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Evaluation of bypass valves at small hydro power plants

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Abstract

Hydropeaking has adverse effects on river ecosystems which are likely to increase as hydropeaking increases. Bypass valves are extensively used in Norway to mitigate the sudden changes in water discharge, and this thesis aims to evaluate their performance. Literature focusing on fish stranding were selected to provide a background on the acceptable changes. Stop/restart scenarios were carried out in five small power plants of different characteristics, measuring discharge, water stage and temperature changes in various points along the affected river reaches.

Results were compared to parameters provided by the EnviPEAK project, resulting in high risk scenarios in most of the cases. A digital model of one of the sites was also tested with different operating strategies, obtaining basic approaches to steer the bypass valve better.

It was concluded that bypass valves have potential to mitigate adverse effects caused by hydropeaking, but better operation is needed.

Preface

I would like to thank my supervisor Knut Alfredsen, for his guidance during the writing of this thesis, as well as his constant availability in the office or by email.

Thank you also to Samuel Vingerhagen, Kjetil Vaskinn and SWECO for providing the data for the study and making themselves available to take me on field measurements.

I confirm that all the necessary sources are included in the References section.

Water level and temperature data has been collected by Samuel Vingerhagen and Kjetil Vaskinn for SWECO, with my participation.

GPS data for the modelling has been collected by Knut Alfredsen and myself.

Pictures are taken by Samuel Vingerhagen and myself.

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1. Introduction

During the last decades, there has been a tendency to increase the use of renewable energies worldwide. Power grids are being increasingly interconnected to allow for electricity transport from producing areas towards deficitary ones. Hydropower can have one of the main roles in this changing market as an alternative energy which is predictable, storable and with rapid response capabilities. This allows for this source of energy to have a balancing role inside the market. Given its availability, some countries have even made it their main source, like in Norway, where hydropower represents 99% of the generated energy (Statkraft 2017).

Small hydropower plants might not have such an important role for balancing the power grid as they usually don't have big storage capacity, but they have become increasingly popular in recent years, and there is potential to build much more (Jensen, Voksø et al. 2004). Meanwhile, recent studies show that small hydro's effect on environment might be higher than initially anticipated (Bakken, Forseth et al. 2016).

Among the usual studied environmental impacts for hydropower production we can find river course alterations, valley flooding, ecosystem changes etc., which usually focus on long term effects or seasonal events. But there are however, shorter term events which are worthy of being studied, like hydropeaking.

Hydropeaking consists on the production of power by hydropower during peak demand, which leads to an intermittent production and quick fluctuations on the rivers flow regime. If hydropower is to be used as a balancing source in a wider power grid, hydropeaking can be expected to be more frequent.

These sudden changes in water release yield several effects, of which we will focus on the following.

1.1. Temperature changes

One of the main advantages of hydropower when comparing it to other sources of renewable energy is its storability. This is achieved collecting excess water in reservoirs, and releasing it when power production is needed. On bigger hydropower plants with big reservoirs, this is accomplished collecting the spring floods and releasing this water during low flow periods like winter, which has the added advantage of flood protection.

Collecting big amounts of water does however create big artificial lakes, and when releasing this water on the previously mentioned low flow winter scenarios, water from a deep lake will have a very different temperature from the natural river flow during winter.

The seasonal effects of these temperature changes on habitats have been widely studied (Alfredsen and Tesaker 2002), while in sub-arctic climates like in Norway, ice itself can be a problem for hydropower production (Gebre, Alfredsen et al. 2013) and water temperature alterations could change its breakage patterns. Research on shorter events indicates that salmon specimens need at least two weeks to acclimate to new temperatures (Peterson and Anderson 1969).

There are several studies trying to implement ways on which to quantify the adverse effects of sub-daily temperature changes on river ecosystems due to hydropeaking. (Zolezzi, Siviglia et al. 2011, Vanzo, Siviglia et al. 2016).

1.2. Fish stranding

When the previously mentioned hydropeaking operations are carried, one of the main consequences of changing water release volume is fluctuations in water stage in the river downstream from the power plant. When the water level drops too fast, areas previously inundated can go dry. In these situations, fish which were in one of these areas can get stranded on dry areas, or be trapped in ponds that have been disconnected from the main river. Stranding can occur both on gravel or cobble river bars and in back channels or pot-holes that become isolated from the main flow when river levels recede (Bradford 1997).

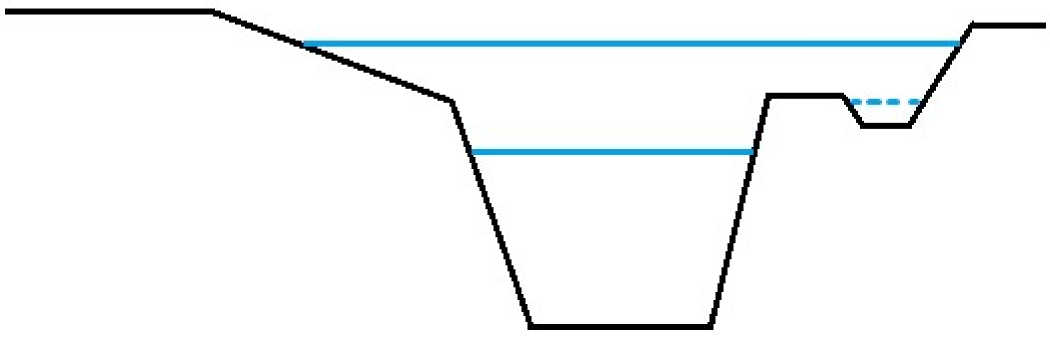


Figure 1 - River cross section representation

In Figure 1 we can see a river cross section representation with two possible water levels. If we consider this cross section to be downstream from the outlet of a power plant subject to hydropeaking, the water level will go down from the highest to the lowest one when production stops. Fish could get stranded on the dry area on the left bank, or on the pond that can be formed on the right bank.

There is an abundance of literature studying stranding, and most it focuses on stranding produced by human activity. In fact, 65.5% of peer-reviewed articles with focus on stranding study the stranding produced by hydropower operations and irrigation projects (Nagrodski, Raby et al. 2012).

Many diverse factors can be studied to see their influence on stranding, like fish presence and species, water stage variation rate, water temperature change, flow change, water stage and flow modification magnitude, riverbed shape and granulometry, hydropeaking frequency, time since last hydropeaking event, time of day and year and several more. Different studies focus on different causes depending on the research to be done or local particularities.

Time of day on which the dewatering takes place is designated as one of the most important factor by many of the studies, the most dangerous resulting time for stranding being afternoon (Irvine, Thorley et al. 2015), during rapid dewatering at night (Halleraker, Saltveit et al. 2003) or daylight (Saltveit, Halleraker et al. 2001). The same study by Saltveit, Halleraker et al. 2001 mentions however that time of day is not relevant if the flow is reduced to be slower than 0.3 cm/min or 20 cm/h. Studies made in the Nidelva river propose a maximum of 13 cm/h sinking velocity to considerably reduce the stranding probability (Harby, Alfredsen et al. 2004).

Fish adapt to their living environment and significantly more fry are stranded in the first versus the second to fifth dewatering episode (Halleraker, Saltveit et al. 2003). Similarly, on a lab experiment 40% of the tested fish never stranded and of those who did, 55-66% just stranded once (Harby, Alfredsen et al. 2004). A conditioning reduction prior to the operational reduction mitigates the stranding, while most stranding happens when the affected areas have been inundated for a long time (Irvine, Oussoren et al. 2009, Irvine, Thorley et al. 2015).

Temperature is an significant factor, as fish tend to strand more in colder waters, due to lower metabolic activity (Peterson and Anderson 1969, Bradford 1997)

The fish specimens are affected differently by the dewatering. Fish are more susceptible to being stranded or damaged during early life stages of development as compared to adult fish and young fish even more susceptible to dewatering than eggs (Casas-Mulet, Saltveit et al. 2016).

Groundwater can also greatly influence egg and fry survival, as it can serve as protection against dry situations and cold temperatures under hydropeaking events. Eggs have up to 99% survival rate when kept wet by groundwater (Casas-Mulet, Saltveit et al. 2015, Casas-Mulet, Alfredsen et al. 2016), while fry can find refuge between rocks or sand and survive for several hours with favourable ground conditions (Harby, Alfredsen et al. 2004).

Hatchery salmon has very different behaviour compared to wild salmon, as they lack the instinct of looking for protection on the riverbed and tend to strand less (Saltveit, Halleraker et al. 2001). Therefore, several stranding probability studies done prior to this discovery were not considered in this thesis.

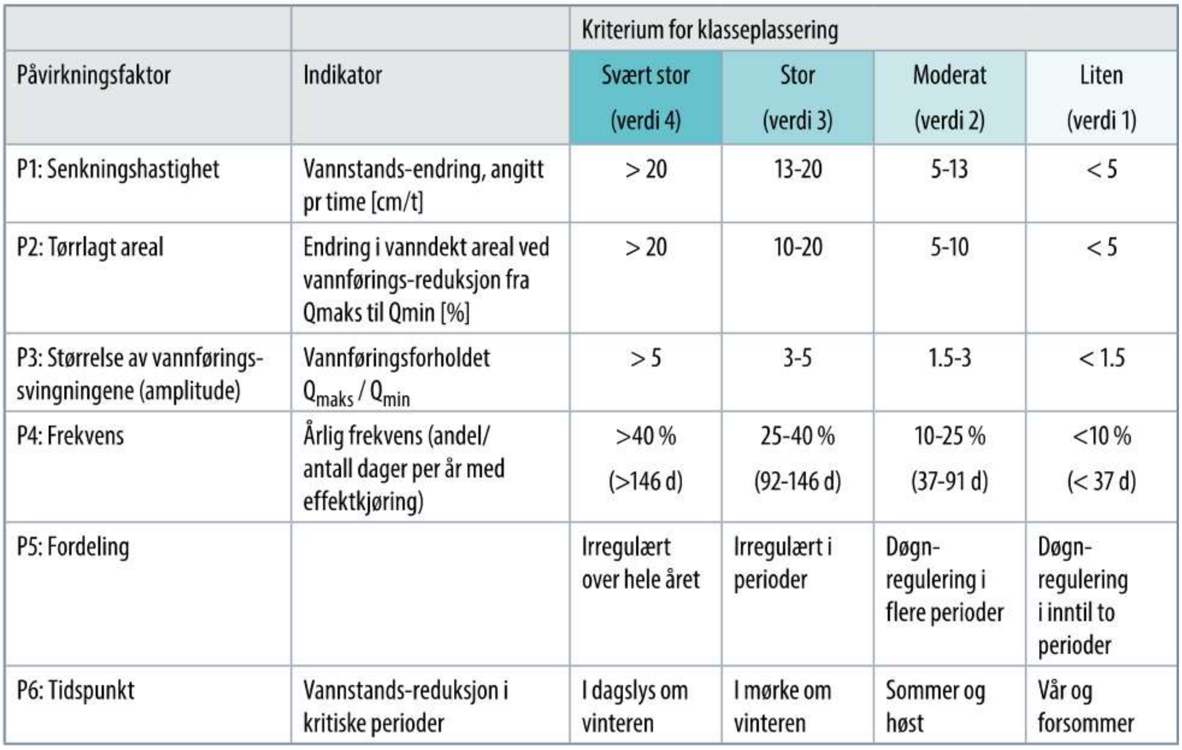
These publications analyse how different variables affect fish stranding and the mortality caused by the stranding. Fish do however often survive these events, sometimes after spending hours in a semi-dry environment, and little is known about the sub lethal and long-term consequences of stranding on growth and population dynamics (Nagrodski, Raby et al. 2012).

As seen in the selected literature, there is a very high number of variables affecting the stranding probability, but the severity and direction of the response varies widely. (Murchie, Hair et al. 2008, Young, Cech et al. 2011). There is however a necessary requirement for anthropogenic induced stranding to occur, which is water stage change, and this study will be centred on it.

1.3. EnviPEAK

EnviPEAK is a project by CEDREN, Centre for Environmental Design of Renewable Energy, to study the effect of rapid and frequent flow changes, it will address the changes that are expected in the operation of Norwegian hydropower plants as a consequence of the development of other energy sources, such as wind power. The main objective of EnviPEAK is to develop knowledge and tools to analyse, predict and mitigate environmental impacts from rapid and frequent changes in hydropower production regimes.(CEDREN)

After numerous studies and publications, a book was published on which some guidelines are given for a systematic and methodical approach to impact measurement on rivers due to hydropeaking, Table 1. (Bakken, Forseth et al. 2016)



		Kriterium for klasseplassering			
Påvirkningsfaktor	Indikator	Svært stor (verdi 4)	Stor (verdi 3)	Moderat (verdi 2)	Liten (verdi 1)
P1: Senkningshastighet	Vannstands-endring, angitt pr time [cm/t]	> 20	13-20	5-13	< 5
P2: Tørrlagt areal	Endring i vanndekt areal ved vannførings-reduksjon fra Qmaks til Qmin [%]	> 20	10-20	5-10	< 5
P3: Størrelse av vannførings-svingningene (amplitude)	Vannføringsforholdet Q_{maks} / Q_{min}	> 5	3-5	1.5-3	< 1.5
P4: Frekvens	Årlig frekvens (andel/ antall dager per år med effektkjøring)	>40 % (>146 d)	25-40 % (92-146 d)	10-25 % (37-91 d)	<10 % (< 37 d)
P5: Fordeling		Irregulært over hele året	Irregulært i perioder	Døgn-regulering i flere perioder	Døgn-regulering i inntil to perioder
P6: Tidspunkt	Vannstands-reduksjon i kritiske perioder	I dagslys om vinteren	I mørke om vinteren	Sommer og høst	Vår og forsommer

Table 1 - EnviPEAK impact quantification (Bakken, Forseth et al. 2016)

Once the impacts from each source are calculated, the sum of them will give a grading on the rivers affection due to hydropeaking, as shown on Table 2.

Klasse	Sum
Svært stor	21-32
Stor	15-20
Moderat	10-14
Liten	4-9

Table 2 - EnviPEAK impact classes (Bakken, Forseth et al. 2016)

There are many studies and methods developed to reduce the negative effects of human action on rivers, the Joint Research Centre of the European Commission proposes the following mitigation measures to avoid rapidly changing flows on their report on "Common understanding of using mitigation measures for reaching Good Ecological Potential for heavily modified water bodies" (Halleraker et al 2016)

- Balancing reservoirs
- Relocation of tailrace to a larger water body
- Reduce rate of flow ramp down (including using a bypass valve)
- Modify river morphology
- Fish stocking

Most of these alternatives are labour intensive, expensive and require maintenance, so they are not feasible for small power plants. Therefore, the use of bypass valves is recommended, or even mandatory for new concessions in rivers with fish presence in Norway, and the use of Pelton turbines with deflectors for the same purpose is not allowed anymore (Størset, Hiller et al. 2012, NVE 2016).

1.4. Bypass valves

Whereas literature on fish stranding and several ways to remedy it was abundant, literature specifically studying bypass valves was difficult to find. It is often mentioned as part of hydropower plants, or as a mean to mitigate hydropower production environmental effects, but it rarely is the main study focus on a publication, and details on how to make them work are not available, or at least not publicly.

The only useful publication found was “Kriterier for bruk av omløpsventil i små kraftverk”, commissioned by NVE and written by SWECO (Størset, Hiller et al. 2012). This document is based on data collected from several field and modelling experiments, and contains recommendations which will be used later in this text, on when a bypass valve is necessary, the capacity it should have, and how it should be operated.

It should be noted that as well as dewatering, hydropeaking also causes sudden flooding of river areas, often with even faster water raising velocities. This phenomenon can cause flushing of fish juveniles (Young, Cech et al. 2011).

2. Research methodology

Five different small hydropower plants were chosen in the Sør-Trøndelag region, with the following characteristics (NVE 2017)

1. Bele
    - Building year 2013
    - Height difference 379 m
    - Installed capacity 2.9 MW
2. Brandåa
    - Building year 2009
    - Height difference 373 m
    - Installed capacity 3.94 MW
3. Gryta
    - Building year 2009
    - Height difference 223 m
    - Installed capacity 1.49 MW
4. Sundli
    - Building year 2015
    - Height difference 207.5 m
    - Installed capacity 1.35 MW
5. Sya
    - Building year 2009
    - Height difference 193.4 m
    - Installed capacity 1.2 MW

Sundli has a reservoir, while the rest are run of the river power plants, Figure 2 shows a map of their location. The main objective of this study is to analyse the drop in water level on natural water courses, and that happens when the power production is stopped, so production stops were agreed with the power production companies. This whole process was carried away by SWECO, while the writer of this thesis participated on the 2017 data collection campaign.

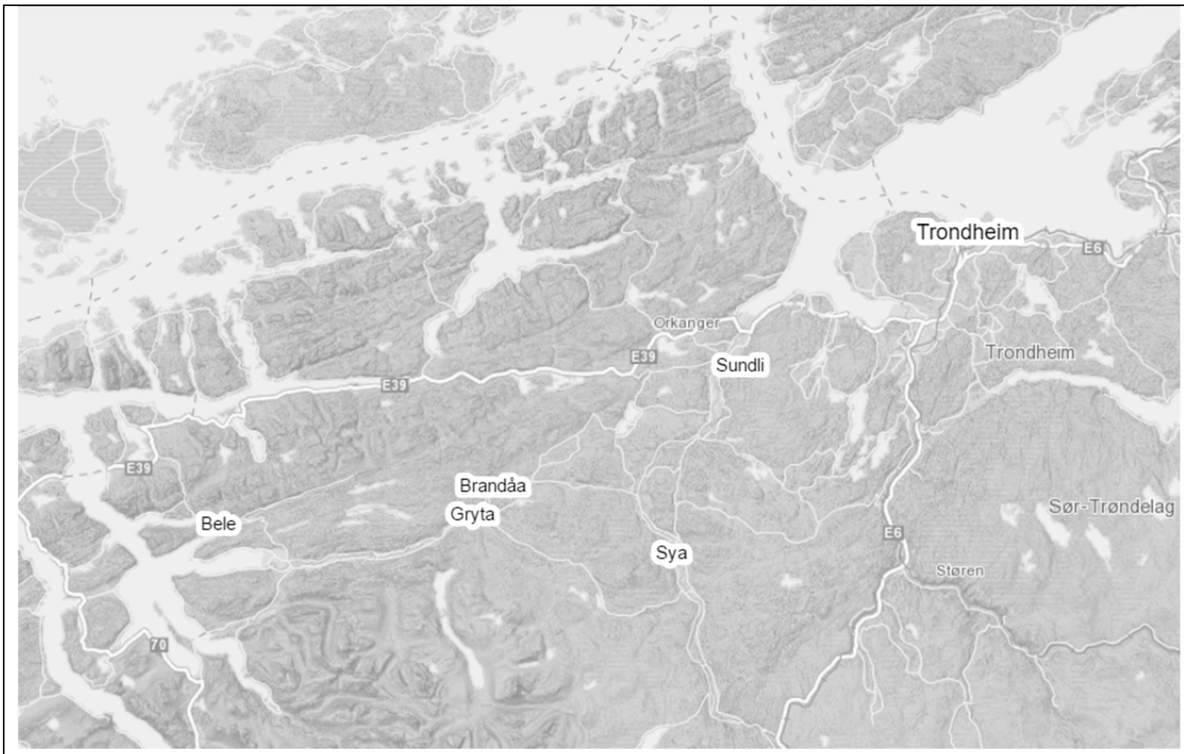


Figure 2 - Situation map (Kartverket 2017)

2.1. Data collection

Prior to stopping the power plant, several water level loggers were placed along the water course, typically

1. Intake dam
2. Right downstream the intake dam
3. Upstream outlet
4. Right downstream the outlet
5. Approx. 100m downstream the outlet
6. Approx. 500m downstream the outlet
7. Approx. 1km downstream the outlet

Positioning the sensors in all the desired places was not always possible due to accessibility difficulties to the stream, impossibility to reach the intake because of snow accumulation and several other practical reasons. The approximate distances of the sensors to the power plant outlet were later measured on Google Earth (Google 2017). The sensors used in this case were Global Water WL16, which are also capable of measuring water temperature. Measurements were taken every 15 seconds. This array of sensors offers the possibility of observing water level and temperature changes on the representative areas of the water course during the stopping/restarting event. The loggers were attached to heavy rocks and placed on deep and calm ponds (Figure 3, Figure 4), to ensure that they wouldn’t move with the current, or go dry during dewatering situations.

This way it should be possible to study water level changes when going from a normal flowing situation to stopping the power plant. Water level downstream of the outlet should go down while staying stable upstream. After a while we should receive water from the intake, after it has flowed through the bypassed reach of the river. Finally, when starting production again, the discharge downstream of the outlet should be maximum, including the natural river flow plus the production discharge.

Once the stopping/restarting event was finished, the loggers were collected and the data downloaded to a computer, from which temperature and water level data could be studied. Some calibrating had to be done, as the loggers register changes in pressure and each one of them had the reference level at a different point. The collected data was also interpolated to avoid peaks

Figure 3 - Placing logger in water

Figure 4 - Logger in water

between the data points and get smoother lines, and have a better representation using 1-D linear interpolation software (XonGrid 2014)

Water discharge measurements were also made, to characterize the flow on the river and through the power plant. These were made before, during and after the stopping event when the water stage stabilised, so that adding or subtracting the different measurements between each other, normal flows, production flows, environmental flows or bypassed flows could be calculated. Water released by the bypass valve could not however always be calculated by this method due to its constant variation, and was taken from the power plants' control software when available.

