and about 6.8 l/s for Configurations 4 and 5. The inconsistency between the measured results can be explained as follows:

1. Pumps perform well below their usual performance.

2. Pipe roughness could not be modelled.

3. Combination of 1. and 2.

Which one exactly, is hard to decide. Figure A2.4 shows the attempt to model the actual situation assuming very different pipes resistance. As can be seen the parallel pumping (assuming normal pump performance) can be simulated through a two-pipe system with two very different k factors, though each pump alone would be supposed to pump a higher rate.

Headloss over flow rate, different pipes and two pumps running

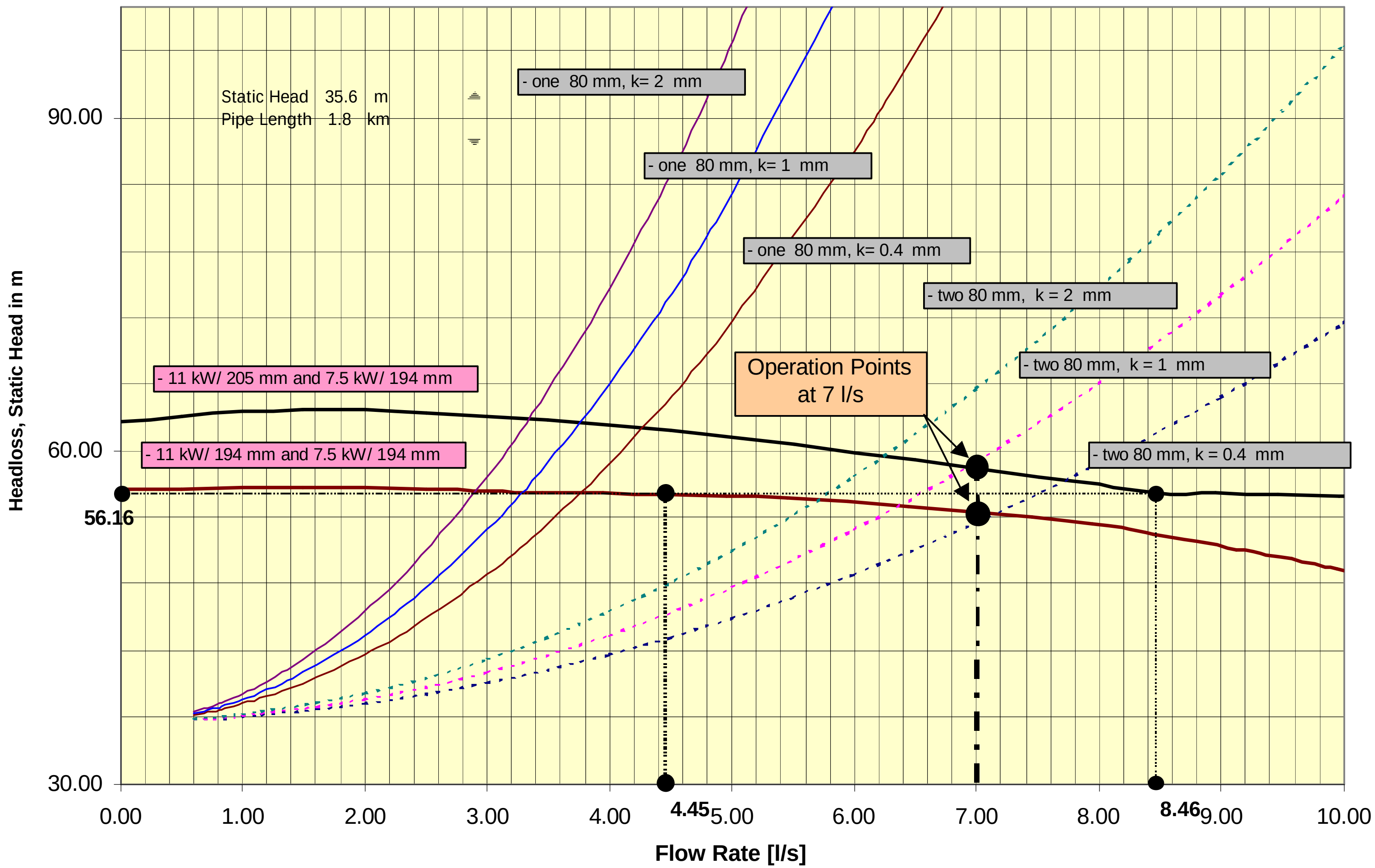

Figure A2.2: Analysis for the two pumps in parallel operation, pumping into different pipe systems of a length of 1800 m.

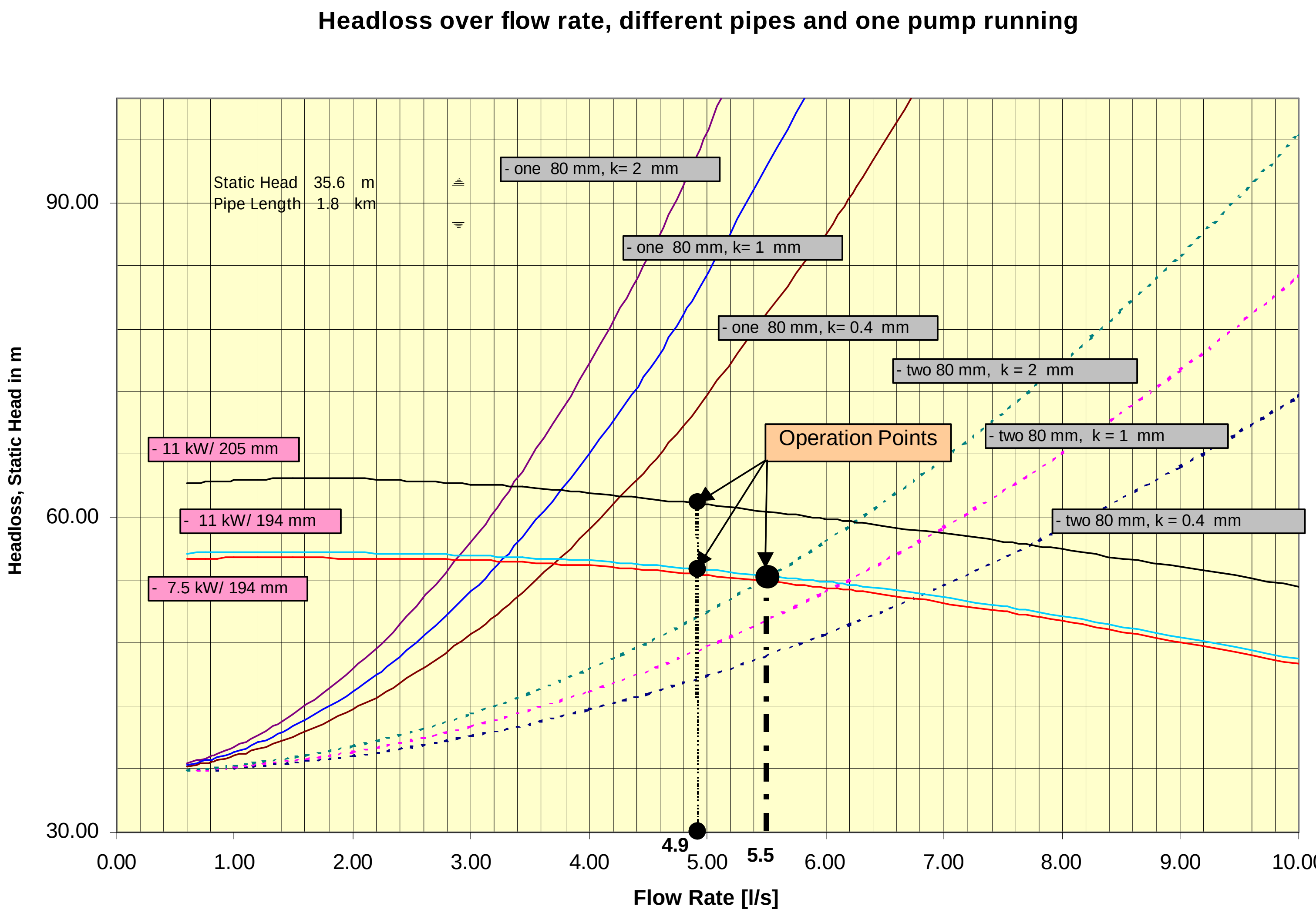

Figure A2.3: Analysis for one pump operating at the time at Kwaibala Source.