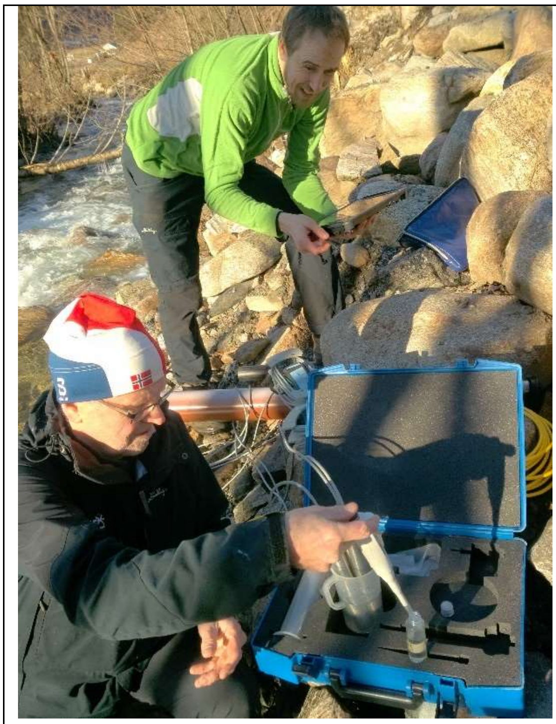


Figure 5 - Conductometer calibration

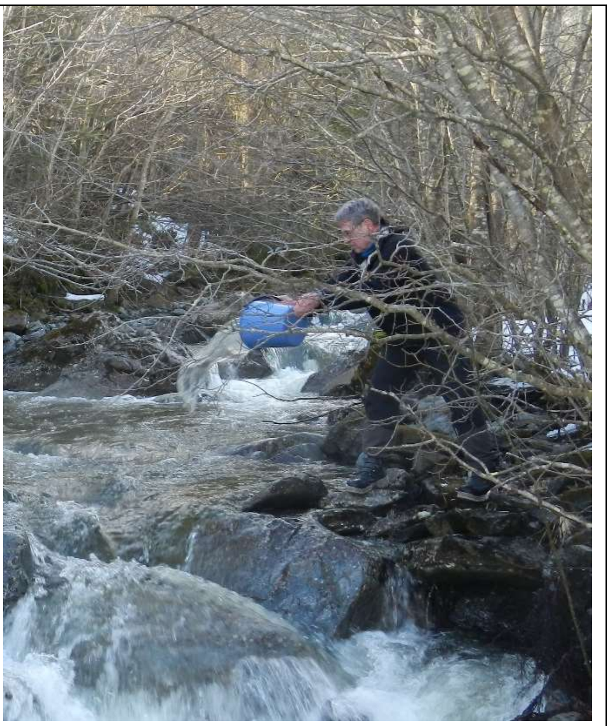


Figure 6 - Pouring salt into river

Salt dilution was used to measure the water flow. In this method, a determined amount of salt is added in the river (Figure 6) and the change in electric conductivity is measured some meters downstream once the salt has had time to completely dissolute in the water. Knowing the amount of salt added, and constant conductivity measurements, the amount of water can be deducted. 1kg of salt per approximately 1m^3/s was used, to ensure enough sensibility and salt was poured into the river already diluted in water, to ensure good mixing before reaching the measurement point.

The conductometers, Sommer Messtechnik TQ-S, were calibrated in each site (Figure 5), to adapt to the different water characteristics found on each stream and provide an exact measurement. This was done by taking a sample of water, and adding known amount of salt in several steps, until an accurate regression was obtained. Changes in water conductivity due to the water coming from the power plant and not the river were deemed insignificant, while the conductometers automatically calibrate the readings to temperature changes.

Several cameras were place along the river reach, typically on the outlet and several points downstream to have a visual depiction of the measured processes. Pictures were taken automatically every 15 seconds and put on stop-motion films afterwards.

All measurements were done and repeated on three different days, with three different flows, high, medium and low on the river, roughly representing 25%, 50% and full production capacity (when conditions allowed).

2.2. Modelling

Once we have the water depth and temperature measurements, we can analyse the behaviour of the water course, the influence of power production stop/restart events and the bypass valves performance.

To further study these aspects and be able to test possible new ways of operating the bypass valve in future scenarios, it was decided to build a digital model to make this possible. The river reach going from the outlet of the Brandåa power plant until the junction with the Surna river was the chosen site. This site was chosen due to its easy accessibility, the possibility to make the measurements with GPS positioning, and the availability of data from the previous water depth measurements to make comparisons.

Figure 7 - GPS measuring

The Brandåa power plant takes water from both the Brandåa and Trøkna rivers through small ponds. The environmental flow in the Brandåa intake is 50l/s from 1. May until 30. September and 20l/s the rest of the year, while on the Trøkna intake is 40l/s from 1. May until 30. September and 20l/s the rest of the year (NVE 2007). The water is carried through the penstock to the power plant, with an installed capacity of 3.94 MW and a maximum flow of 1,3 m^3/s. The water is released on the Trøkna river, very near the point where it flows into the Surna river. The installed bypass valve in this power plant has a capacity 50% of the maximum flow, and is manually operated.

Figure 8 - River and the taken cross sections (Kartverket 2017)

Data collection was done on 9. May 2017, a total of 18 cross sections of the river were collected with GPS (Leica Viva RTK), as illustrated on Figure 7, making sure they were close enough between each other, and collecting enough points in each cross section to have a reasonable resolution on them. Cross sections of the outlet channel from the power plants outlet were collected as well. After the cross sections, some water level points as well as a flow measurement were done to correctly calibrate the model. The model was a 1-D model built and tested on HEC-RAS, as it is simple to operate and has been proven before to provide good estimates (Casas-Mulet, Alfredsen et al. 2015).

Stranded fish were found on the study site previously, as depicted in Figure 9, Figure 10 and Figure 11.

Figure 9 - Stranded fish in the studied reach

Figure 10 - Stranded juvenile found in the studied reach

Figure 11 - Stranded juvenile found in the studied reach

The cross-section coordinates were processed in Excel and fed to HEC-RAS, with the final configuration seen on Figure 8 and some examples of cross sections on Figure 12. A flow measurement was also taken, to be able to calibrate the model correctly, obtaining 700l/s. Production values at the time of making the measurement were asked to the power company, which resulted in a corrected value of 740l/s.

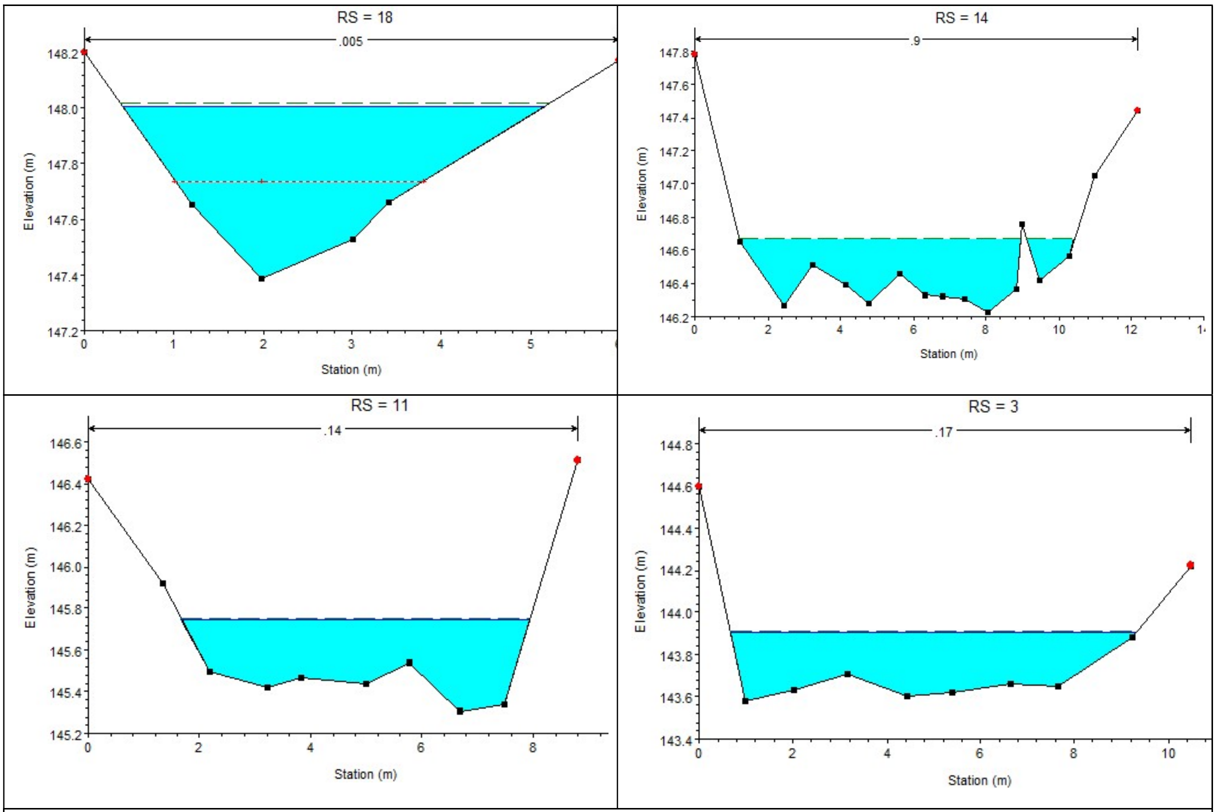


Figure 12 - Cross section examples

With the geometry defined and the flow at the moment of making the water stage measurements available, Manning numbers were assigned to the cross sections based on literature. These Manning numbers were adjusted on a long trial an error iterative process until the water stage at each cross section resembled the most possible to the real measured water stage, which sometimes lead to using Manning numbers outside of the range initially considered on literature. This situation is quite typical when setting up HEC-RAS models, as the Manning value in this software represents total friction and hydraulic losses, and not just roughness. Flow coming from the bypassed river reach was fed to the model as uniform lateral inflow between the two corresponding cross sections and was considered to be 40l/s for calibration, which is the environmental flow. Table 3 shows the final numeric values of water stage and Manning values for the affected cross section, Figure 13 the correlation between the values, and Figure 14 the complete model.

Original water stage (m)	Simulated water stage (m)	Difference (m)	Manning

148.01	148.01	0	0.005
147.78	147.78	0	0.11
147.45	147.47	0.02	0.13
146.69	146.67	0.02	0.9
146.28	146.3	0.02	0.21
145.74	145.75	0.01	0.14
145.18	145.2	0.02	0.1
145.08	145.09	0.01	0.59
144.76	144.74	0.02	0.65
144.49	144.49	0	0.13
144.23	144.21	0.02	0.43
143.91	143.9	0.01	0.17
143.68	143.68	0	0.26
143.36	143.36	0	0.4

Table 3 - Real and simulated values

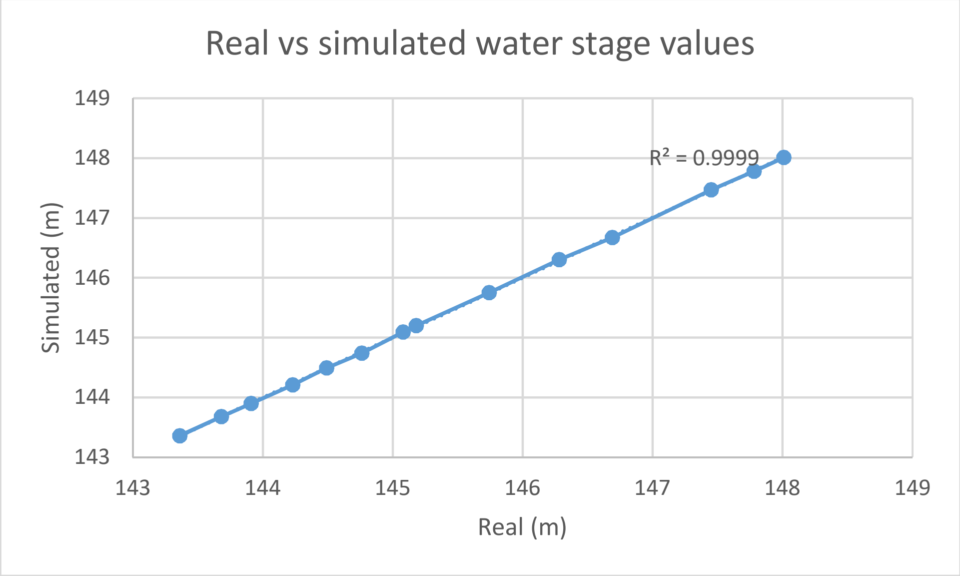


Figure 13 - Real vs simulated water stage

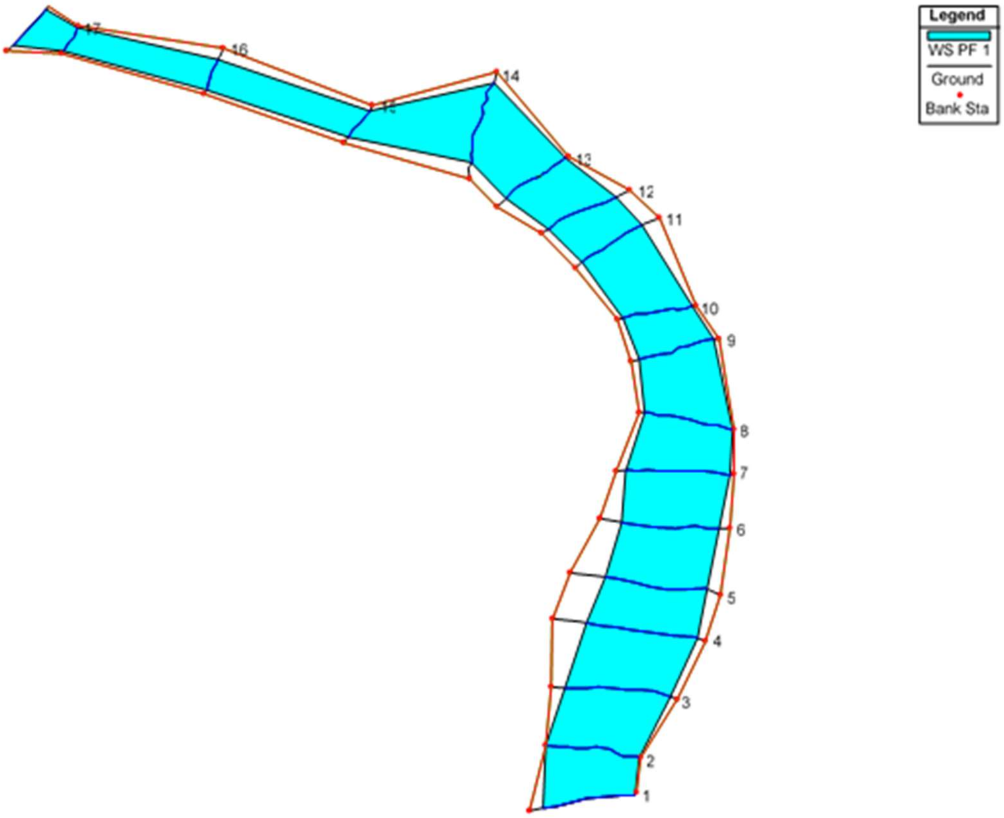


Figure 14 - Modelled river reach

3. Results

Only some of the significant results are shown in this section, all the graphs with full results can be seen on the Appendix, where several pictures are provided for visual context.

3.1. Water level

Each graph shows the water level change relative to the starting point through time. Power plant stop and restart points are also shown for reference.

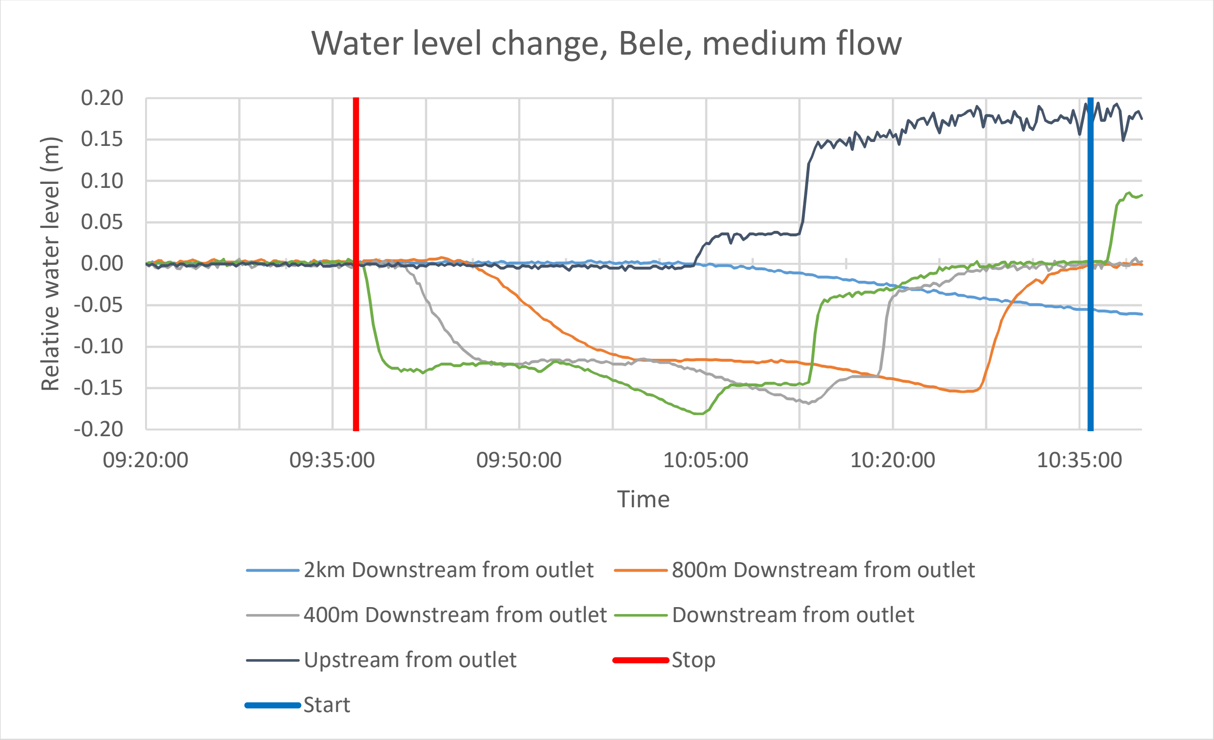


Figure 15 - Water level change, Bele, medium flow

This is a good example, Figure 15, showing all water stage movements. We see the initial steep drop, and the bypass valve releasing a stable flow until the minimum stage. We also clearly see the wave travelling the river, and how it gets dampened the lower on the river we go. Finally, half an hour later the water from the intake arrives to the power plant, which is shown by the steep increase, that later can be seen on the sensors downstream as well.

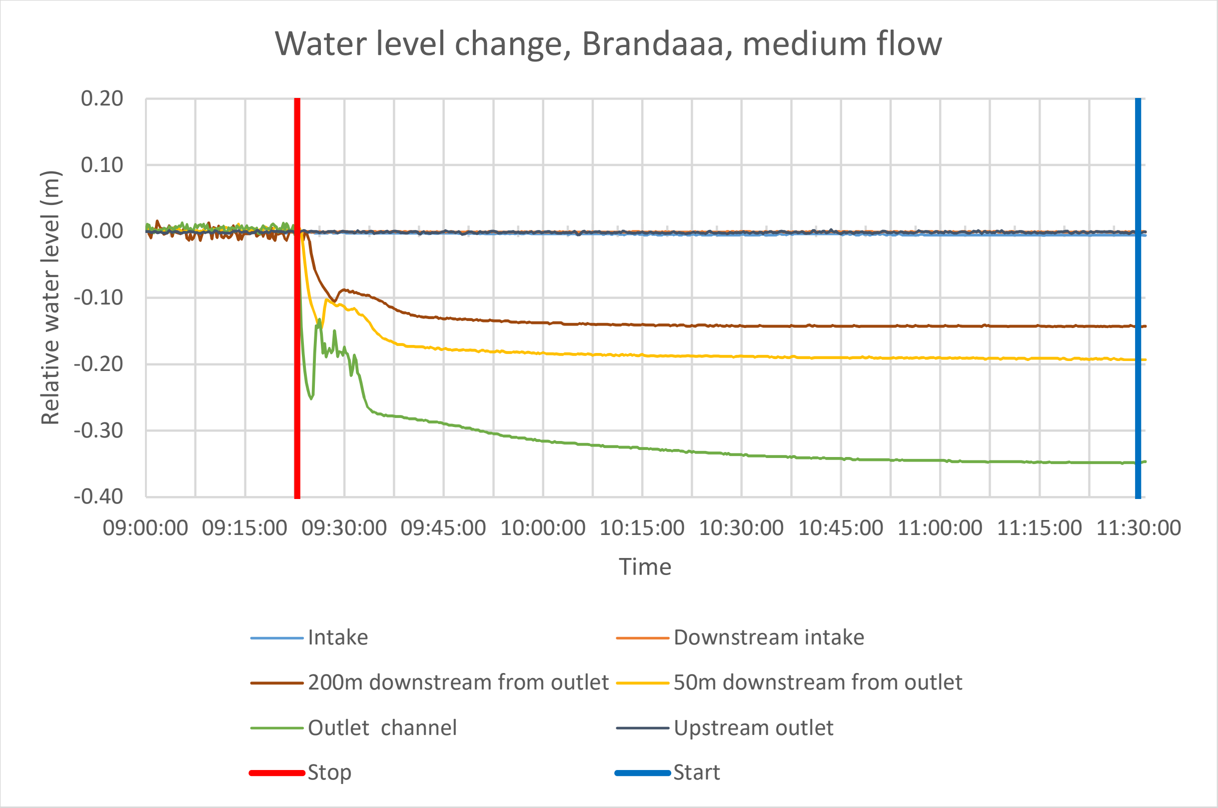


Figure 16 - Water level change, Brandåa, medium flow

In Figure 16, we see a very steep drop the moment the power plant is stopped, with a fast recovery of part of the drop. In Brandåa the bypass valve is manual, so it was activated shortly after the power plant was stopped. We also see that even after waiting for two and a half hours the water from the intake didn’t reach the power plant.

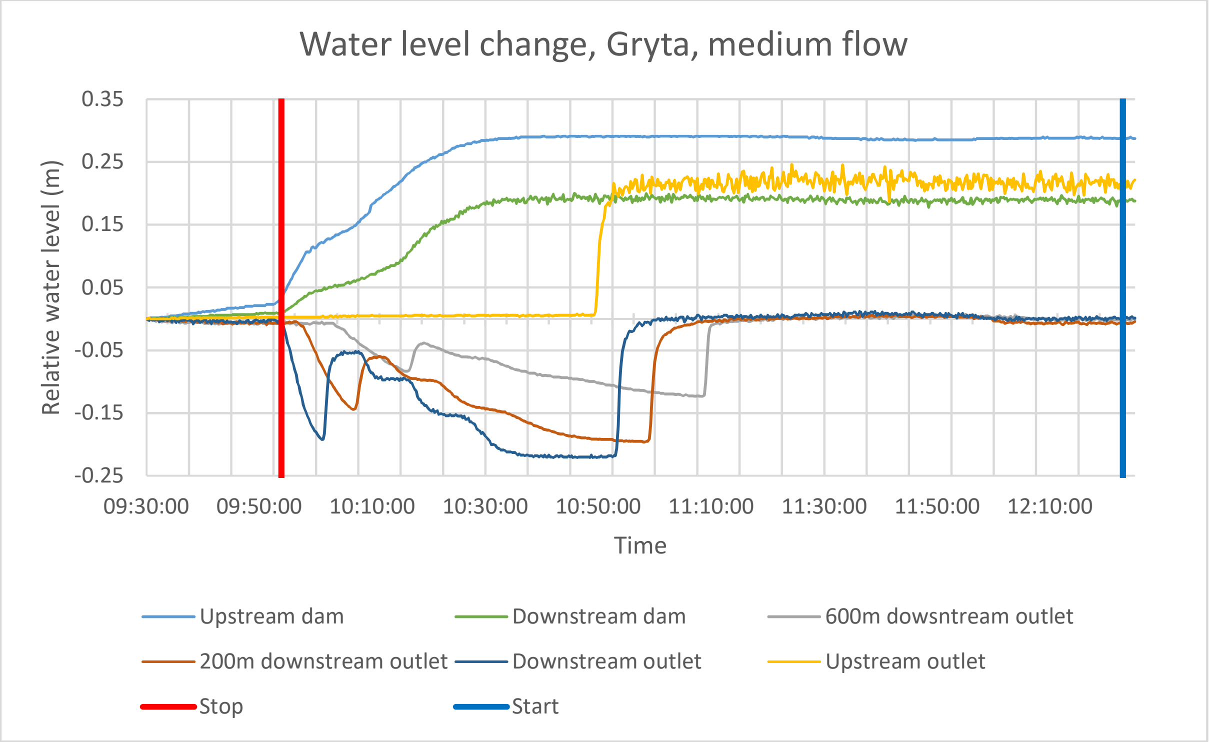


Figure 17 - Water level change, Gryta, medium flow

In Gryta, Figure 17, the initial drop is also pronounced, followed by an immediate recovery due to the action of the bypass valve. The bypass valve is then progressively closed to let the water level sink slowly. We can also see how the wave travels downstream. In this case an increase in the intake pond as well as the arrival of the water from the intake to the power plant can be observed.

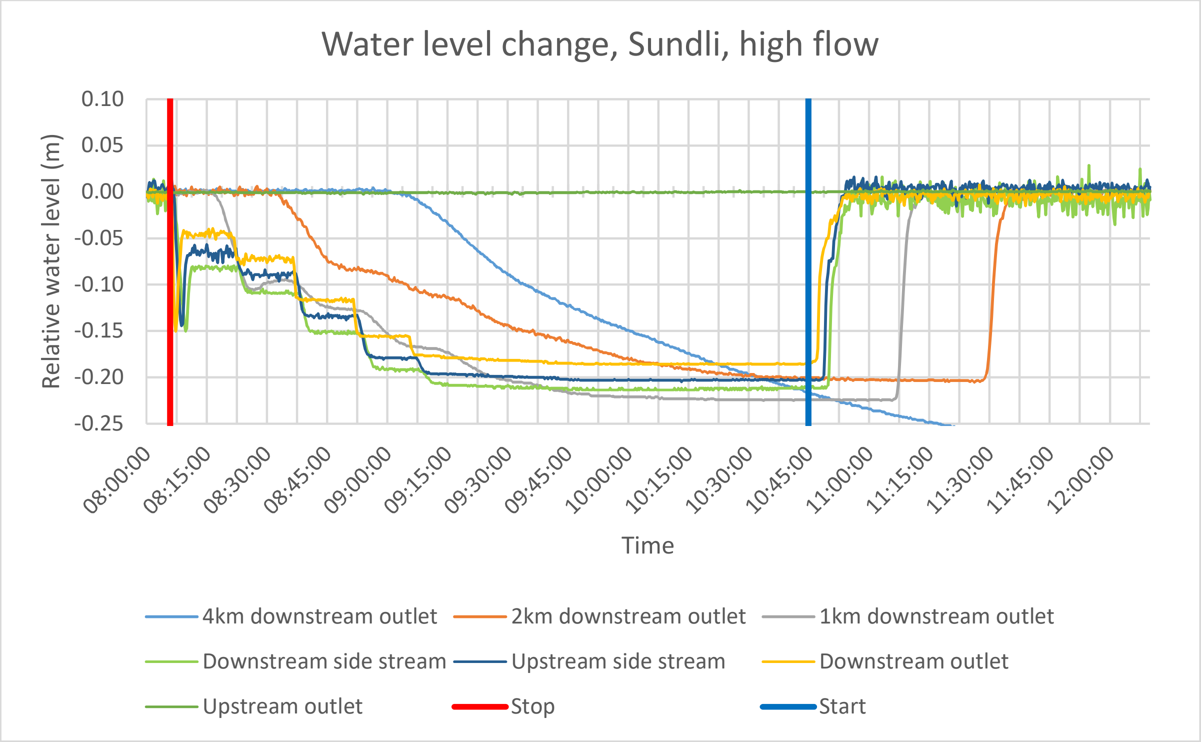


Figure 18 - Water level change, Sundli, high flow

In Figure 18, corresponding to Sundli, we see the same characteristics as before with the initial drop and the action of the bypass valve, but in this case the different openings of the bypass valve are very visible and show as steps on the water level change. As we see on the graph, these steps get dampened as we go downstream. This is the only power plant from the studied samples with a reservoir, as seen, no changes were detected on the reservoir water level.

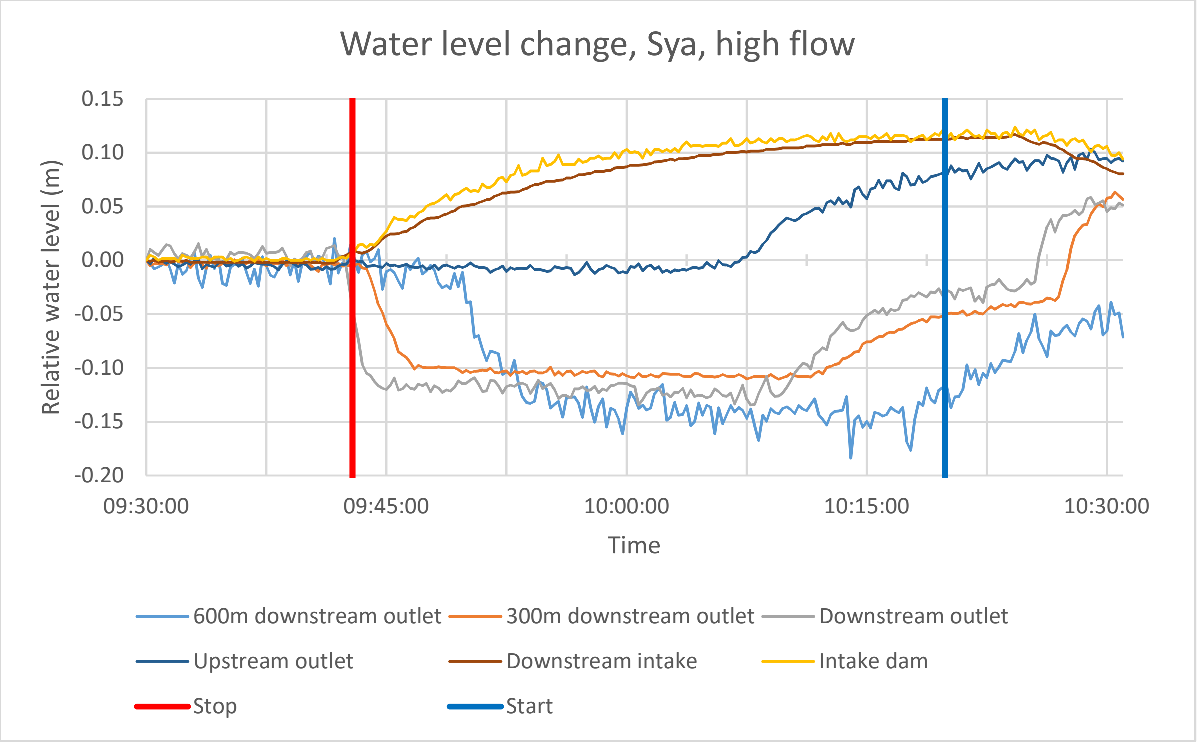


Figure 19 - Water level change, Sya, high flow

In Sya, Figure 19, the previously mentioned phenomena can be observed, as well as a quite high natural water level fluctuation.

With the collected data, water stage sinking velocities can be calculated. Values presented in Table 4 have been calculated following EnviPEAK guidelines, always taking the first sensor after the outlet of the power plant, where the height difference will be highest and with the fastest response time. Brandåa has an outlet channel bringing the water from the turbine back to the river, but it wasn't considered in this case so the results have consistency and can be compared between each other. This outlet channel should however be studied, as it's flow is entirely controlled by the power plants output, and the changes in it are extreme, as seen on the graphs. Despite not being part of the natural course several fish juveniles were observed in it during the autumn data collection campaign, so it has great stranding danger.

	Bele			Brandåa			Gryta			Sundli			Sya		
cm/h	16	180	120	280	90	73	84	130	190	270	450	168	200	40	300

Table 4 - EnviPEAK water stage change velocities

3.2. Temperature

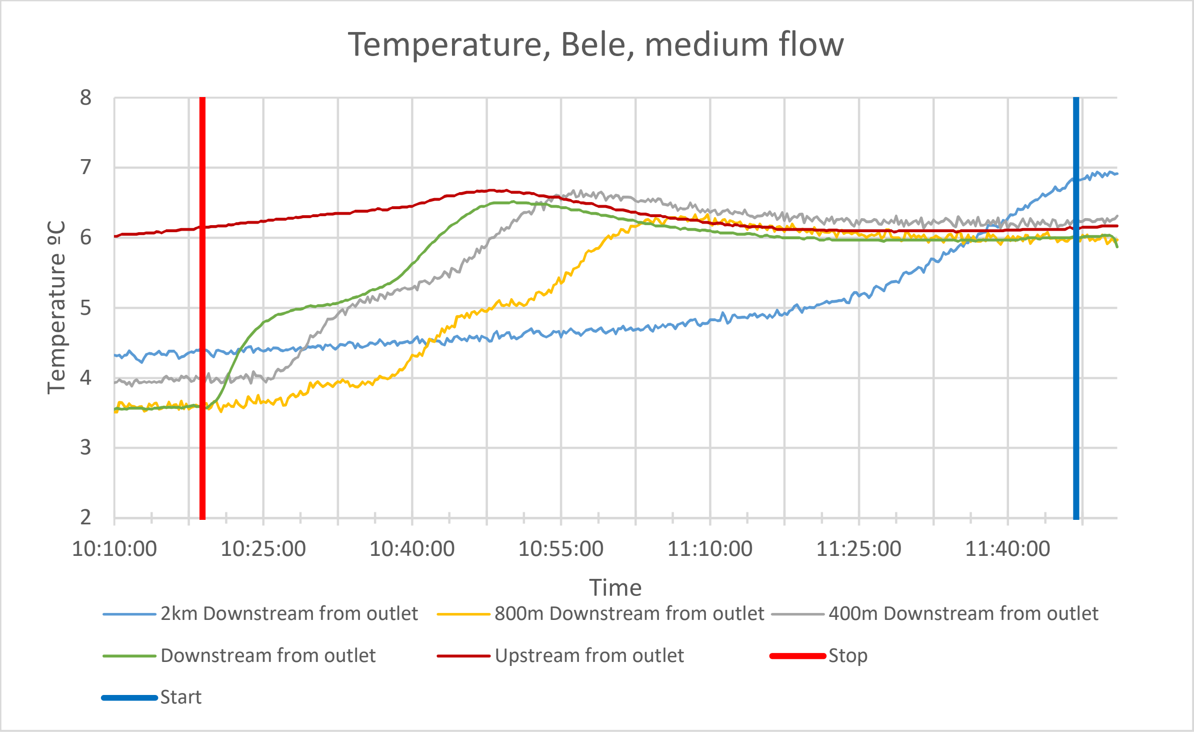


Figure 20 - Temperature, Bele, medium flow

Figure 20 shows an increase in the temperature when cold water from the intake stops flowing through the power plant, and how the wave of this warmer water travels down the river.

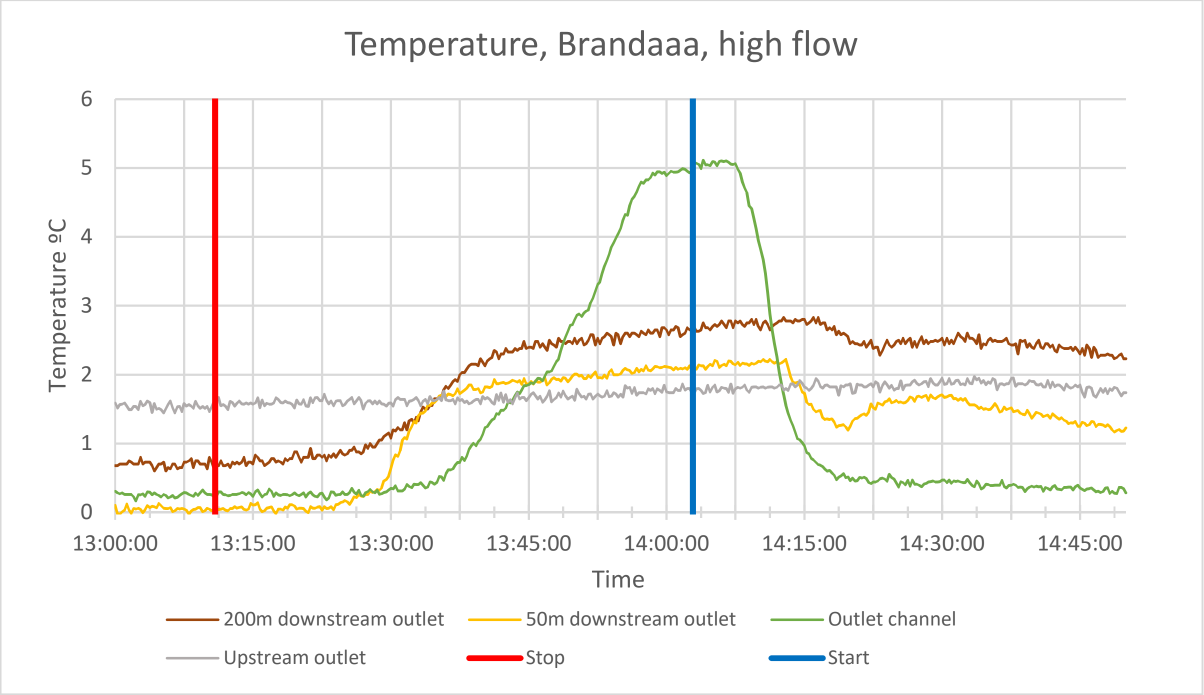


Figure 21 - Temperature, Brandåa, high flow

We also see an increase in temperature in Figure 21, as in the case before. The increase is especially big in the outlet channel, as its water is entirely controlled by the water flowing through the power plant.

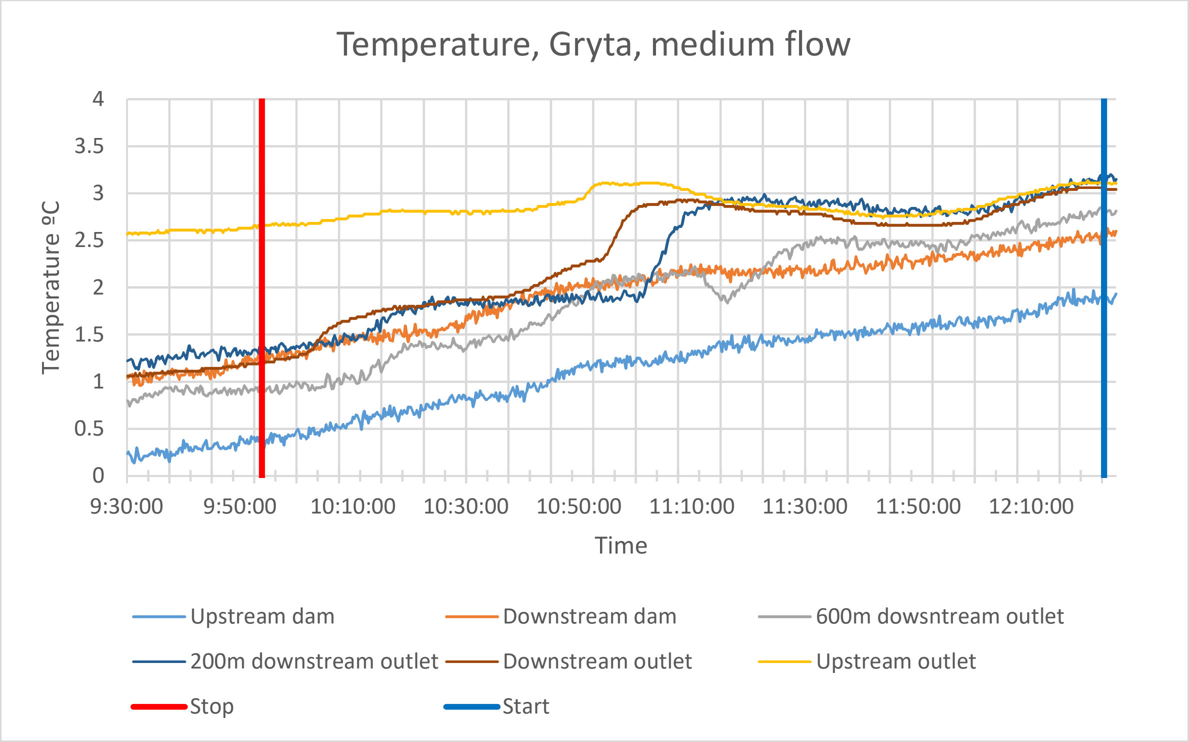


Figure 22 - Temperature, Gryta, medium flow

General increase on the temperature in Figure 22, probably due to natural morning time temperature increase. Steeper increases can be observed when water from the intake reaches downstream measurement points.

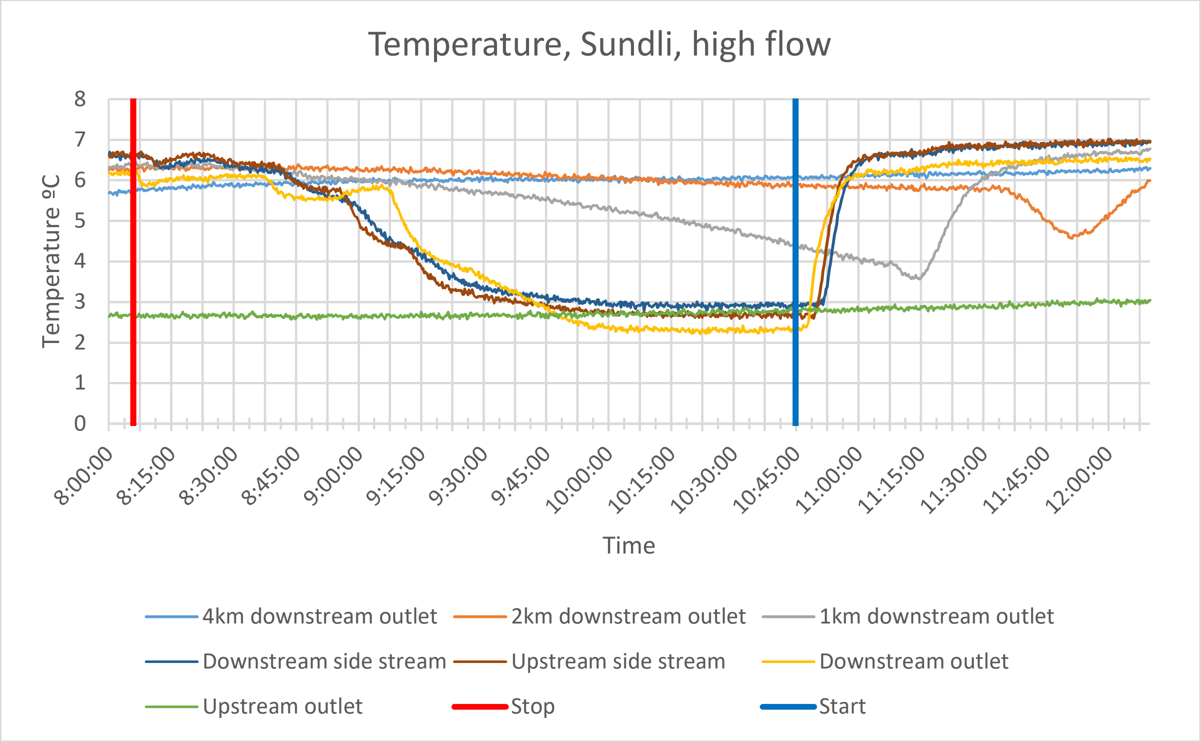


Figure 23 - Temperature, Sundli, high flow

A big decrease can be observed as water flow stops in Figure 23. Sundli is the only study site with an effective reservoir, and the effect can be seen on this graph. 2 km downstream temperature change only happens when the wave from power plant restart arrives, which can indicate a big storage effect on river.