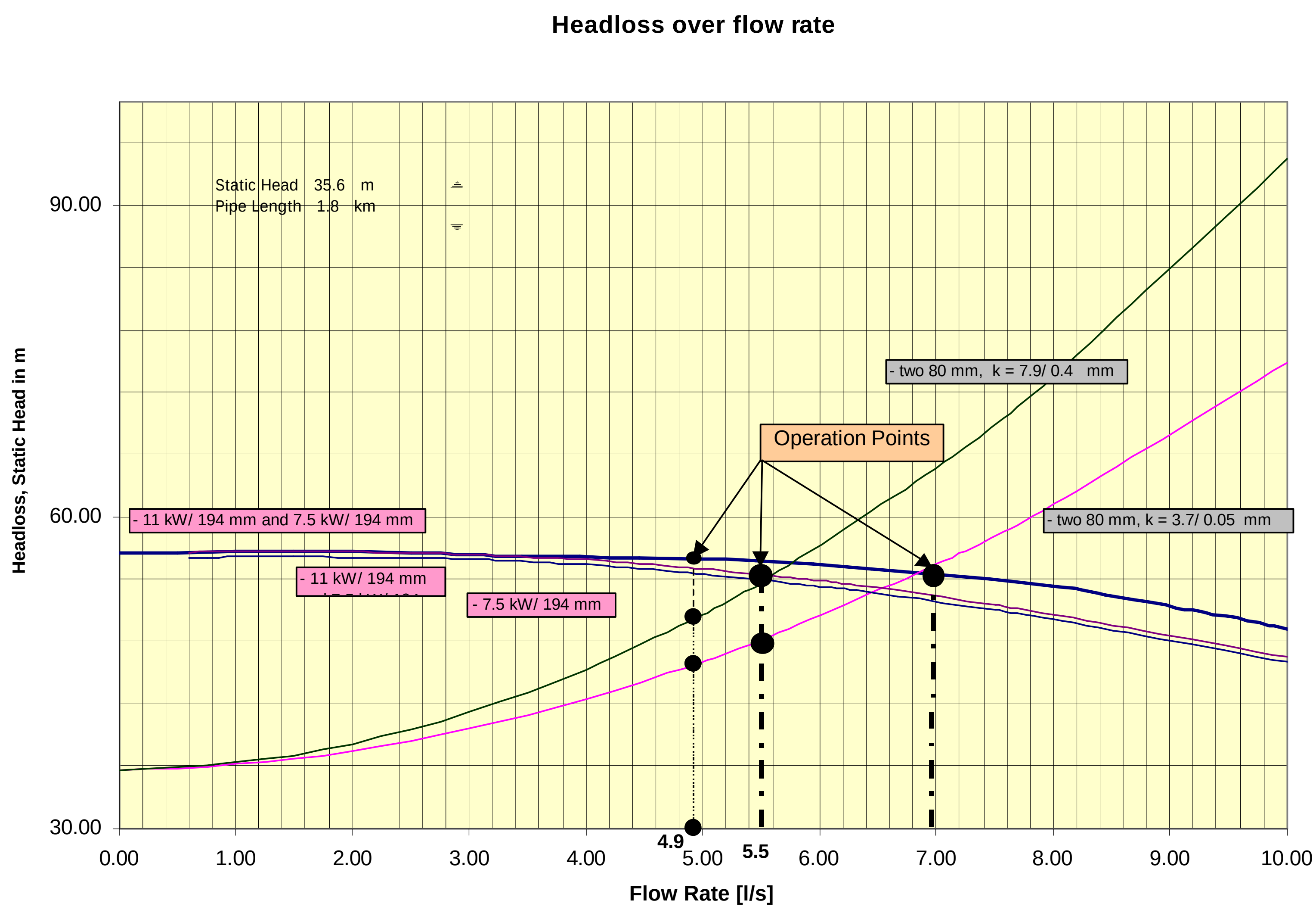

Figure A2.4: Final Analysis at Kwaibala Source

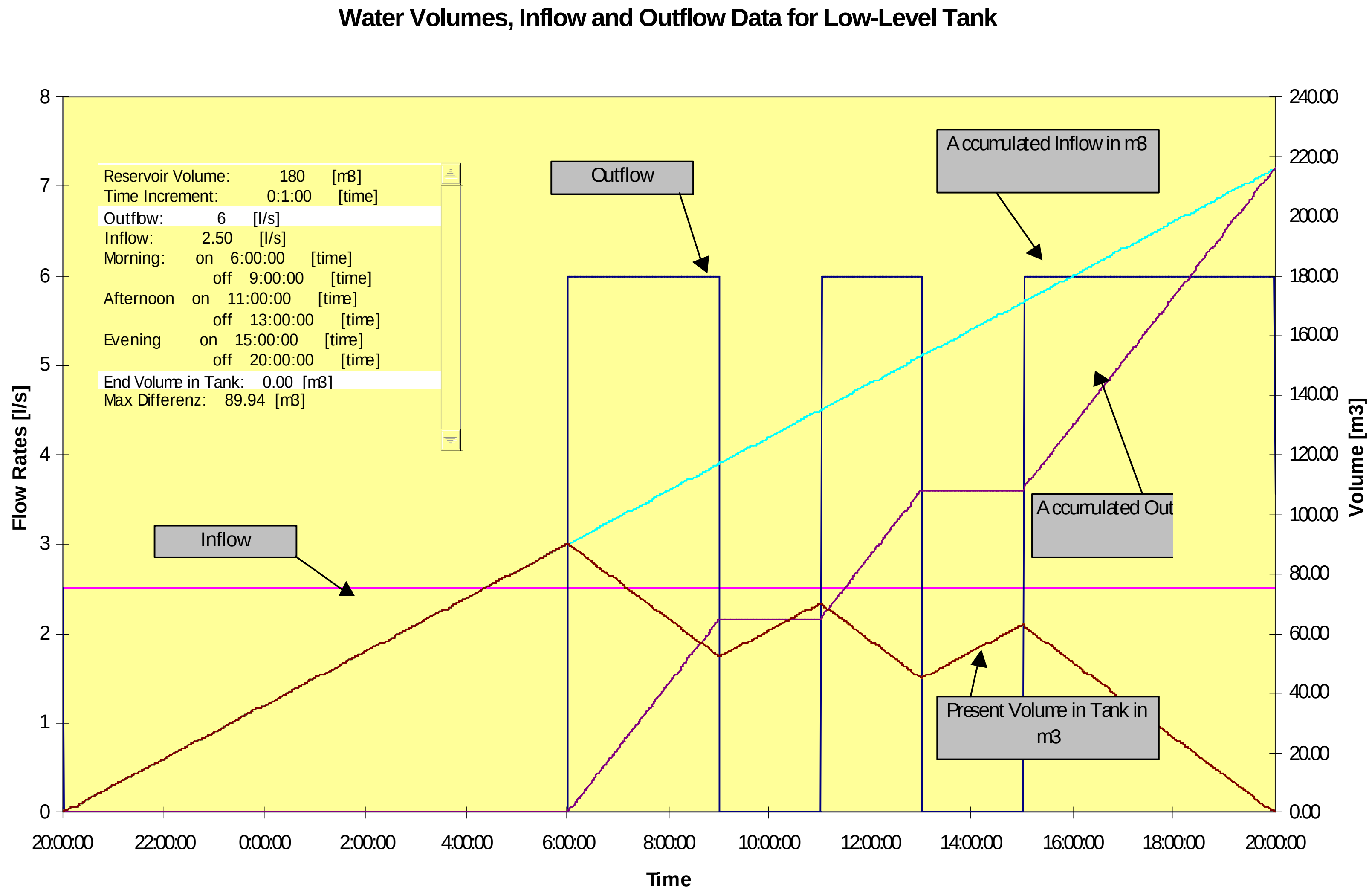

Figure A2.5: Analysis for the low-level storage tank assuming a constant inflow of 2.5 l/s and a constant outflow of 6 l/s