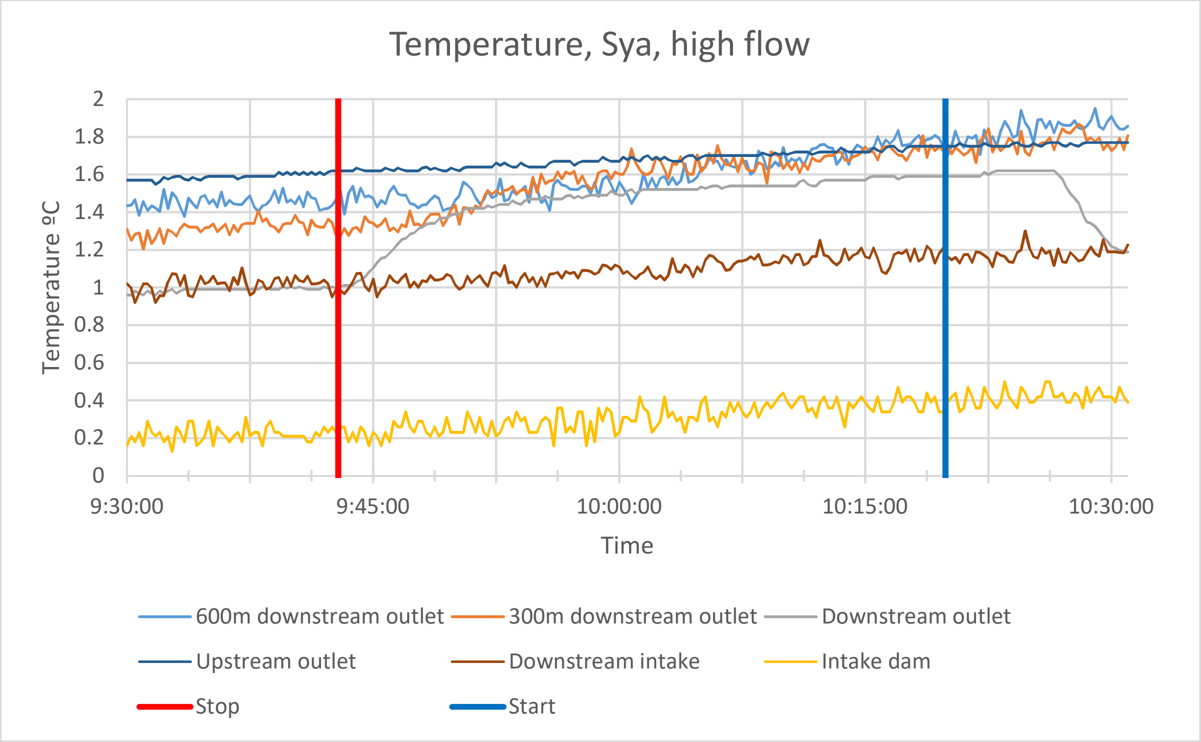


Figure 24 - Temperature, Sya, high flow

In Figure 24 temperature is stable except for increase downstream of the outlet, due to stop of contribution from power plant, and it returns to the initial value once the power plant is restarted.

3.3. Modelling

Simulations are done progressively decreasing the flow through the turbine while opening the valve at the same rate so that the total contribution to the river decreases in a controlled manner. Figure 25 represents how the flow going through the turbine, the bypass valve and the total released to the river (the sum of both) evolves in a turbine shutdown episode. After the turbine has been shut down the entire flow coming out of the power plant is controlled by the bypass valve, and can be reduced at the necessary speed.

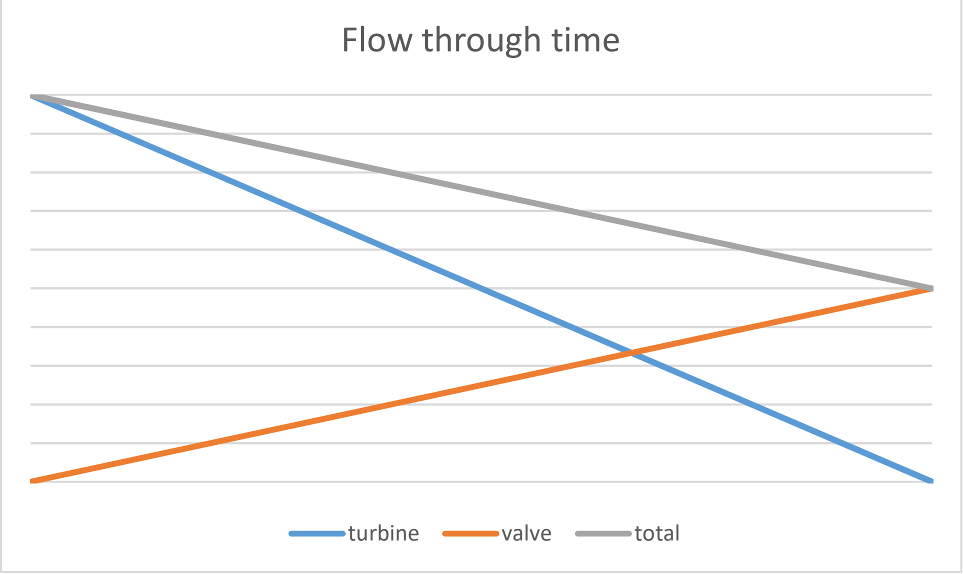


Figure 25 - Flow through turbine, bypass valve and total

Several situations are simulated and described in this section, full results available in the Appendix. Unless noted otherwise, simulation results and presented stage hydrographs are shown for the cross section shortly after the junction of the outlet channel and river (cross section 12), virtually the same position on which the logger was put during the field data collection. This way, results from the modelling and the water stage sinking velocities calculated in previous sections are comparable.

The modelled site, Brandåa has a bypass valve with a 50% capacity of the total flow through the turbine. As described in Kriterier for bruk av omløpsventil i små kraftverk (Størset, Hiller et al. 2012) a more typical starting value is 25%, so this situation will also be tested. Worst case scenarios with shutdown from maximum production and just the minimum 40l/s environmental flow flowing in the river will be the starting point, with turbine shutdown times ranging from 3 minutes (emergency shutdown) up to 1 hour. Time and date of the simulations were chosen arbitrarily and have no meaningful value. Simulations are given 5 minutes at the start to stabilise the water stages to the selected flow, and flow is reduced as described in each case.

Real situation: full production to 50% bypass valve and 40l/s environmental flow in 3 min (emergency shutdown), Figure 26:

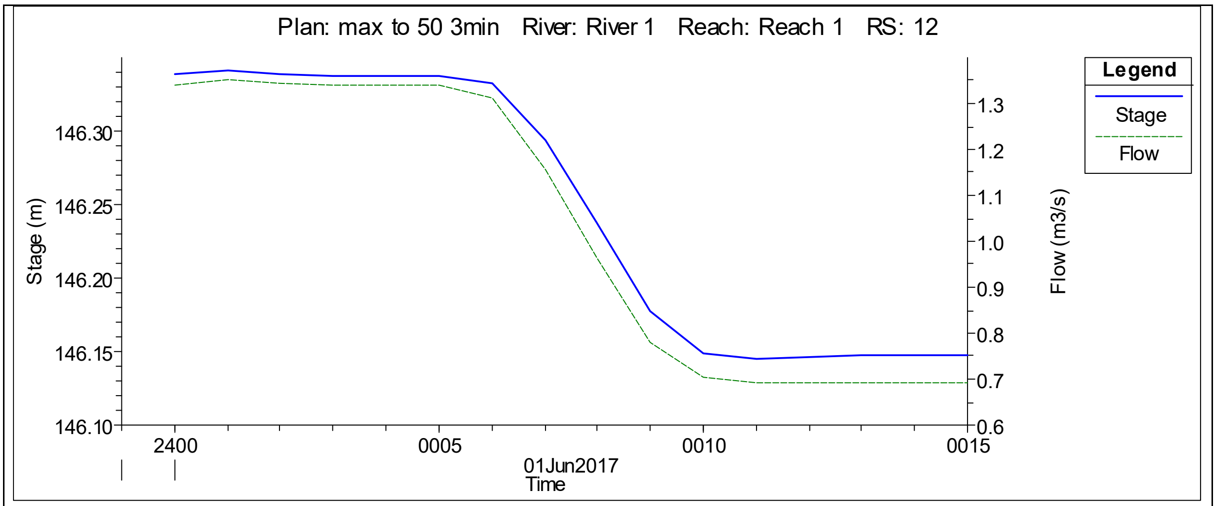


Figure 26 - Simulation full production to 50% bypass valve in 3 min

Same situation but during one hour, Figure 27:

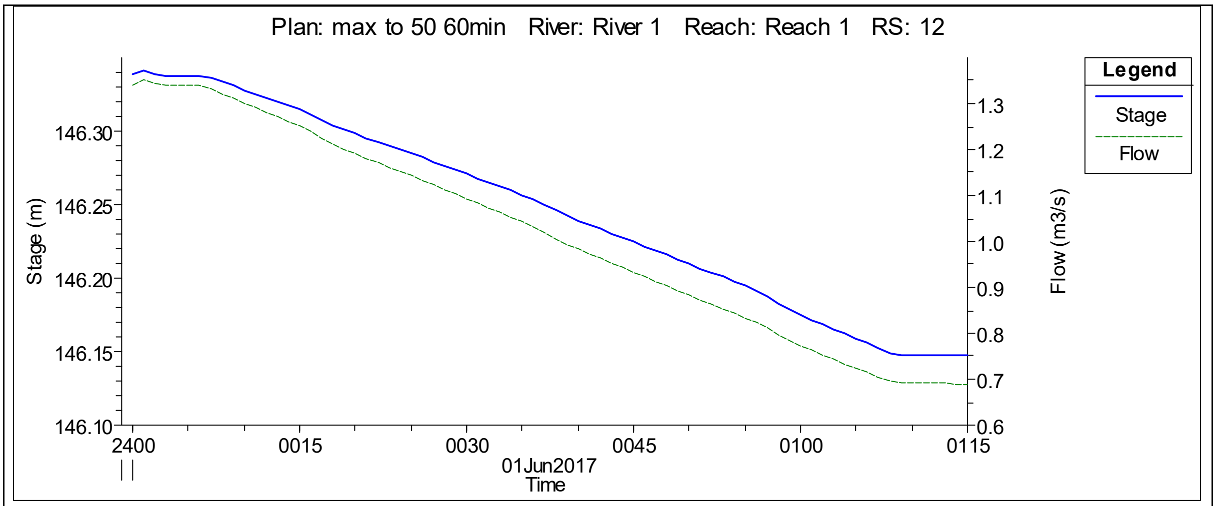


Figure 27 - Simulation maximum production to 50% bypass valve in 60 min

Same situation can be tested but assuming a 25% capacity bypass valve and a 30 min shutdown, Figure 28:

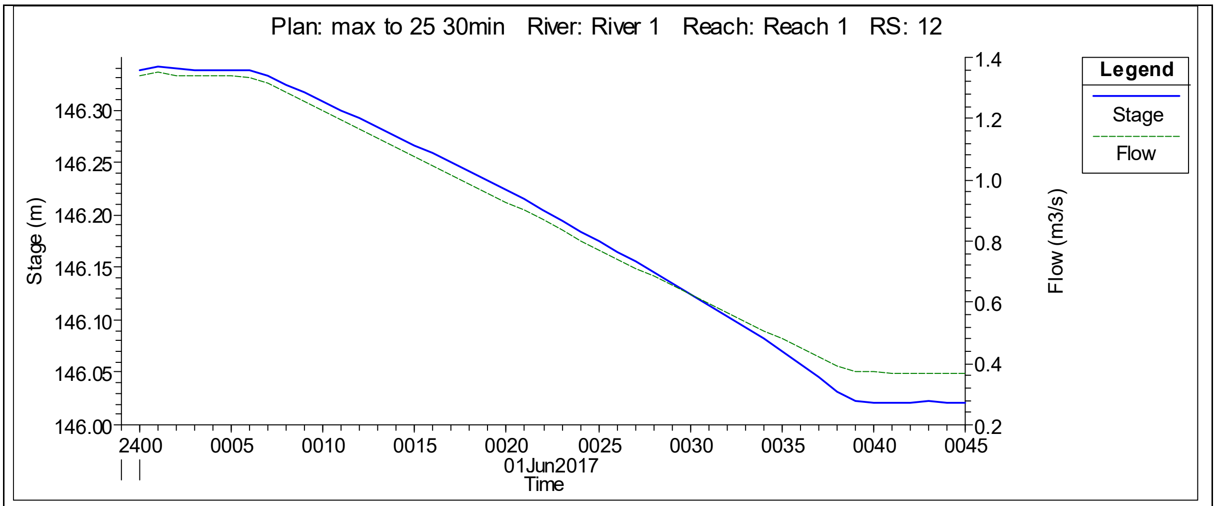


Figure 28 - Simulation maximum production to 25% bypass valve in 30 min

Or simulating a bypass valve malfunction, in Figure 29:

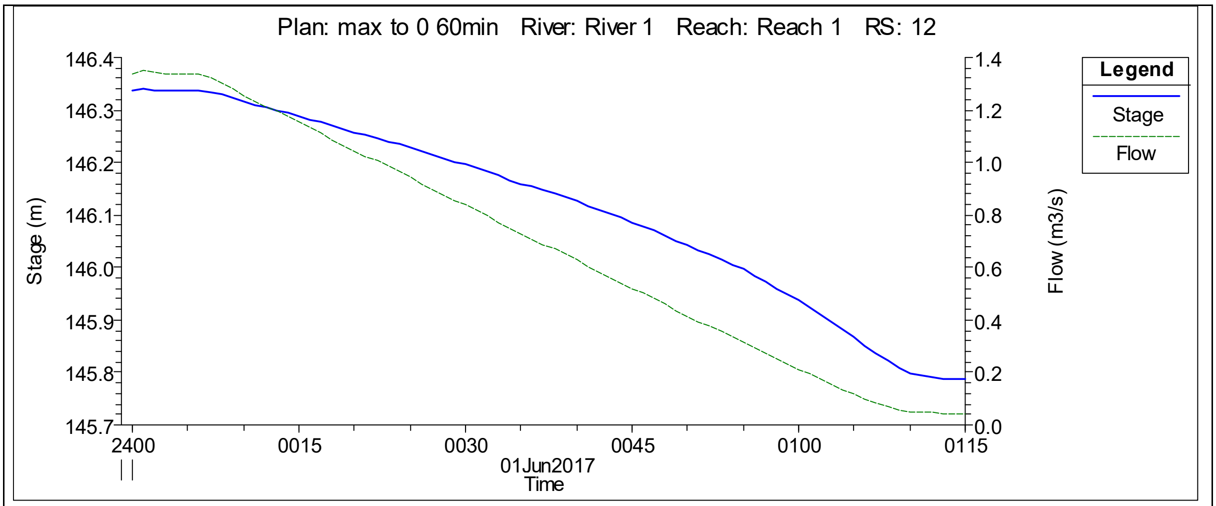


Figure 29 - Simulation maximum production to no bypass valve in 60 min

These are the worst-case scenarios, on which the flow must be reduced from maximum capacity to the bypass valve capacity, while the discharge in the river is the minimum environmental flow. Other scenarios, with more typical middle values can also be tested. We can safely assume that the company wants to produce as much as possible whenever the turbine is running so the environmental flow will always be 40 l/s, unless there is more water available than the turbine's maximum capacity. Other times of the year is 20 l/s, but it is outside fish spawning season. With this in mind, shutdowns from 80, 60 and 40% productions to 50 and 25% bypass valves have been simulated.

Shutdown from 80% production to a 50% capacity bypass valve in Figure 30:

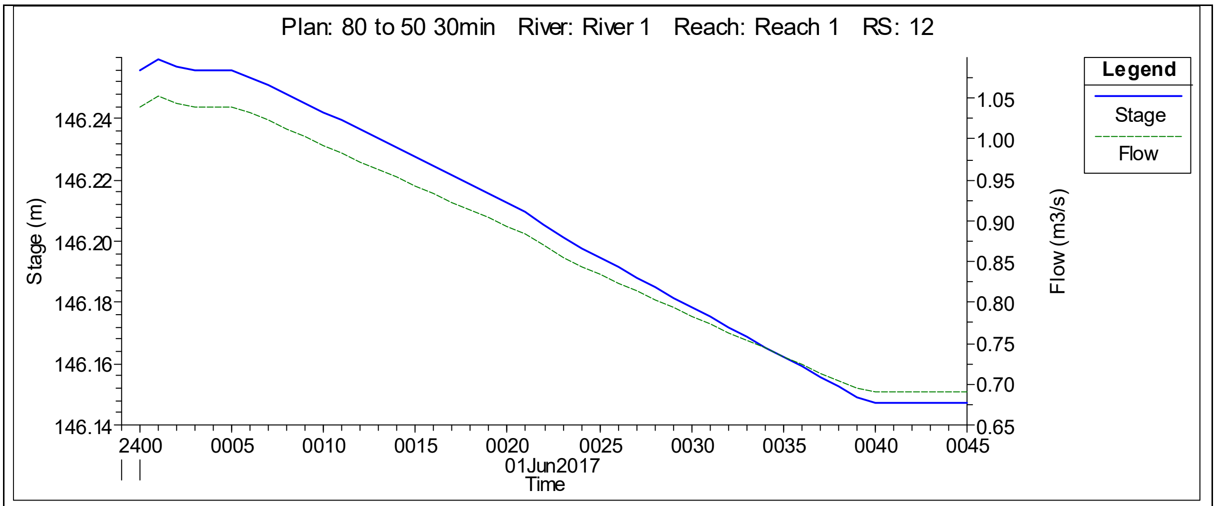


Figure 30 - Simulation 80% production to 50% bypass valve in 30 min

Shutdown from 60% production to a 50% bypass valve in Figure 31. The steps that can be seen in the representation are just illustration errors that tend to happen for very little height differences over a long time, there are no actual steps on the raw simulation data.

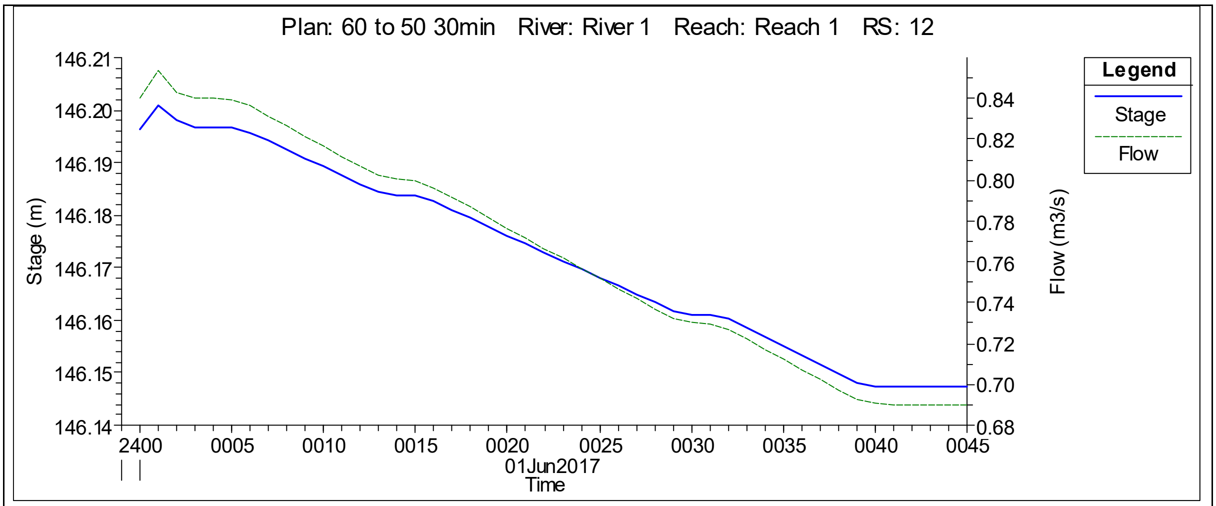


Figure 31 - Simulation 60% production to 50% bypass valve in 30 min

Simulation of a shutdown from 80% production to a 25% bypass valve in Figure 32.