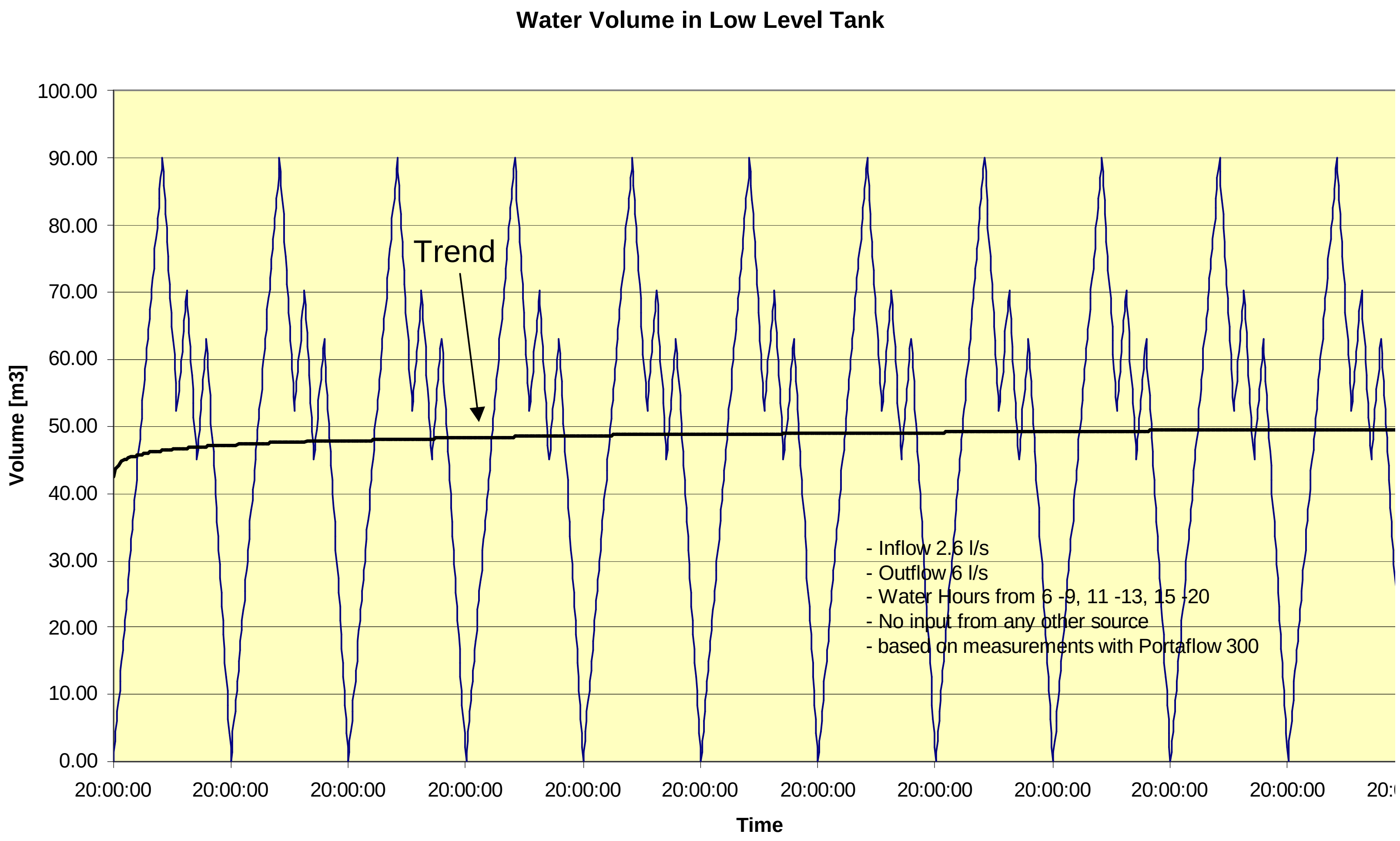

Figure A2.6: Twelve-day simulation for the low-level tank for the most likely inflow rate of 2.5 l/s

Appendix 2.2: Photographs of the Kwaibala Pumps

Photo A2.1: Operator Charles Fox in the pump house at Kwaibala Source

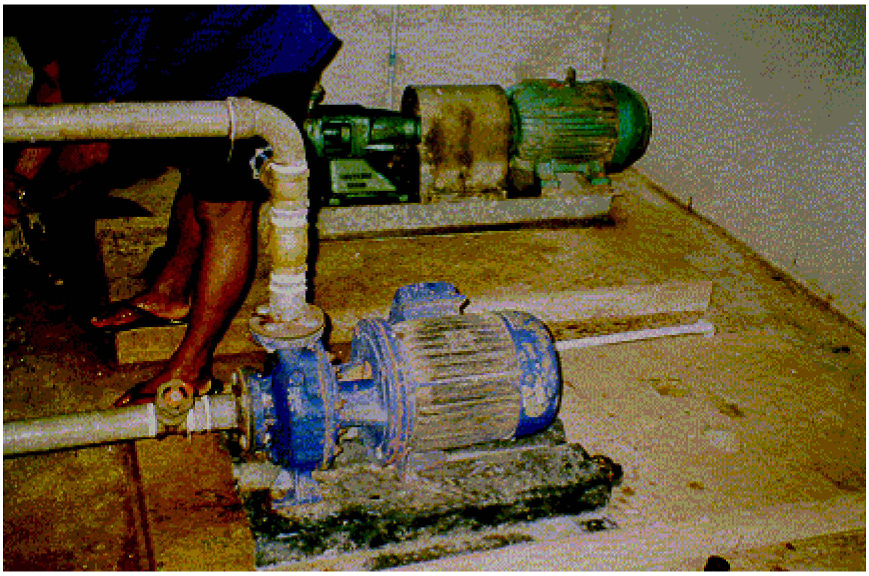

Photo A2.2: Pumps at the Kwaibala Source, foreground 7.5 kW Southern Cross, background 11 kW Southern Cross

Photo A2.3: Lemuel Siosi taking flow measurements at the suction pipe of the 7.5 kW pump

Photo A2.4: Lemuel Siosi taking flow measurements at the pressure pipe of the 7.5 kW pump.