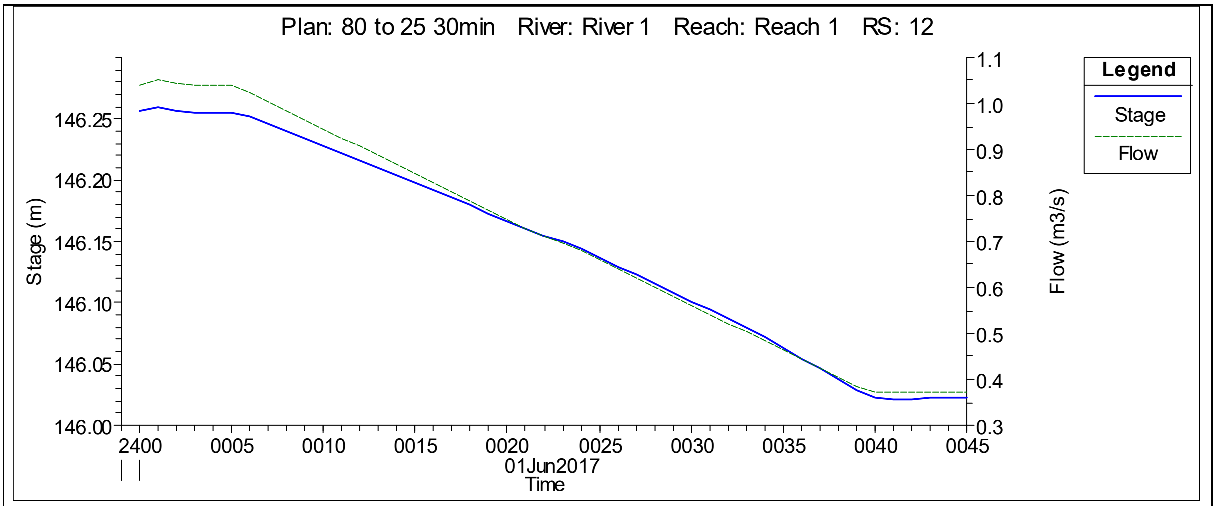


Figure 32 - Simulation 80% production to 25% bypass valve in 30 min

Finally, shutdown simulations going from 60 and 40% to a 25% capacity bypass valve are shown on Figure 33 and Figure 34 respectively:

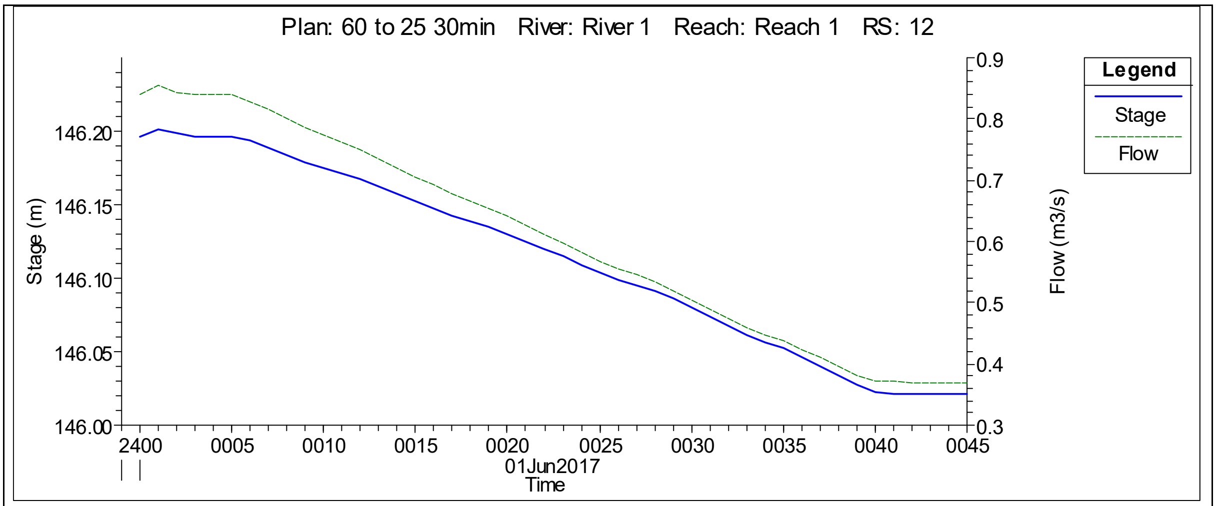


Figure 33 - Simulation 60% production to 25% bypass valve in 30 min

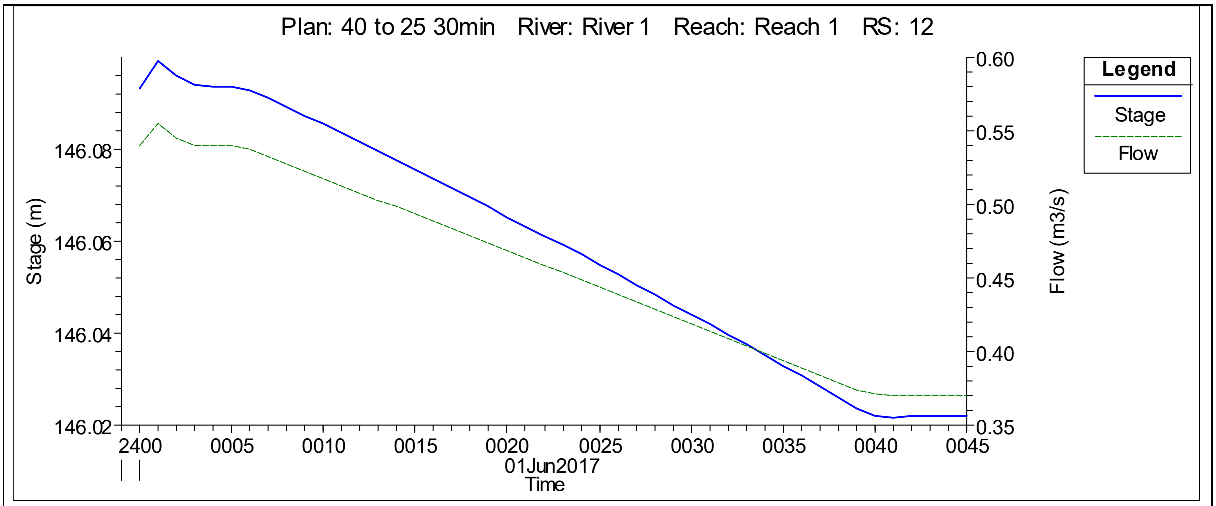


Figure 34 - Simulation 40% production to 25% bypass valve in 30 min

As mentioned before, situations on which the discharge in the river is bigger than the minimal environmental flow should also be tested, as the river discharge will not be influenced as much by the power plant, and the effect should be smaller. This will happen most probably during snow melting in spring floods. Shutdowns going from maximum production to a 50% and a 25% capacity bypass valves, as well as a bypass valve malfunction were tested. The simulated natural flow in the river is 0.5 m^3/s.

Shutdown simulation from max production to a 25% bypass valve with 0.5m^3/s flowing in the river is shown in Figure 35.

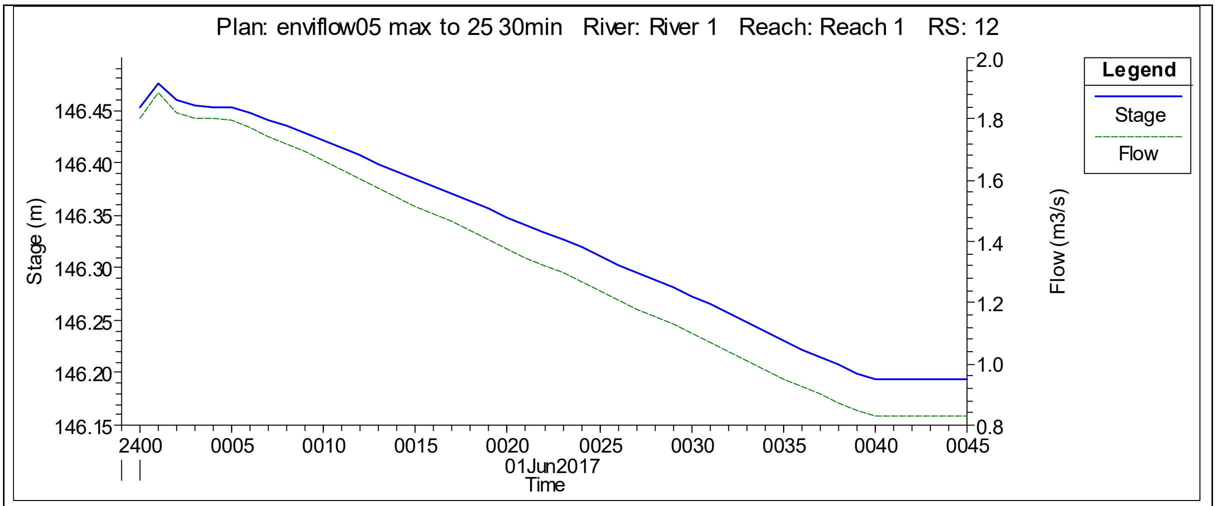


Figure 35 - Simulation max production to 25% bypass valve in 30 min with 0.5 m^3/s flow in the river

Figure 36 is a representation of the same phenomenon with a bigger bypass valve, shutdown from full production to a 50% bypass valve with a 0.5m^3/s flow in the river.

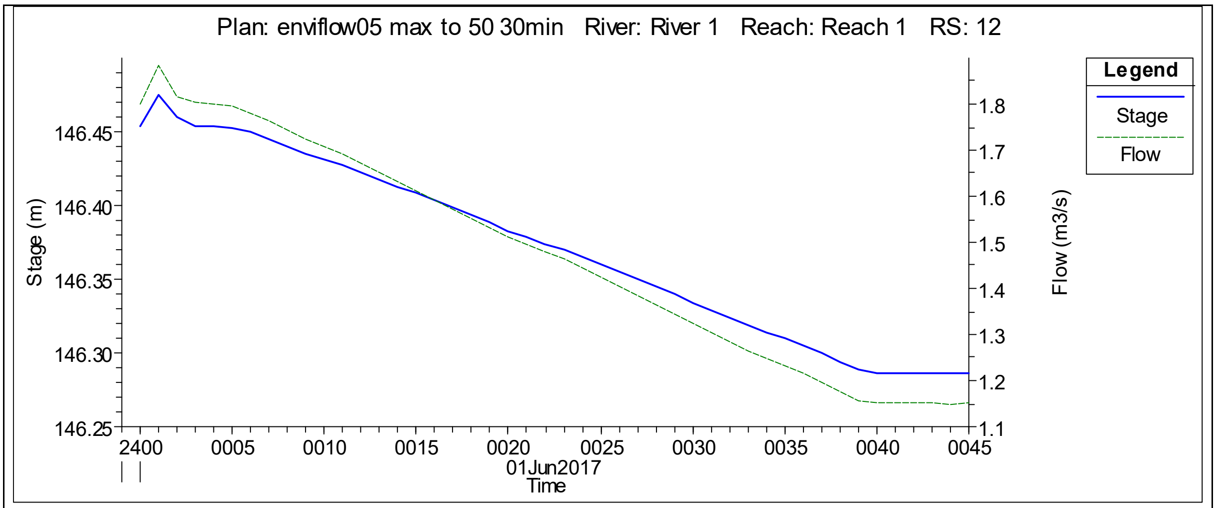


Figure 36 - Simulation max production to 50% bypass valve in 30 min with 0.5 m^3/s flow in the river

Finally, Figure 37 demonstrates a simulation of a shutdown from full production, with a malfunction of the bypass valve, and 0.5m3/s in the river.

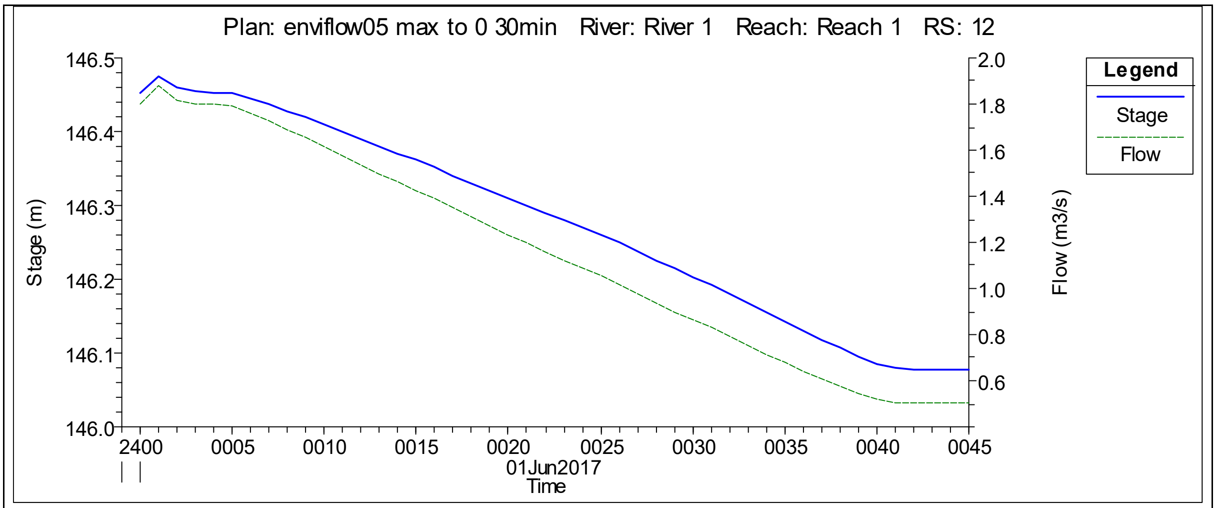


Figure 37 - Simulation max production to no bypass valve in 30 min with 0.5 m^3/s flow in the river

All of the simulations above represent the stage and flow changes when going from a certain value of production to a determinate bypass valve capacity. Once the flow from the power plant to the river is entirely governed by the bypass valve, we can choose to remain spilling water due to environmental reasons, or it could be necessary to completely stop the flow. Situations going from both bypass valve capacities to a total stop in one hour are represented in Figure 38 and Figure 39.

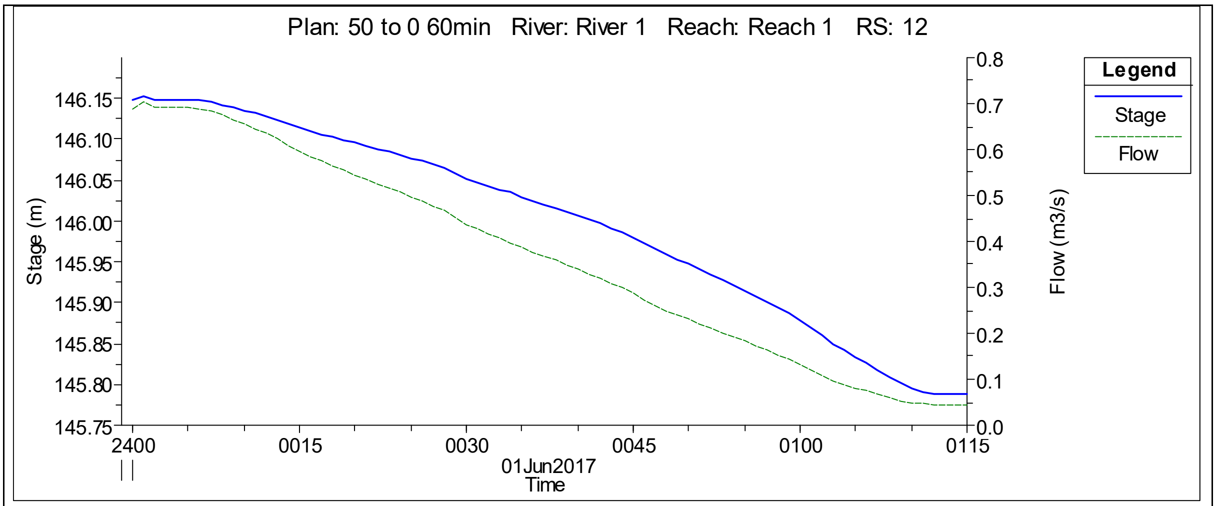


Figure 38 - Simulation 50% bypass valve to 0 in 60min

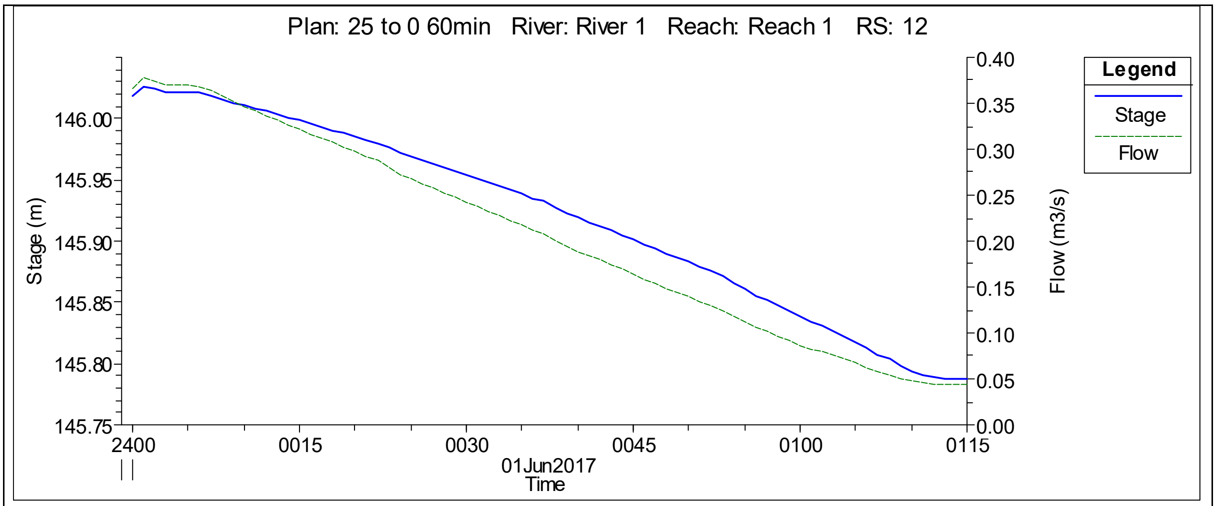


Figure 39 - Simulation 25% bypass valve to 0 in 60min

As mentioned at the beginning of this chapter, all the data and graphs shown until now in this section are taken in cross section 12. To study how these changes are in the rest of the river, we can look at the last cross section immediately before the junction with the Surna river. These cross sections are separated by 74 metres of river, so the waves arrive to the lower section later, with around 4 minutes difference. There is a variation however depending on how much flow the river is carrying and subsequently the speed of the water. This difference is increased to about 6 minutes with very low flows, while it is just 3 minutes with high flows. As expected from the results from the field collected data, the wave gets dampened as well, and sinking velocities are around 10% lower on the cases with mildest sinking velocities, up to 30% lower on the fastest ones.

An example of this phenomenon is shown on the following figures. A very short event of an emergency shutdown in 3 minutes is chosen so that fluctuations happen fast and are appreciable on the graphs. The flow contribution goes down from maximum production flow to a 50% bypass valve in 3 minutes, with the minimum environmental flow of 40l//s is flowing in the river. Figure 40 corresponds to cross section 12, the one used until now, just after the junction between the outlet channel and the natural river. Figure 41 is a cross section in the middle of the reach, while Figure 42 is the last cross section before the water flows into the Surna river. The sinking velocities in each of the cross sections are 190, 156 and 137 cm/h respectively.

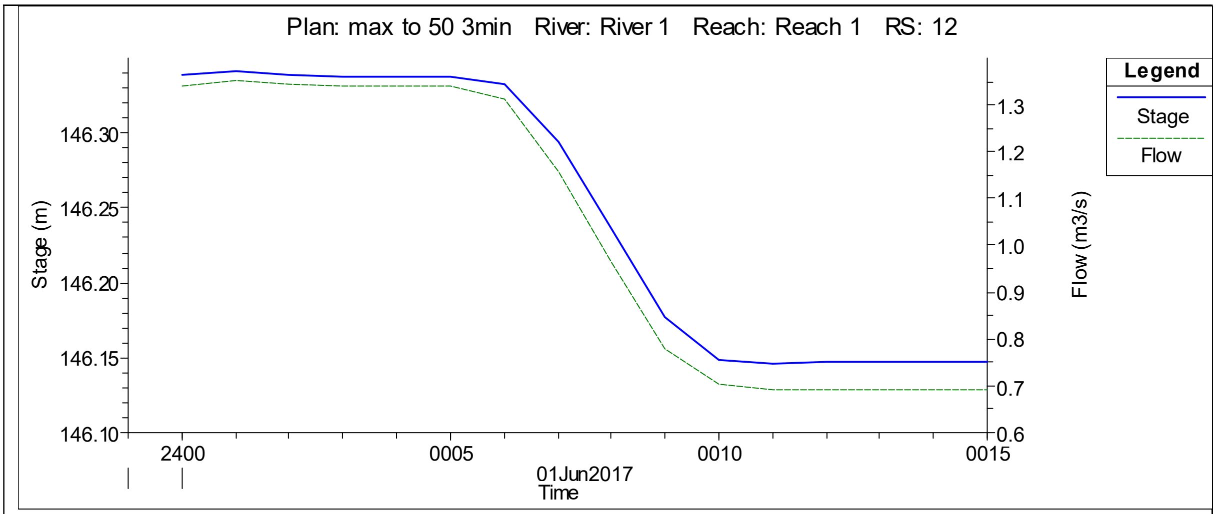


Figure 40 - Wave travel and dampening, cross section 12

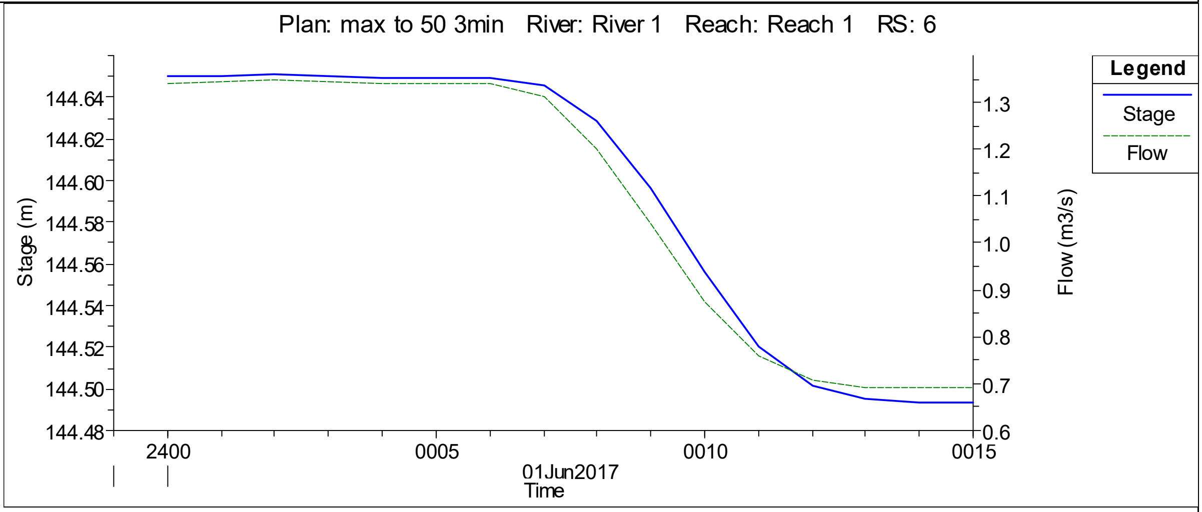


Figure 41 - Wave travel and dampening, cross section 6

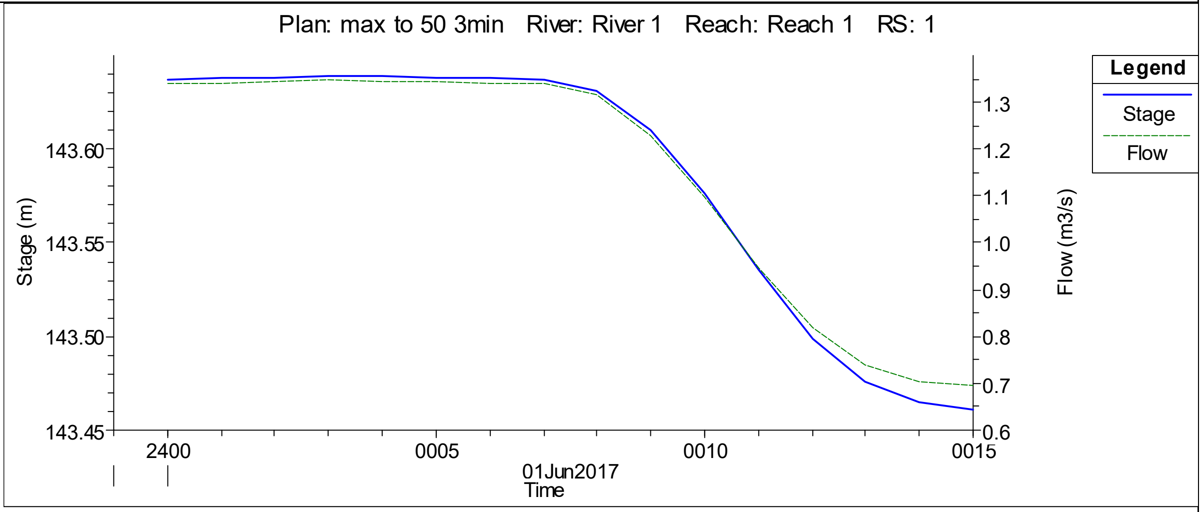


Figure 42 - Wave travel and dampening, cross section 1

A summary of the sinking velocities for all the calculated simulations in cross section 12 can be seen in Table 5.