Appendix 3: Gallery Pumps

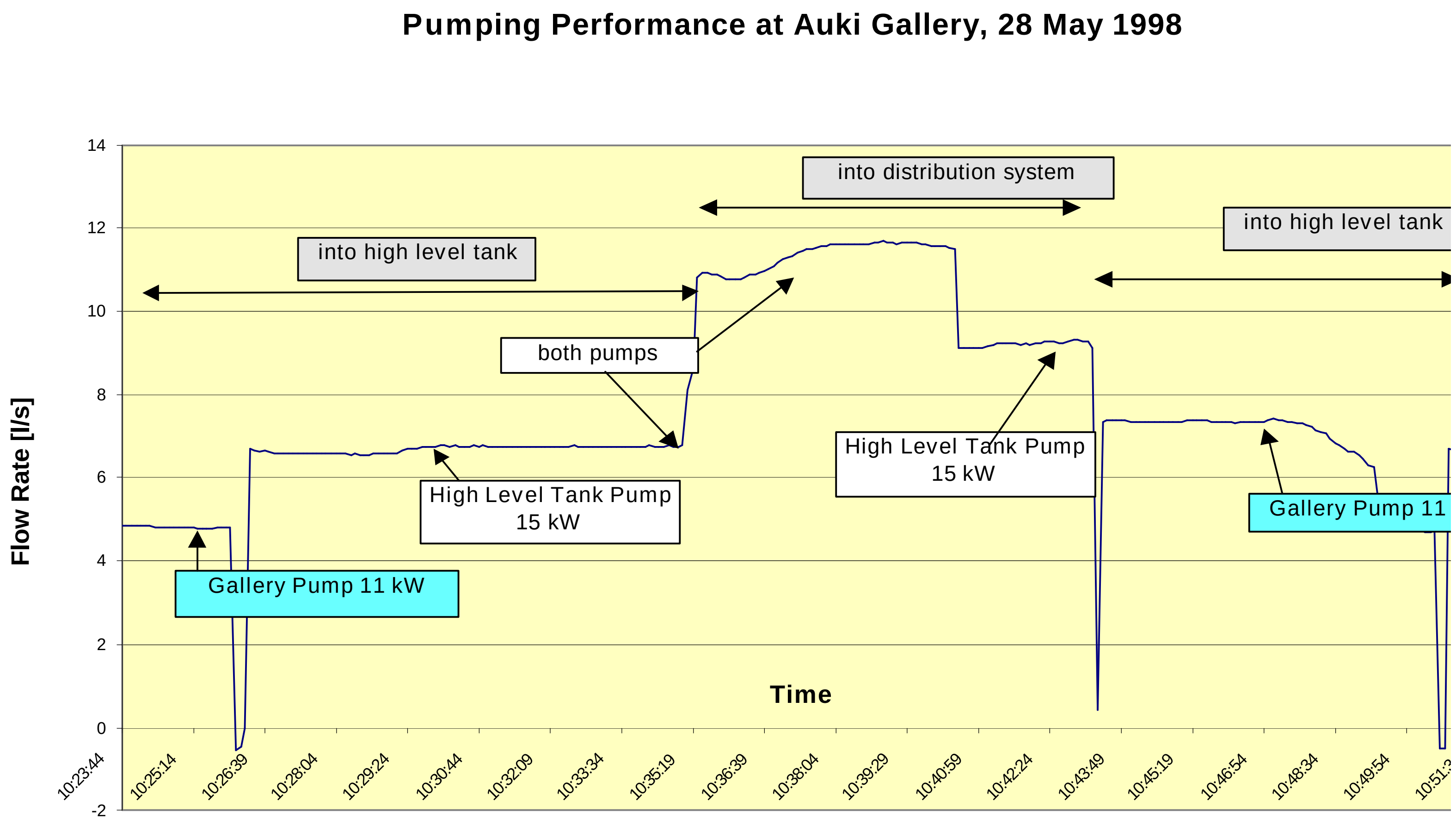

Figure A3.1: Pump performance test for the gallery pumps switching between pumping into the high level-tank and the distribution system.