FLOW FROM	FLOW TO	3 MIN	10 MIN	30 MIN	60 MIN	90 MIN
0,04 M^3/S ENVIRONMENTAL FLOW						
MAX	**0%**	300			45	
MAX	**25%**	310	145	56	29	
MAX	**50%**	190	78	34	18	
80%	**25%**	165	85	38	21	
80%	**50%**	100	49	17	10	
60%	**25%**	146	75	29	16	
60%	**50%**	50	21	10	6	
40%	**25%**	60	30	14	8	
50%	**0%**			60	32	18
25%	**0%**			40	21	15
0,5 M^3/S ENVIRONMENTAL FLOW						
MAX	**0%**	247	136	62	34	
MAX	**25%**	197	99	45	24	
MAX	**50%**	129	60	30	16	

Table 5 - Summary of simulation sinking velocities in cm/h

As observed in the summary in Table 5, not all possible scenarios have been calculated. Especially when going from the 50 and 25% bypass valves to 0, there is no hurry to stop as there can be when stopping the power plant, so shorter times have not been considered. Even more, being a run of the river power plant, spilling from the bypass valve could take even longer than the times portrayed here, as no storage water is being spilled, but no longer times have been calculated after reaching the limit for high risk as described by EnviPEAK of 20cm/h.

The modelling can also provide data on the water surface changes, with this in mind free water surfaces were calculated for different given flows in the reach, Table 6.

Flow (m^3/s)	0.08	0.15	0.3	0.5	0.74	1	1.3	1.5	1.8	2	2.3
Area ($1000m^2$)	0.54	0.63	0.7	0.76	0.81	0.83	0.87	0.89	0.91	0.92	0.94

Table 6 - Free water surface area for different flows

The minimum calculated flow was 0.08 m^3/s, assuming the minimum environmental flow of 40l/s in the natural course of the river, and another 40l/s coming from the bypass valve. A total dry out of the reach was not considered, as HEC-RAS is not capable of calculating these situations and runs into problems. Equally, the maximum simulated flow was 2.3 m^3/s. Greater flows could happen during extraordinary episodes during production or floods, however, after 2 m^3/s, the model overflows in certain cross sections as shown in Figure 43, so measurements of water stage or surface area are no longer reliable. This does not necessarily mean that the river will overflow, as the farthest sides of the river channel could not be correctly measured to include them in the model due to dense vegetation and poor GPS reception. It should be expected then that when this high flows happen the vegetation will make the water velocity slower, raising the water stage.

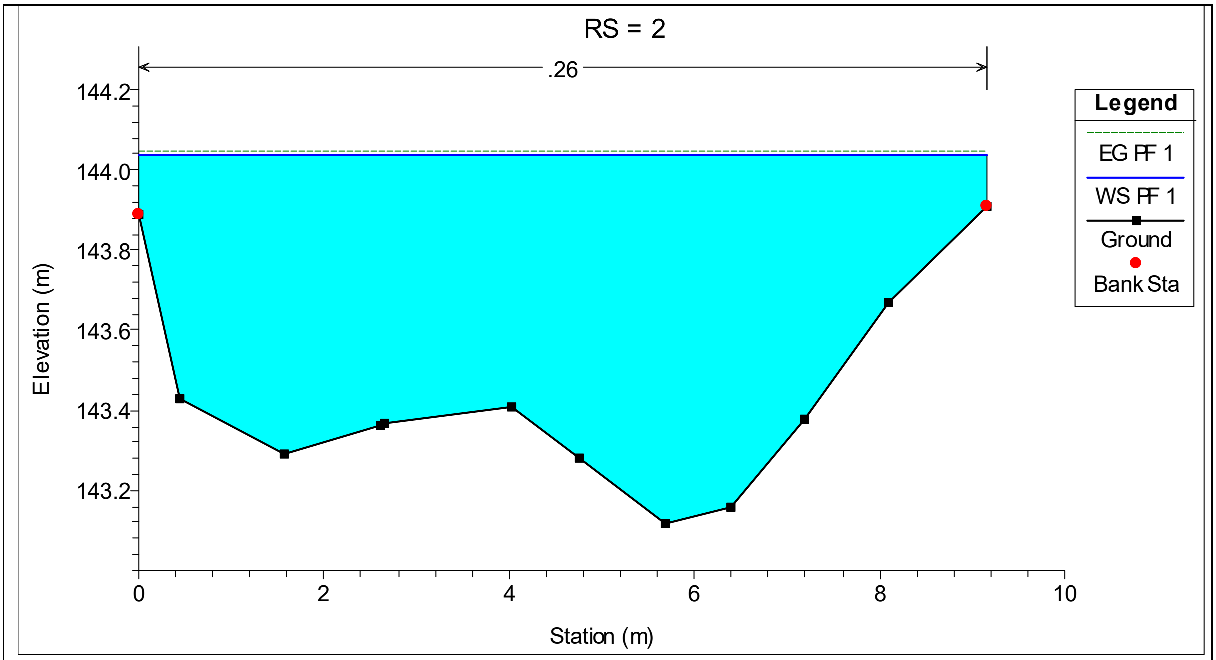


Figure 43 - Overflowing cross section

4. Discussion

4.1. Water level

As mentioned before, EnviPEAK guidelines were chosen to provide a reference on how dangerous the water stage changes are. With the calculated water level sinking velocities from the field measurements, the risk grade according to EnviPEAK can be assigned in Table 7.

	Bele			Brandåa			Gryta			Sundli			Sya		
cm/h	16	180	120	280	90	73	84	130	190	270	450	168	200	40	300
risk	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 7 - Sinking velocity risk grade

As we can see, the clear majority of measured cases are in the highest risk grade. In fact, some of them are well above, as the high risk starts from 20 cm/h. As seen before, the bypass valve has the capacity to mitigate this fast changes but as can be observed on the provided graphs, it is not kept open long enough. Some of the studied sites have also extremely defined steps for the valves opening, and the changes between them is abrupt.

EnviPEAK defines the sinking velocity as the velocity in which the water stage changes from when the water stage starts sinking until it finishes sinking for a determined flow change episode. It is expressed as cm/h, and the event starts when the sinking starts, and is considered finished when 90% of the total sinking has happened (Bakken, Forseth et al. 2016). This way, misinterpretations caused for example by the sudden changes in valve opening are avoided.

But this way of measuring sinking velocity raises another question, as it can be argued that really fast partial sinking episodes can be very damaging get concealed in the whole episode. To try to see if this is the case, maximum sinking velocities calculated with the shortest possible resolution of 15 seconds were compared to the sinking velocities of the same episode, measured according to EnviPEAK's definition in Figure 44.

We see that there is a certain correlation, but some points are quite far from the rest. These cases are the ones on which the bypass valve is manual, so there is a very steep sinking in the beginning, followed by the opening of the valve and a softer decline.

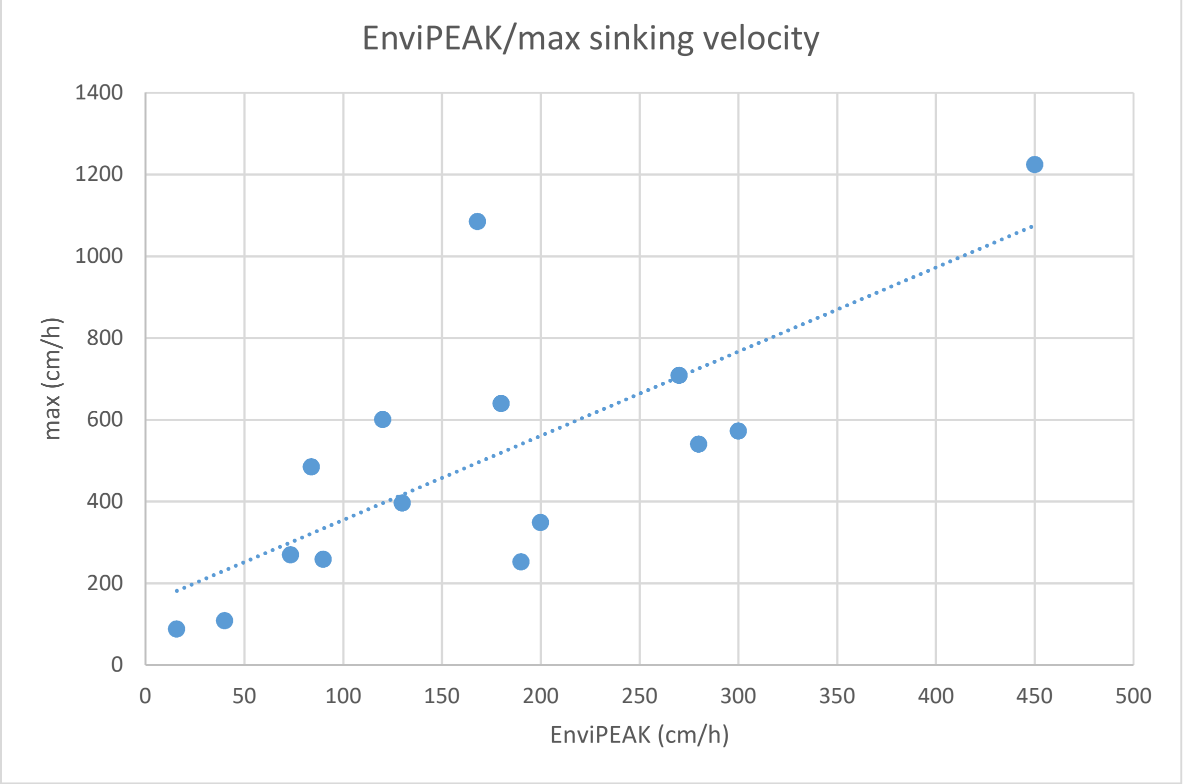


Figure 44 - EnviPEAK/maximum sinking velocities

Use of the sinking velocity as defined by EnviPEAK is therefore valid, as long as these fast initial drops are avoided.

As an example, Figure 45 is provided. And unwise power plant owner could say that they comply with EnviPEAK standards, as the sinking velocity calculated by the EnviPEAK definition is 16.6 cm/h, however, during the first minutes it is above 150 cm/h.

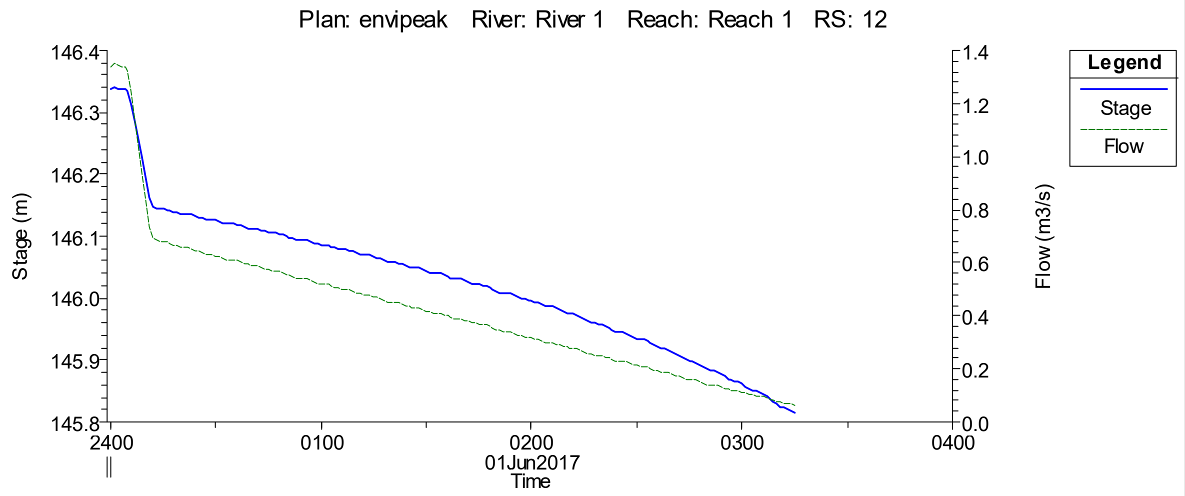


Figure 45 - EnviPEAK simulation

With the available data EnviPEAK risk grades can also be assigned to the flow changes, in Table 8. We see that in this case the result is better than in the water stage study. This is probably due to the small size of the studied power plants and rivers.

	Bele			Brandåa			Gryta			Sundli			Sya		
ratio	1.5	9.2	2.9	8.2	4.8	6.9	2.2	3.2	13.5	6.5	11.6	1.5	1.3	1.4	3.2
risk	2	4	2	4	3	4	2	3	4	4	4	2	1	1	3

Table 8 - EnviPEAK flow ratio risk

As seen in all the provided examples, the rivers have a natural dampening effect. The further down the river the water is carried, the stage fluctuations are smaller, as well as having a smoothening effect on the wave's shape the farther from the source it gets. A quantitative analysis was not possible due to the great variation of this phenomenon. It greatly depends on the river geometry as well as other hydraulic parameters, so a site by site study is needed. The clearest example is how long the wave from the intake takes to arrive to the power plant, which greatly varies on different measurements.

4.2. Temperature

The recorded water temperature changes were not as drastic as the water level changes. The maximum temperature change observed during this data collection campaign was around 3ºC except in the outlet channel. These changes might not seem like much, but they can lead to very significant behavioural changes in fish. specially the closer to 0ºC the temperature is, fish tend to be less active to conserve energy (Brown 2001), this can be the case in the studied streams, especially during winter or snow melting seasons, as seen in the collected data.

The collected temperature data has good resolution and the fluctuations induced by the stop/restart events can be clearly seen on the provided graphs, but the available literature does not provide a clear framework to study how these rapid changes affect fish stranding.

There are studies analysing which temperatures lead to more stranding risk (Halleraker, Saltveit et al. 2003) or how growth of fish is affected by fluctuating temperatures (Flodmark, Vøllestad et al. 2004), but more research is needed on how rapid temperature fluctuations affect the stranding risk. Research has been done on the effect of hydropeaking and thermopeaking waves on benthic invertebrates for example, resulting in catastrophic and behavioural drift (Bruno, Siviglia et al. 2013) and some effect on fish is also to be expected.

EnviPEAK does not provide quantification tools for temperature fluctuation impact and the selected literature to provide indicators (Zolezzi, Siviglia et al. 2011, Vanzo, Siviglia et al. 2016) do not provide significant results for the measured variations. These studies were made measuring sub-daily changes but on a seasonal scale, on bigger plants with greater altitude difference between the intake and the power plant, obtaining more varying results.

Contrary to the aforementioned literature, the data in this case was collected in small run of the river plants, with small intake ponds or reservoirs, where the very shortly stored water's temperature is not very different from the temperature of the natural flowing river.

4.3. Modelling

Numerous situations were tested to measure the sinking velocity in the study site. Table 9 is the same table as the one presented before, recovered for easy referencing. Results from the modelling are in line with the ones from the measured data, and show a better representation of all the possible scenarios. The resulting sinking velocities are quite high in general, and the sinking episodes must be stretched for a long time to get acceptable results. While there is an obvious difference between using a 50 or a 25% capacity bypass valve, it is not as big as initially expected.

We have to remember that these are representing a total stop of the power plant, which usually happen less than 5 times a year in areas with good quality network (Størset, Hiller et al. 2012).

FLOW FROM	FLOW TO	3 MIN	10 MIN	30 MIN	60 MIN	90 MIN
0,04 M3/S ENVIRONMENTAL FLOW						
MAX	**0%**	300			45	
MAX	**25%**	310	145	56	29	
MAX	**50%**	190	78	34	18	
80%	**25%**	165	85	38	21	
80%	**50%**	100	49	17	10	
60%	**25%**	146	75	29	16	
60%	**50%**	50	21	10	6	
40%	**25%**	60	30	14	8	
50%	**0%**			60	32	18
25%	**0%**			40	21	15
0,5 M3/S ENVIRONMENTAL FLOW						
MAX	**0%**	247	136	62	34	
MAX	**25%**	197	99	45	24	
MAX	**50%**	129	60	30	16	

Table 9 - Summary of simulation sinking velocities in cm/h

As seen in the previous section, the river has a natural dampening effect on the wave and the sinking velocities, and this dampening effect is proportional to the sinking velocities, being much larger with higher sinking velocities.

Based on this data, the Brandåa power plant can be operated better with the available bypass valve, to get more acceptable parameters.

As a proof of concept, the whole stop-restart event seen during the data collection can be modelled to see how it can be improved.

First situation, the current one with a manual valve being opened after stopping production in Figure 46:

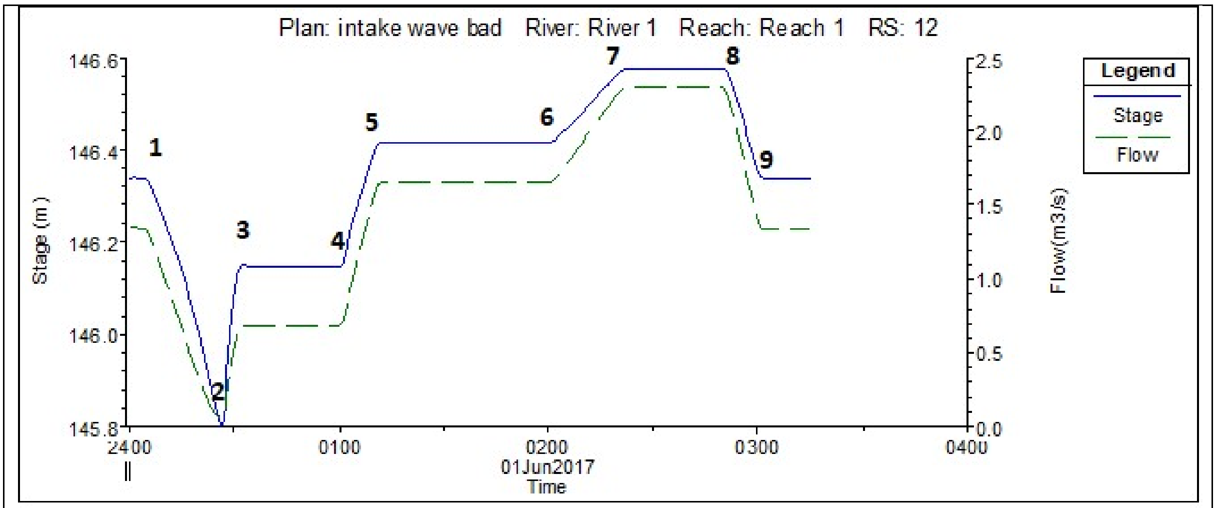


Figure 46 - Stop restart event initial

- 1 to 2 stop the power plant
- 2 to 3 open bypass valve
- 4 to 5 intake wave arrives
- 6 to 7 restart power plant
- 8 to 9 all water from intake through the power plant again and close bypass valve

Second situation, same as before but stopping the power plant slower, opening the valve on time and closing it while the intake wave arrives (Figure 47):

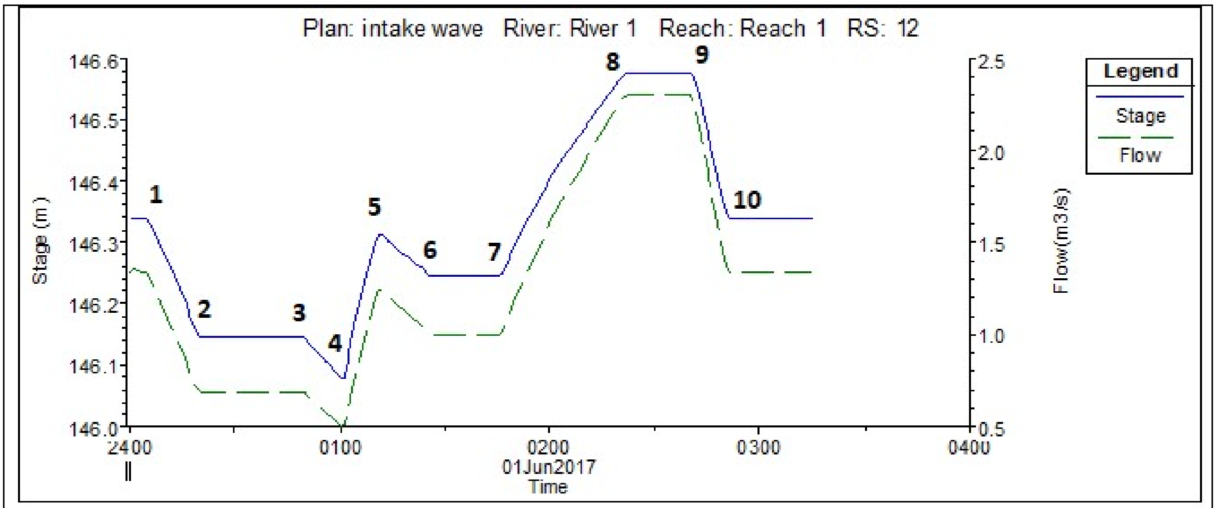


Figure 47 - Stop restart event middle

- 1 start stopping production while opening the valve
- 3 to 6 close the valve
- 4 to 5 intake wave arrives

Same situation but controlling the timing of the different occurrences better is shown on Figure 48:

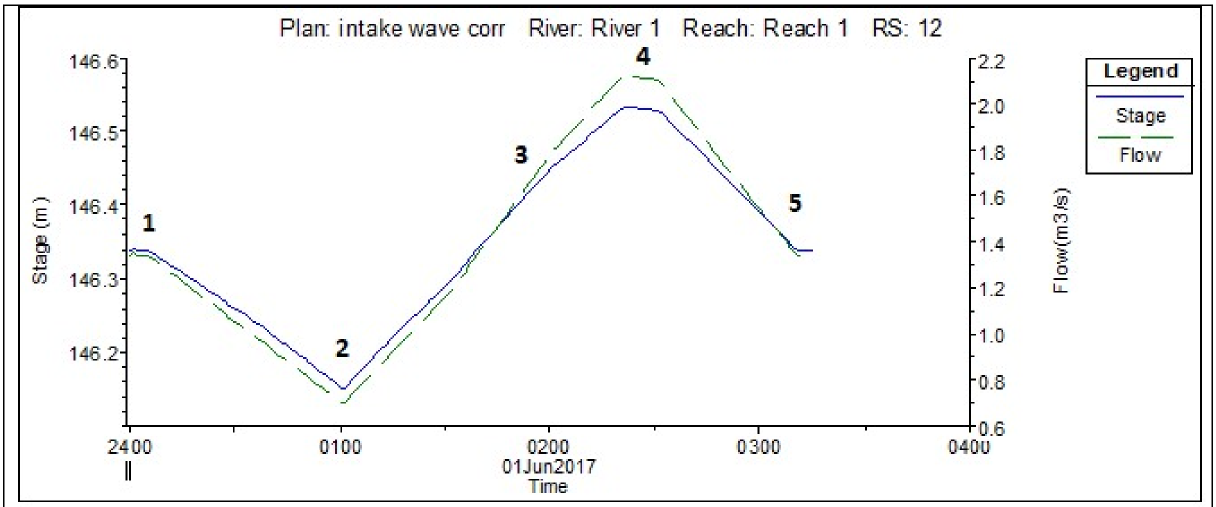


Figure 48 - Stop restart event final

- 1 to 2 stop production and open valve
- 2 to 3 intake wave comes, valve closed as the wave arrives
- 3 to 4 production restarted
- 4 to 5 water from intake through power plant

As shown in this examples, sinking velocities when stopping production can be controlled progressively stopping during a longer time, while opening the valve. There is no direct control over the intake wave when flooding or drying, but it can be indirectly done more gradual by stopping and starting production over a longer time.

Table 10 shows a summary of these hypothetical cases, demonstrating the changes and their EnviPEAK risk grade. Maximum stage difference is shown illustratively.

Case	Sinking velocity (cm/h)		Max stage diff (m)	Flow ratio (Q_{max}/Q_{min})		Surface area change (%)		EnviPEAK risk grade sum
1	148	4	0.78	46	4	48	4	12
2	75	4	0.5	4.6	3	19	3	10
3	19	3	0.38	3	2	14	3	8

Table 10 - Stop restart simulations summary and EnviPEAK risk grade

As expected, EnviPEAK risk grade is reduced when reducing the risk factors. The reduction is not as drastic however, as in the first case the parameters were well above the highest risk grade.

5. Recommendations

As seen on the simulations, bypass valves have great potential to reduce the impacts of hydropeaking.

Several recommendations can be given, which have already been covered in Kriterier for bruk av omløpsventil i små kraftverk (Størset, Hiller et al. 2012).

- Bypass valves must be automatic and open as soon as the power plant stops.
- They must be closed slowly enough to avoid fast stage changes
- Must be opened until the wave from the intake arrives.

As seen in the modelling, the difference between a 25 and a 50% bypass valve is not very high, so if kept open long enough, a 25% valve can be enough. This will depend on the specific site, and an individualised hydraulic study is necessary for each case and the operating parameters will have to be finely tuned for each site.

In the modelling examples can be observed, that timing of the opening and closing of the valve is critical. Tuning of this data will be very site specific and will also be vastly influenced by the conditions during the specific event. On Brandåa for example, the intake wave took one hour to arrive to the power plant in spring, while it took more than two hours in autumn. Just a two minutes difference in the valve functioning can create critical water stage changes, so it is not an easy task to get it right.

To remedy that, the proposal is to build a permanent stage monitoring station near the power plant, and use these readings automatically as input to the valve's opening. Given enough resolution, the valve can open or close accordingly to avoid unwanted water level changes.

Given that fish adapt to the particular water flow regimes in the specific site, it would be advisable to keep the dewatering and reflooding episodes as regular as possible.

In the specific case of the outlet channel, Brandåa is a run of the river plant, so water spilling does not imply an economic loss, and it should be spilling the whole time the power plant doesn't output enough flow, especially during fish spawning season.

To get a proper temperature fluctuation characterisation, a wider temperature data set is needed, to be able to compare it to the literature. There is also a knowledge gap in the effects that rapidly fluctuating temperature has on fish.

We see that the extreme sinking velocities are mainly given immediately after the power plant, as the river has a strong dampening effect on the wave while it travels downstream, and the stronger the wave, the stronger the dampening as seen in the results. Given it is a short distance, other measures initially discarded due to being expensive could be implemented immediately after the power plant. Case specific studies and economical evaluations would be needed if this was to be implemented.

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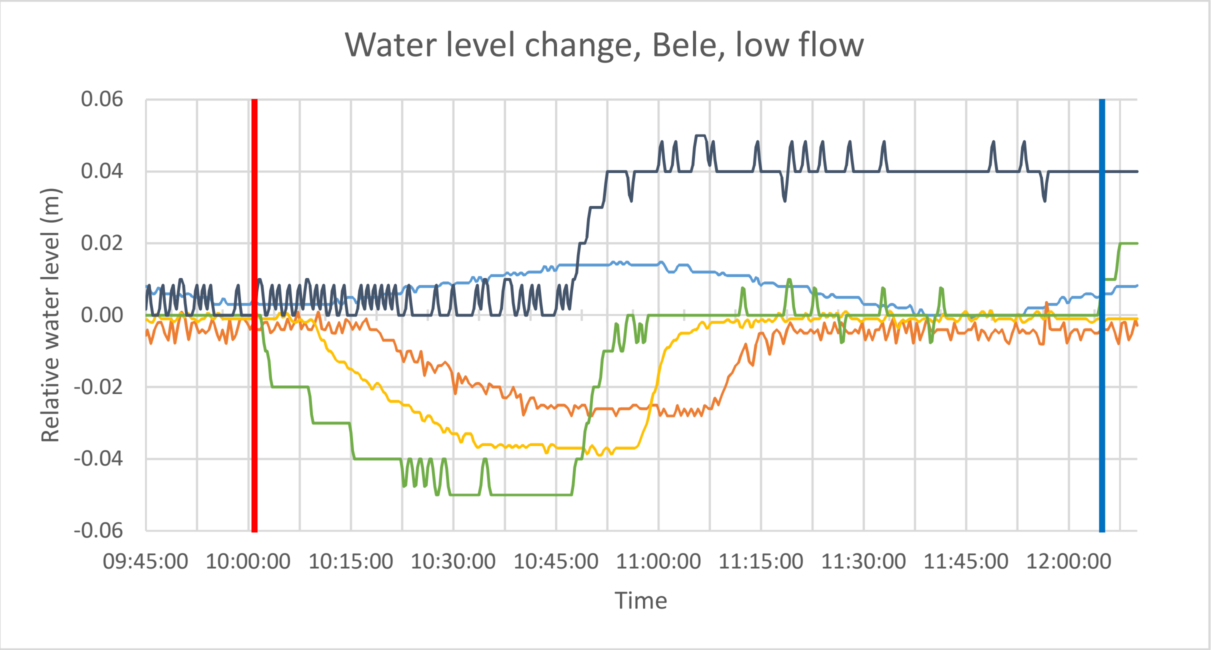
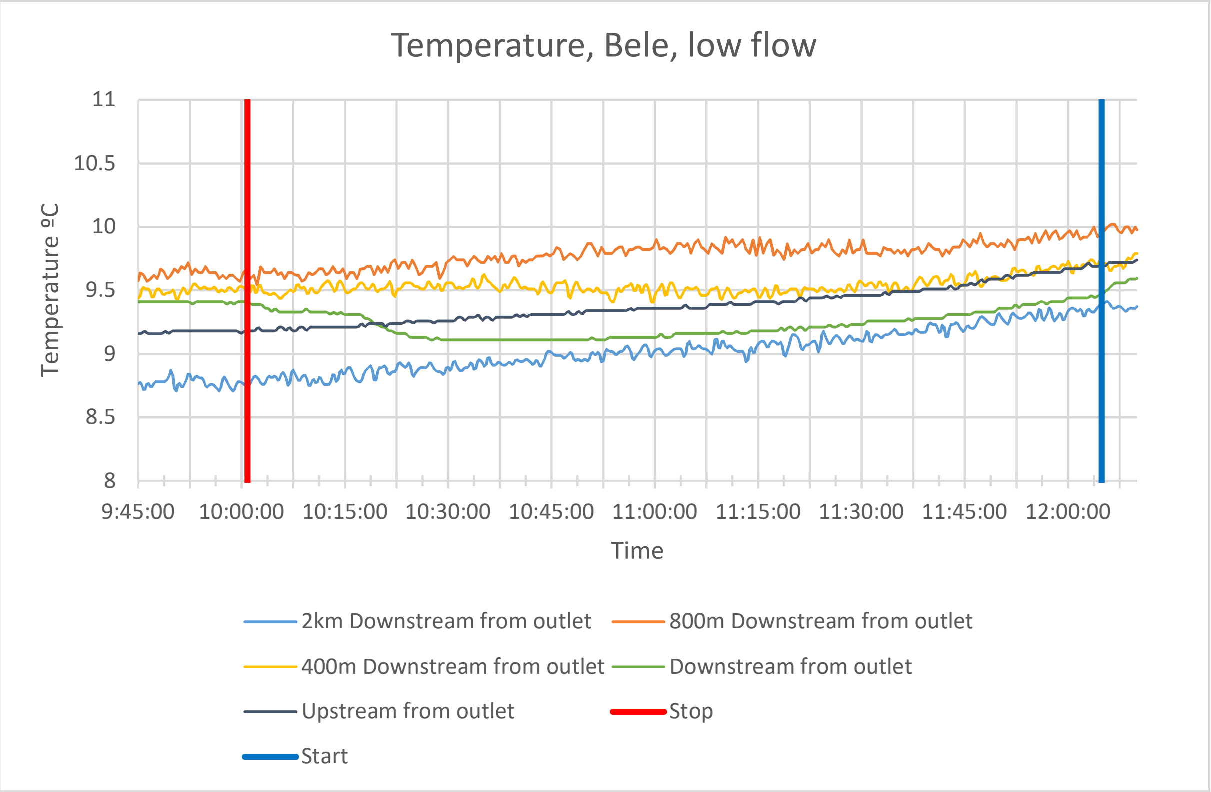
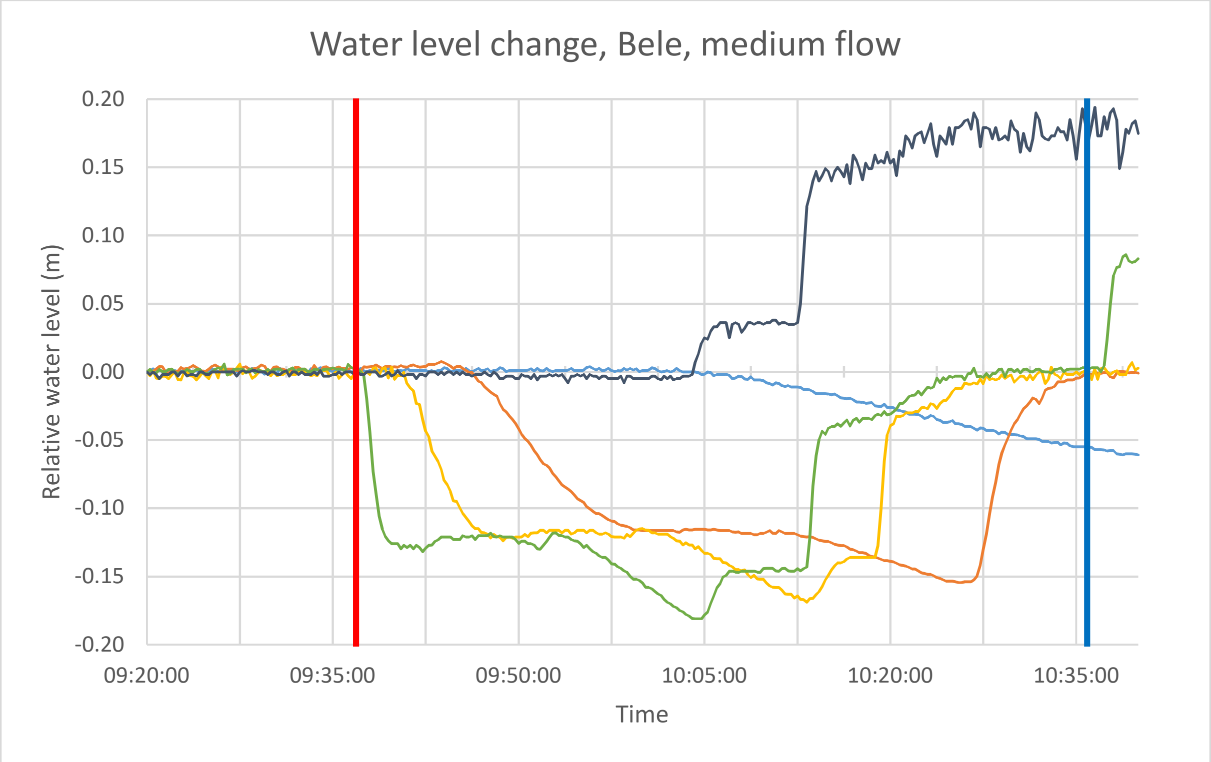
Appendix

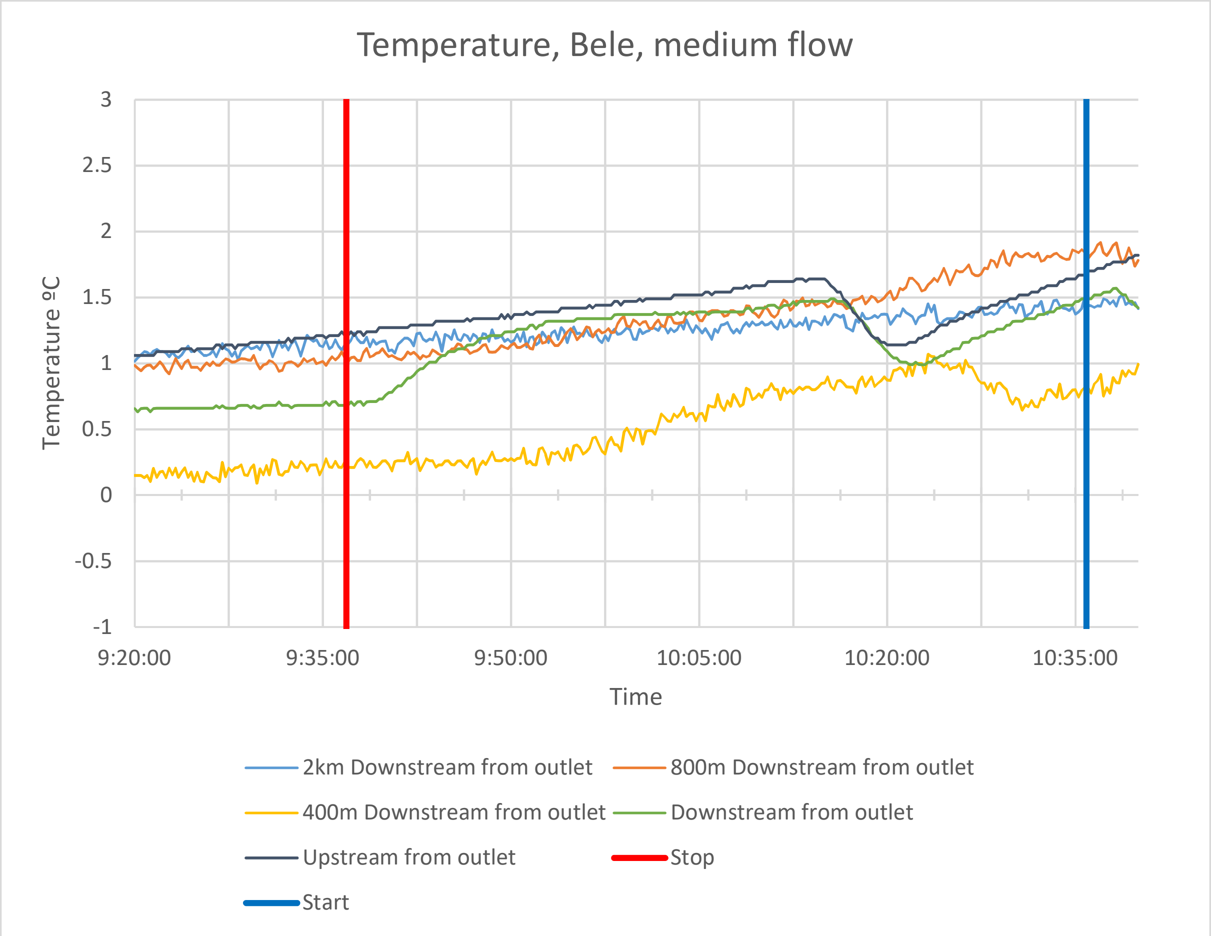
Stage and Temperature graphs

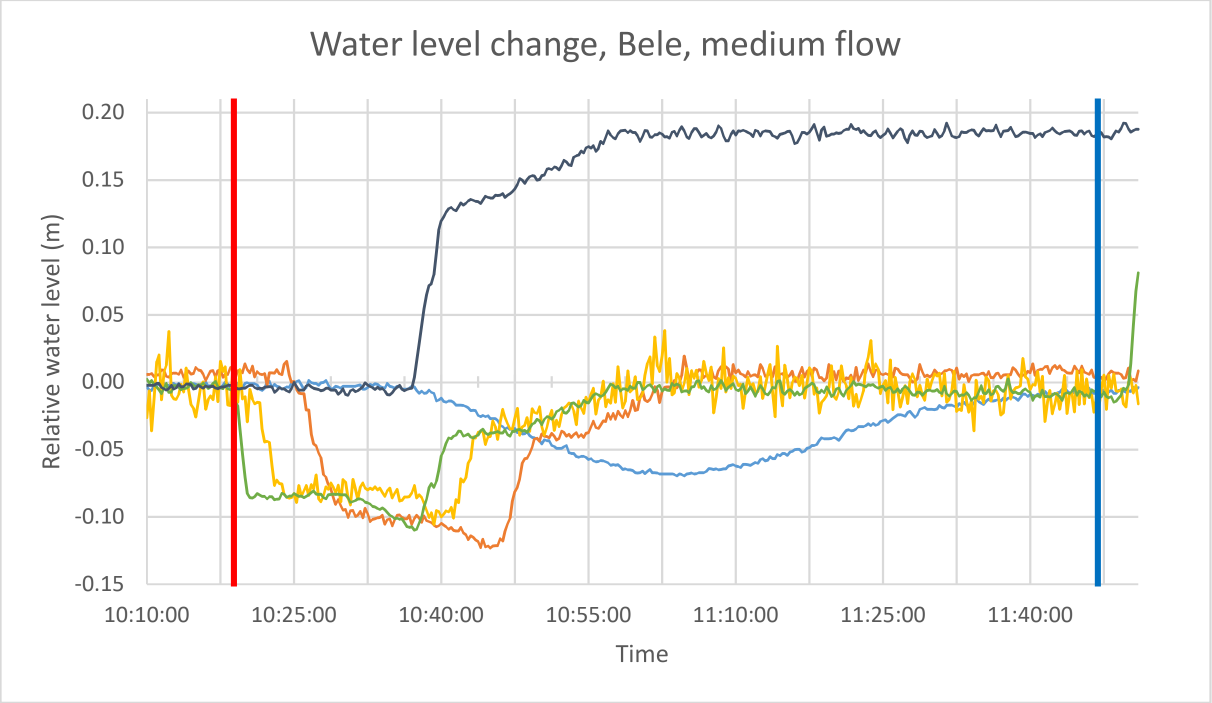
Stage change and temperature graphs of the same event are provided on the same page for easier correlation.