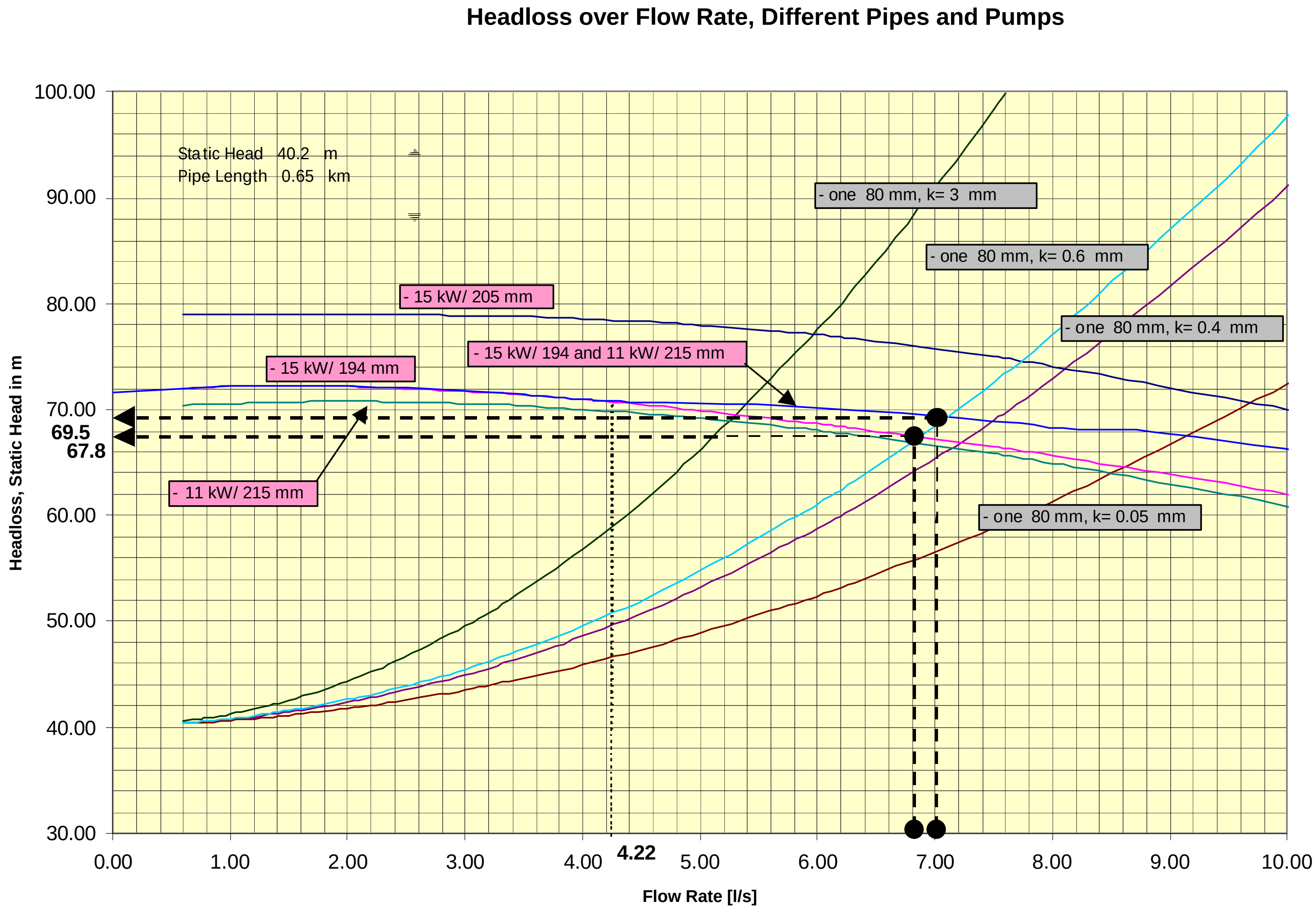

Figure A3.2: Pipe and Pump Analysis for the gallery pumps pumping into the high- level tank.

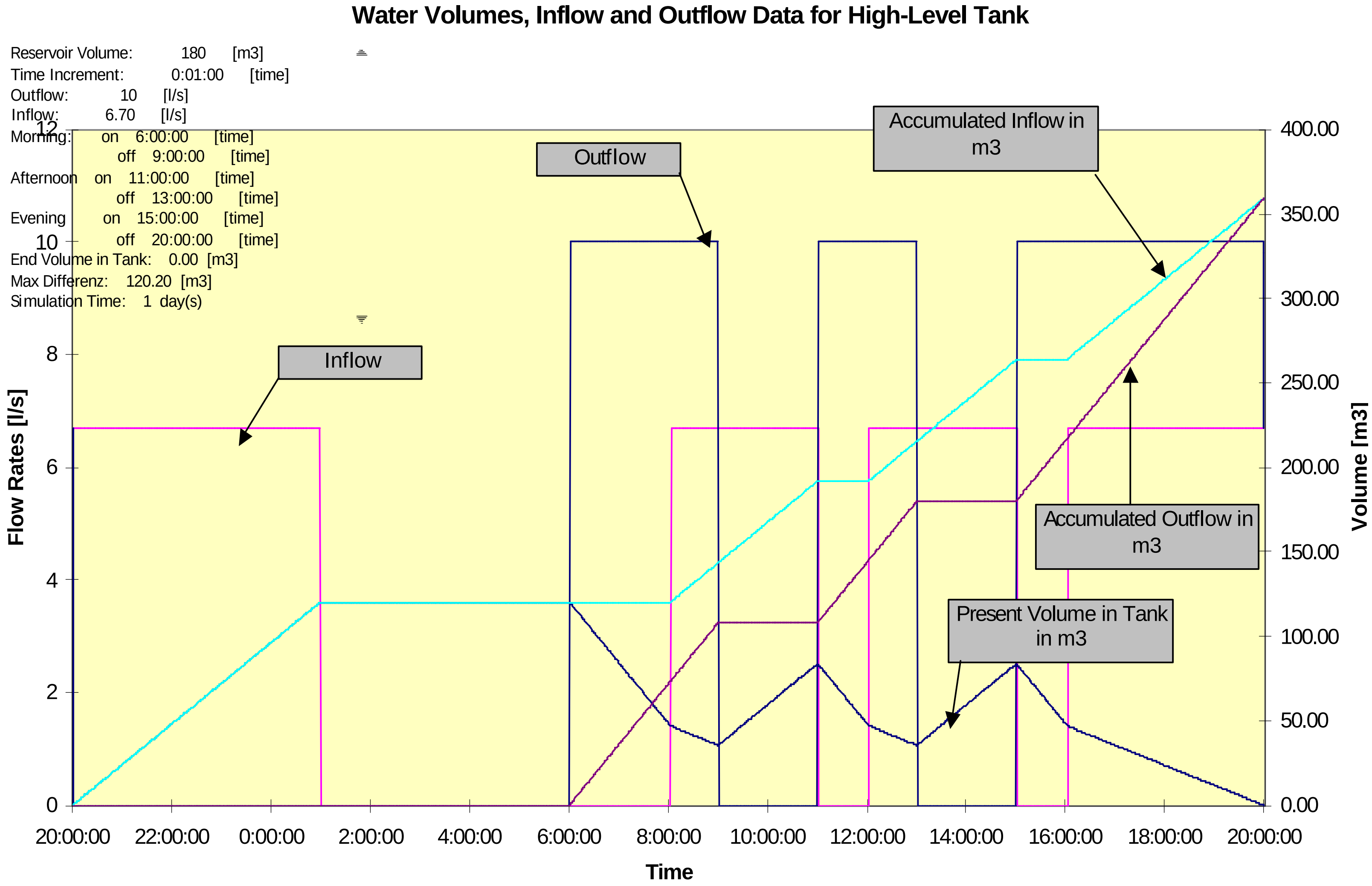

Figure A3.3: One-day simulation for the high-level tank (pumping time into the tank optimised).

Water Volumes, Inflow and Outflow Data for Intermediate Tank

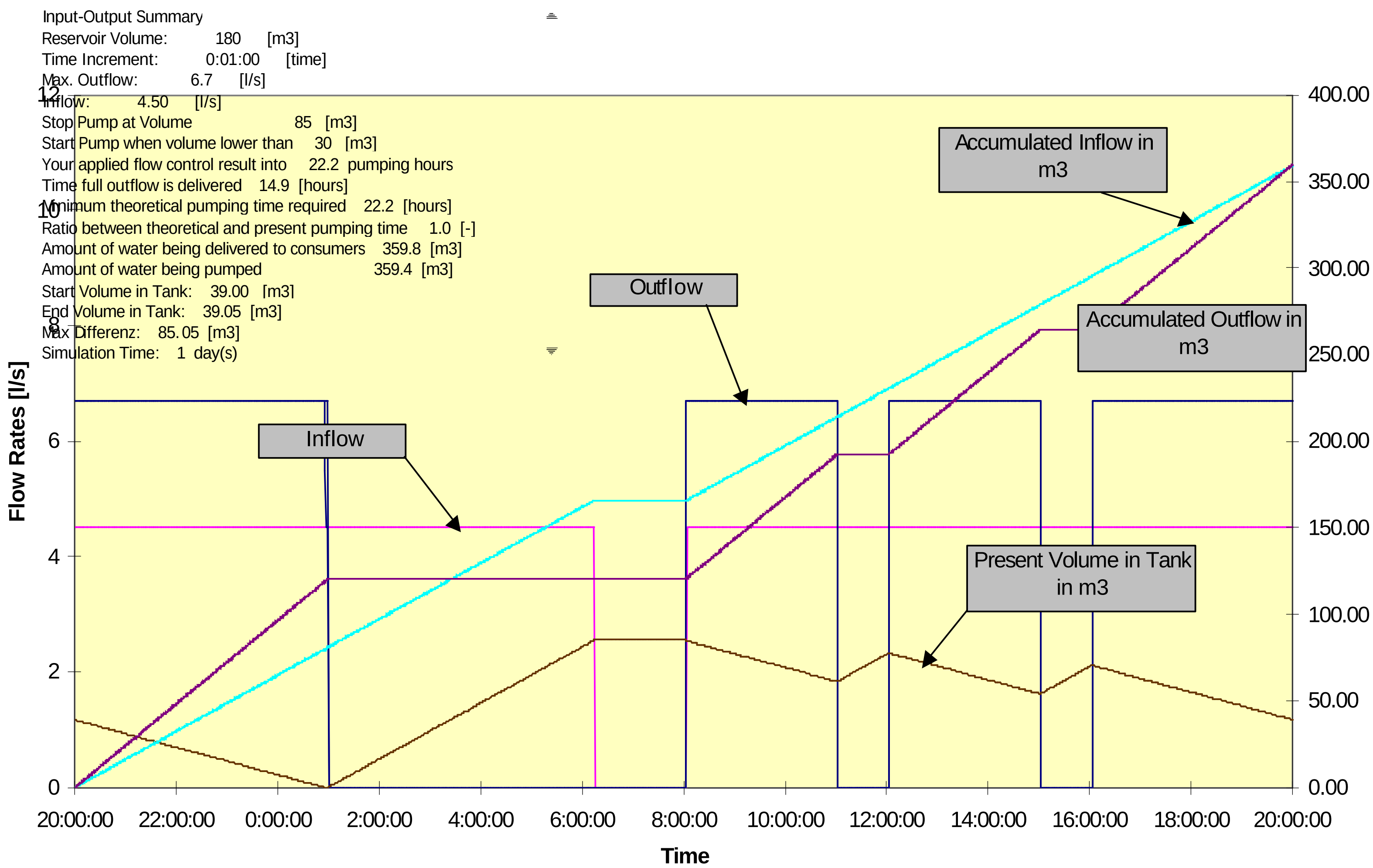

Figure A3.4: One-day simulation for the intermediate tank (pumping time into the tank opti-

Photographs of the gallery Pumps, gallery source and storage facilities

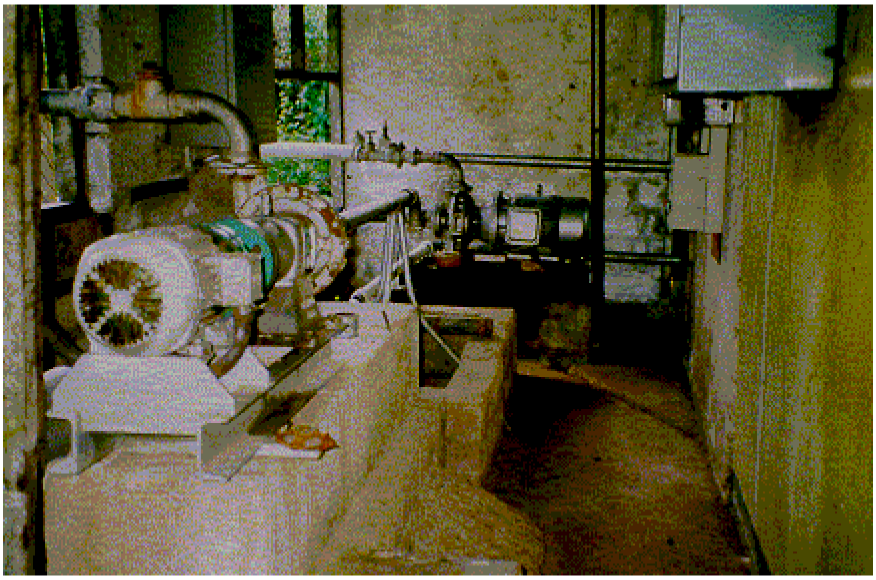

Photo A3.1: Gallery pumps and gallery source

Photo A3.2: Flow measurements outside gallery pump house

Photo A3.3: Storage facilities, the left tank is serving the low-level tank, the right one is the intermediate tank

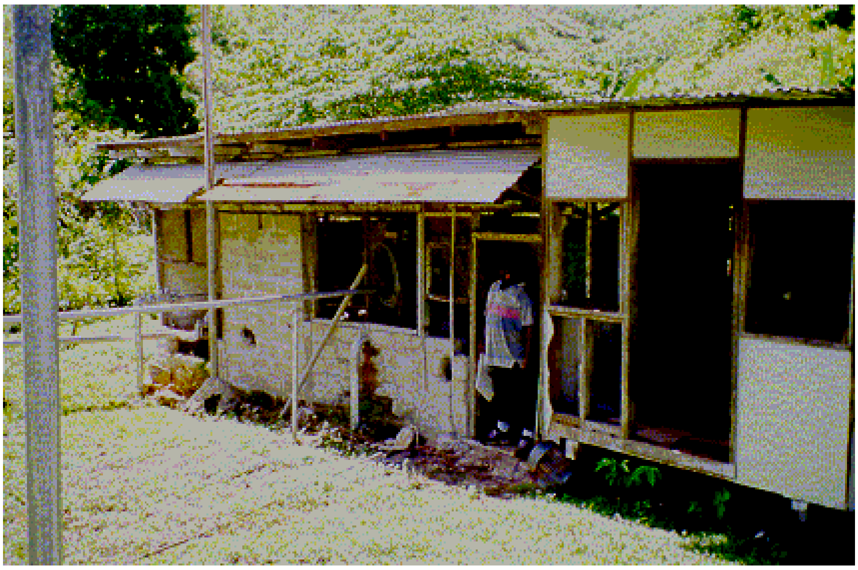

Photo A3.4: Pump house at Auki Gallery

Appendix 4: Recommendations

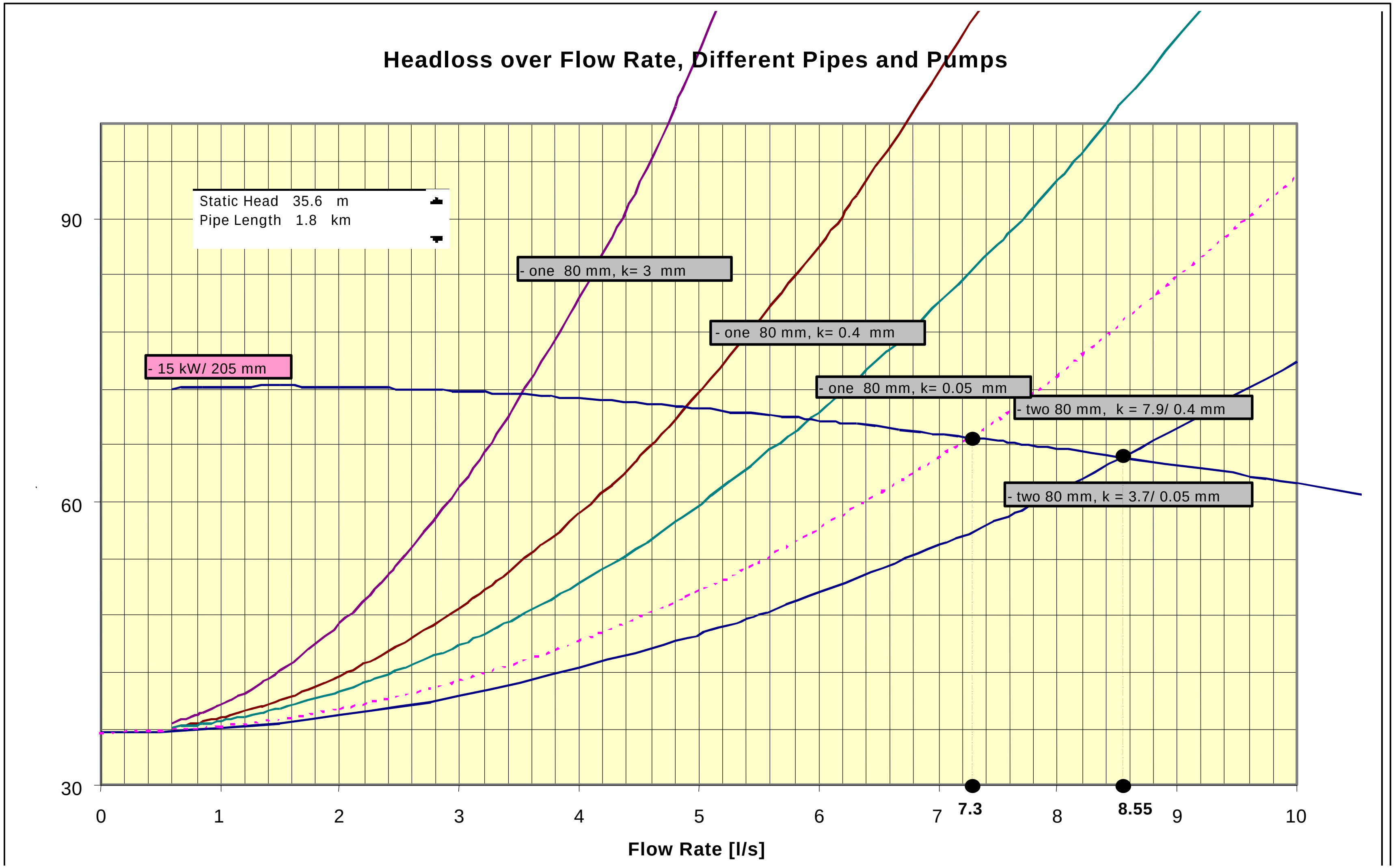

Figure A4.1: Impact of relocating the 15 kW pump from the gallery to the Kwaibala source