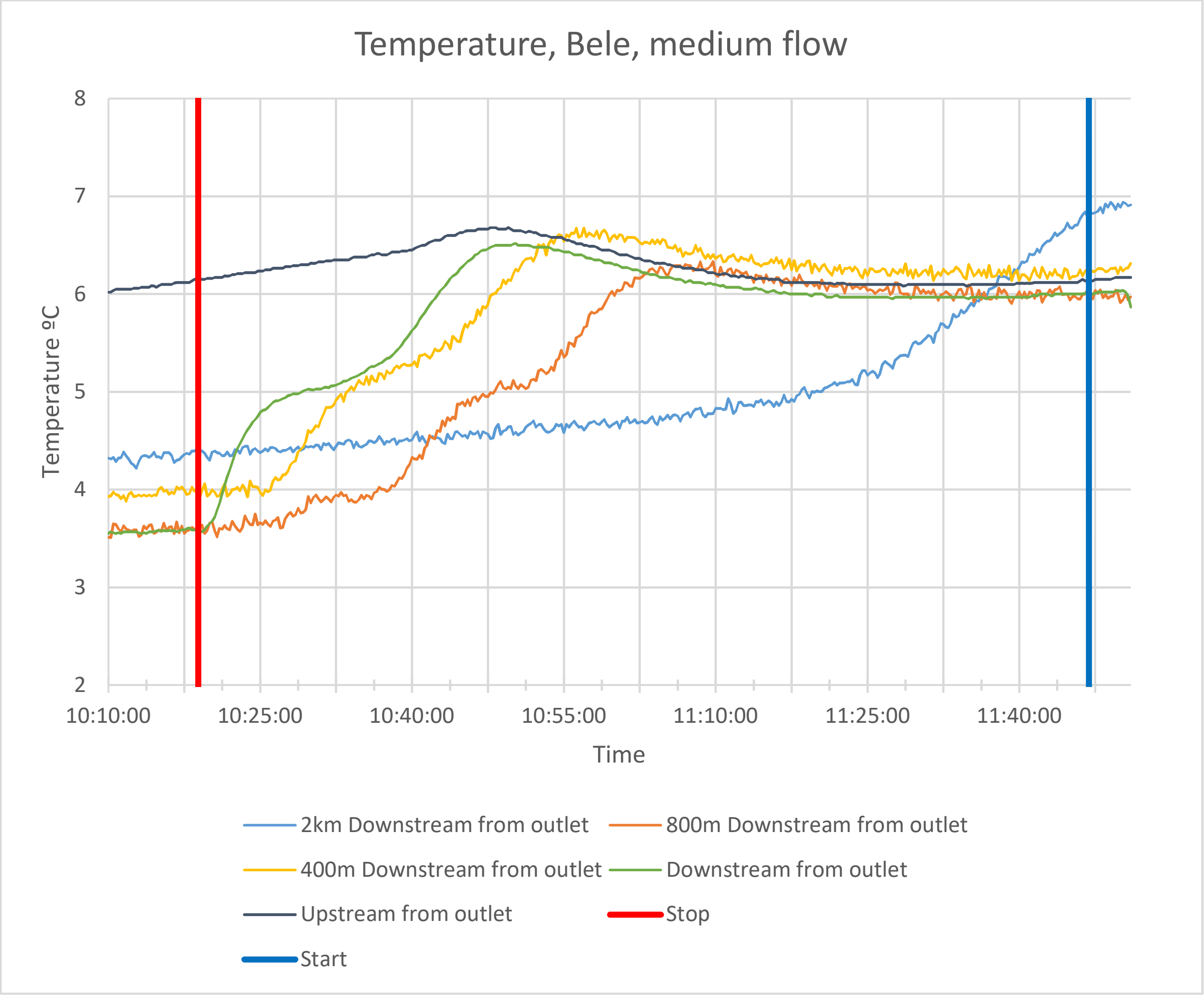


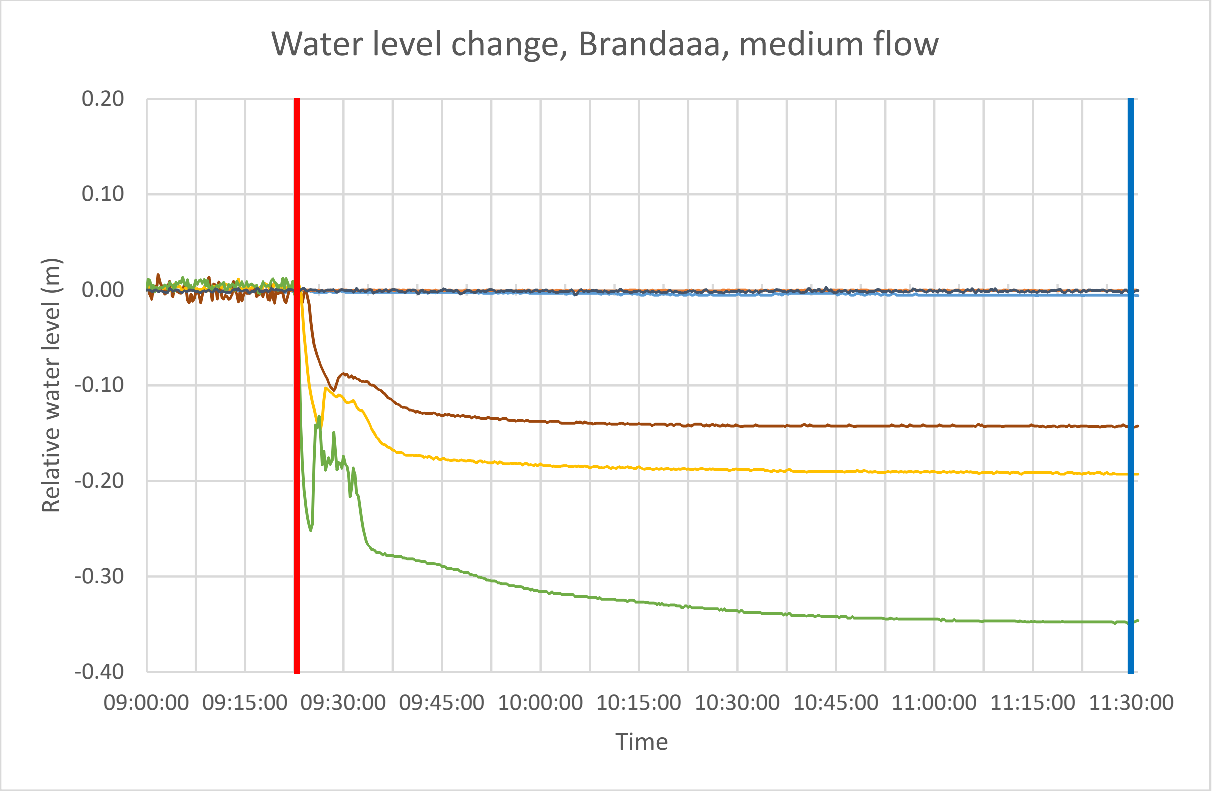


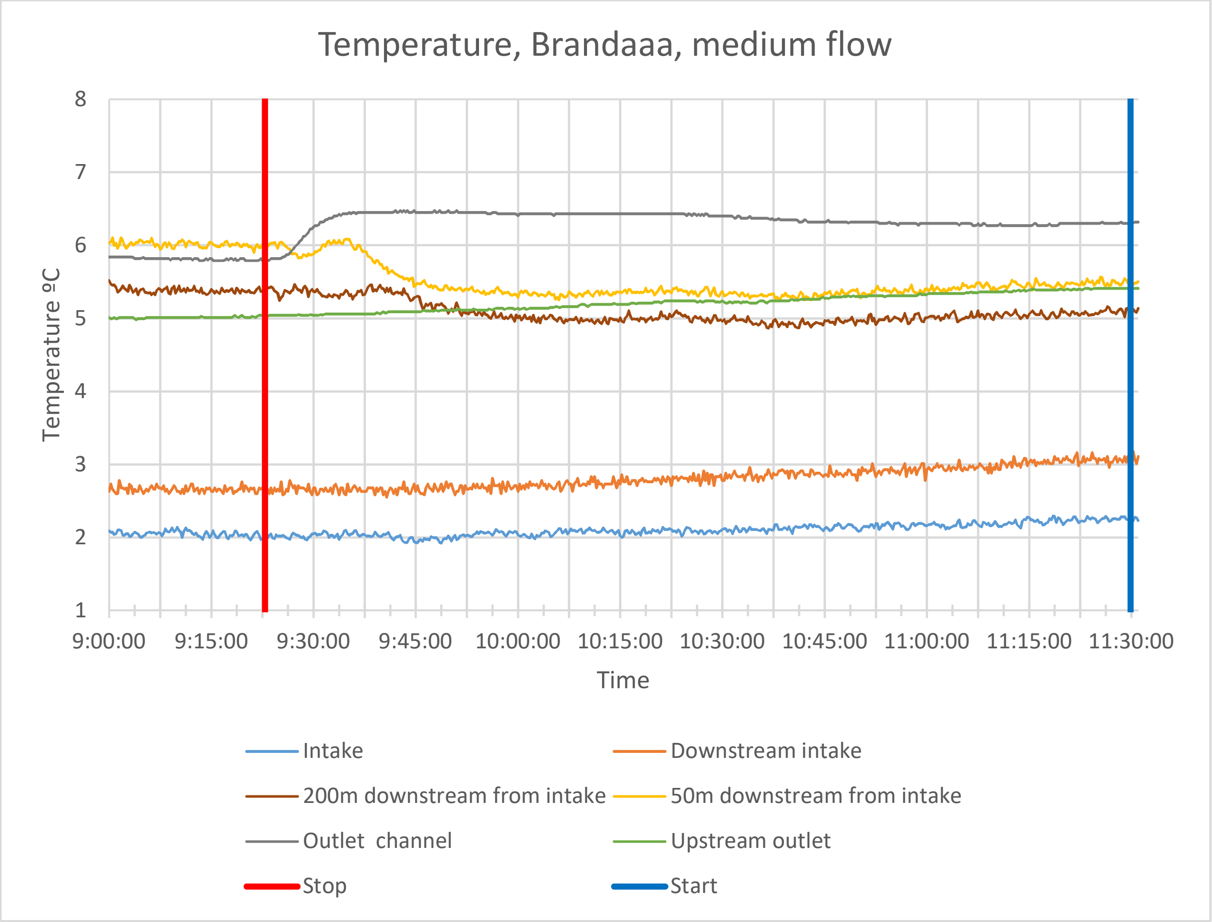

Water level change, Bele, medium flow
Relative water level (m)
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
09:20:00
09:35:00
09:50:00
10:05:00
10:20:00
10:35:00
Time

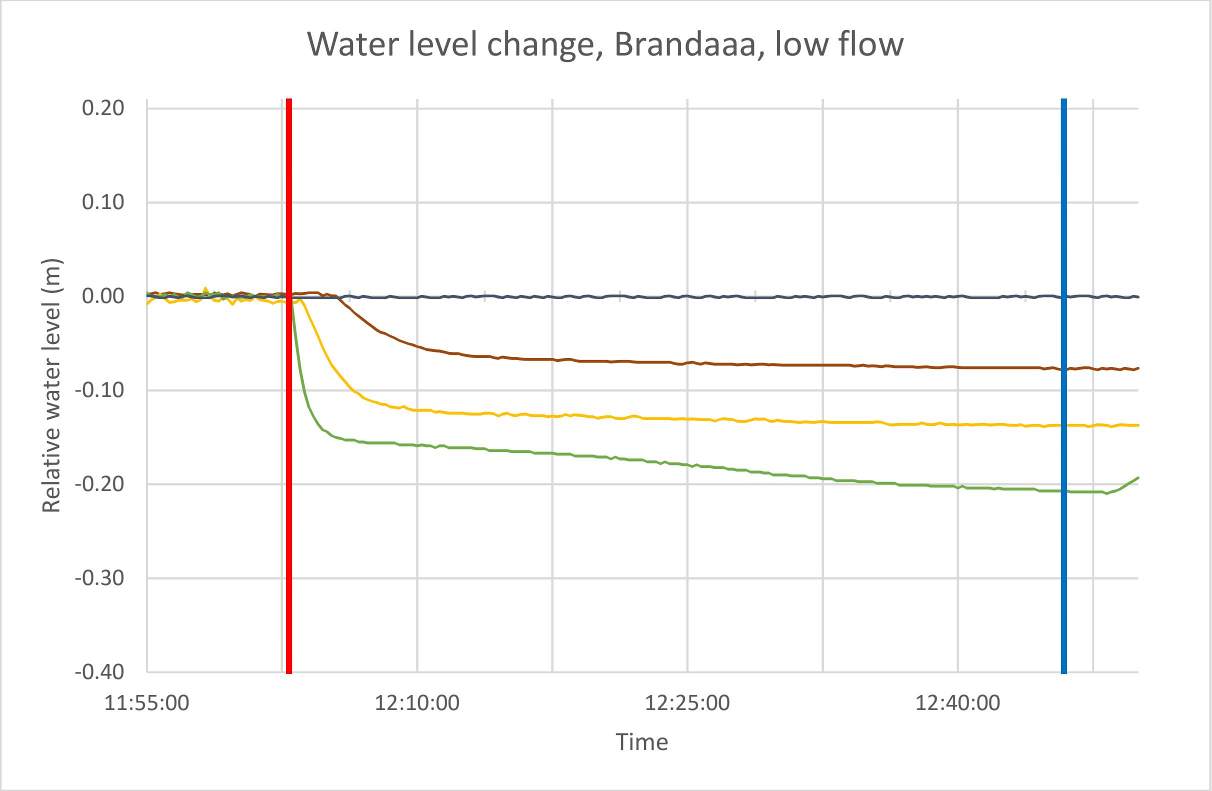

Temperature, Bele, medium flow
Temperature ºC
3
2.5
2
1.5
1
0.5
0
-0.5
-1
9:20:00
9:35:00
9:50:00
10:05:00
10:20:00
10:35:00
Time
2km Downstream from outlet
800m Downstream from outlet
400m Downstream from outlet
Downstream from outlet
Upstream from outlet
Stop
Start

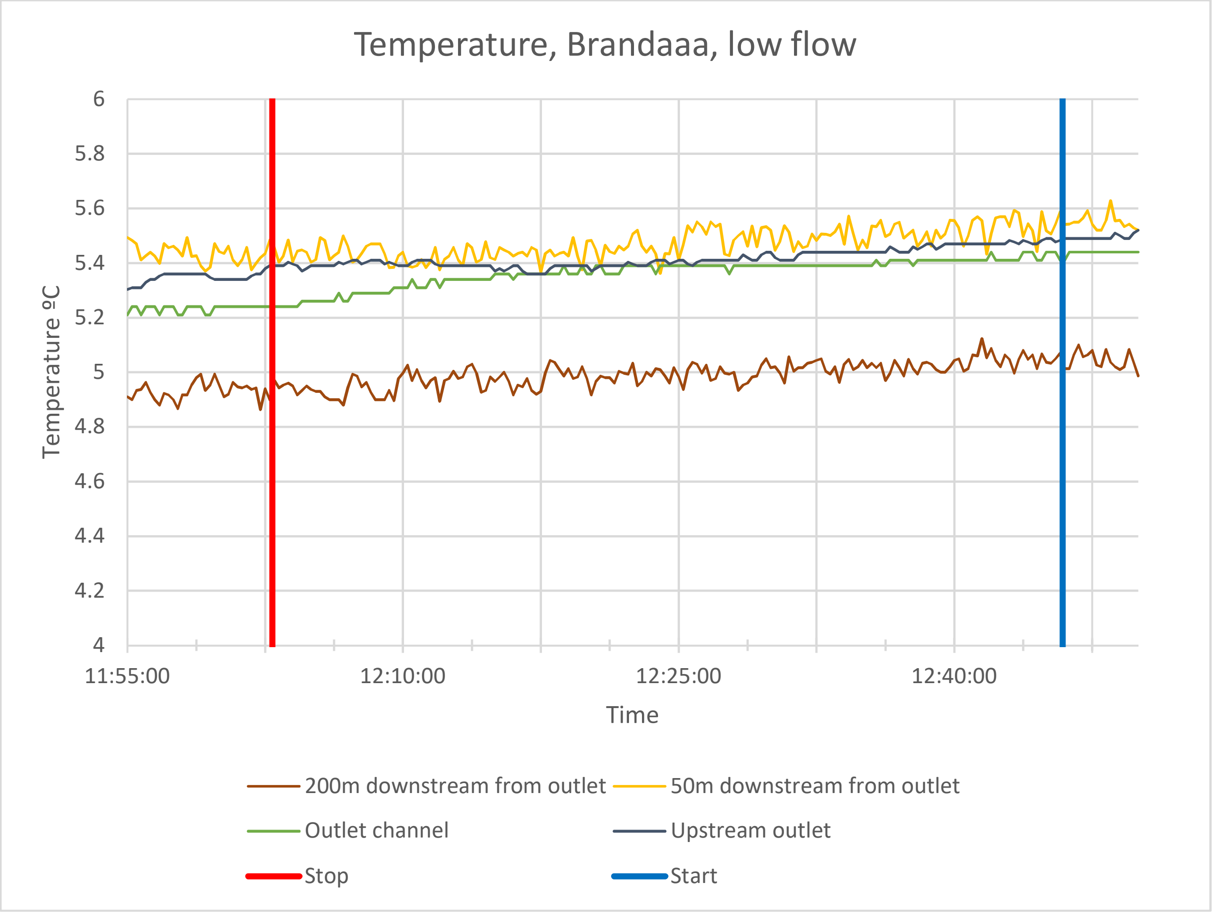

Water level change, Bele, medium flow
Relative water level (m)
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
10:10:00
10:25:00
10:40:00
10:55:00
11:10:00
11:25:00
11:40:00
Time

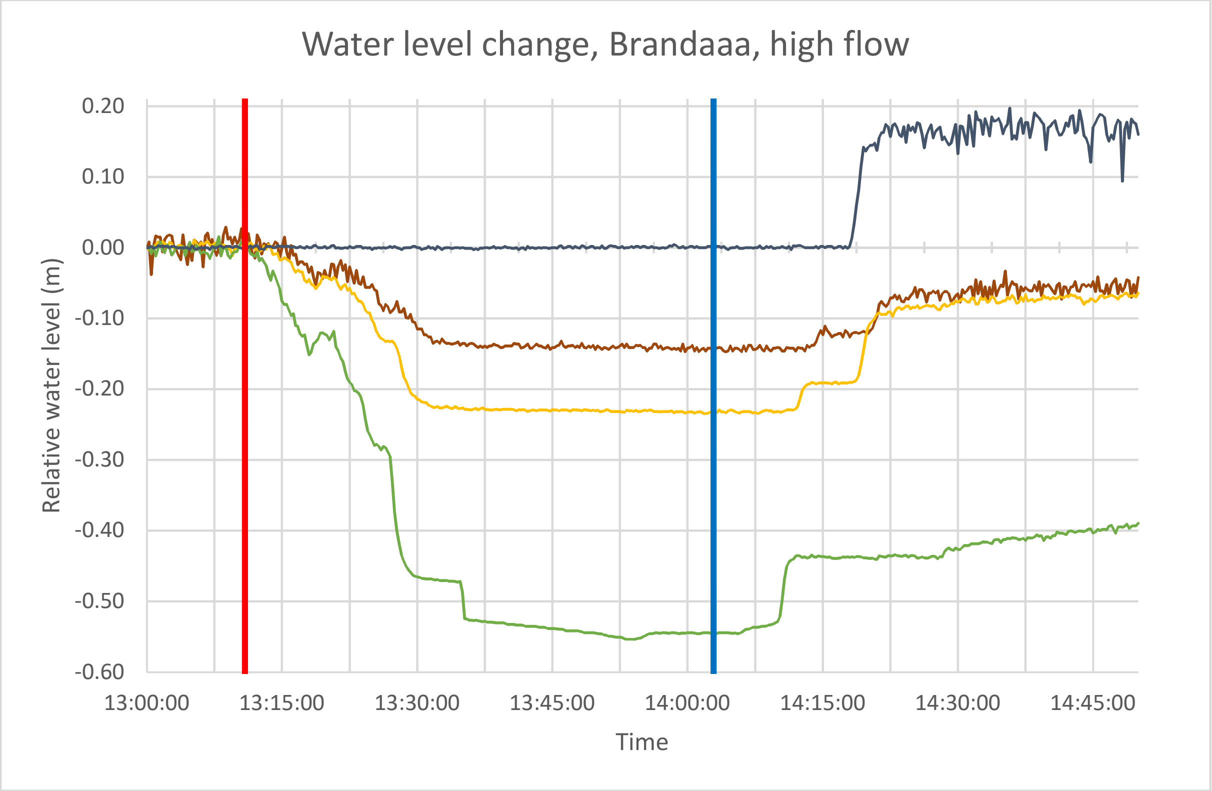

Temperature, Bele, medium flow
Temperature ºC
8
7
6
5
4
3
2
10:10:00
10:25:00
10:40:00
10:55:00
11:10:00
11:25:00
11:40:00
Time
2km Downstream from outlet
800m Downstream from outlet
400m Downstream from outlet
Downstream from outlet
Upstream from outlet
Stop
Start

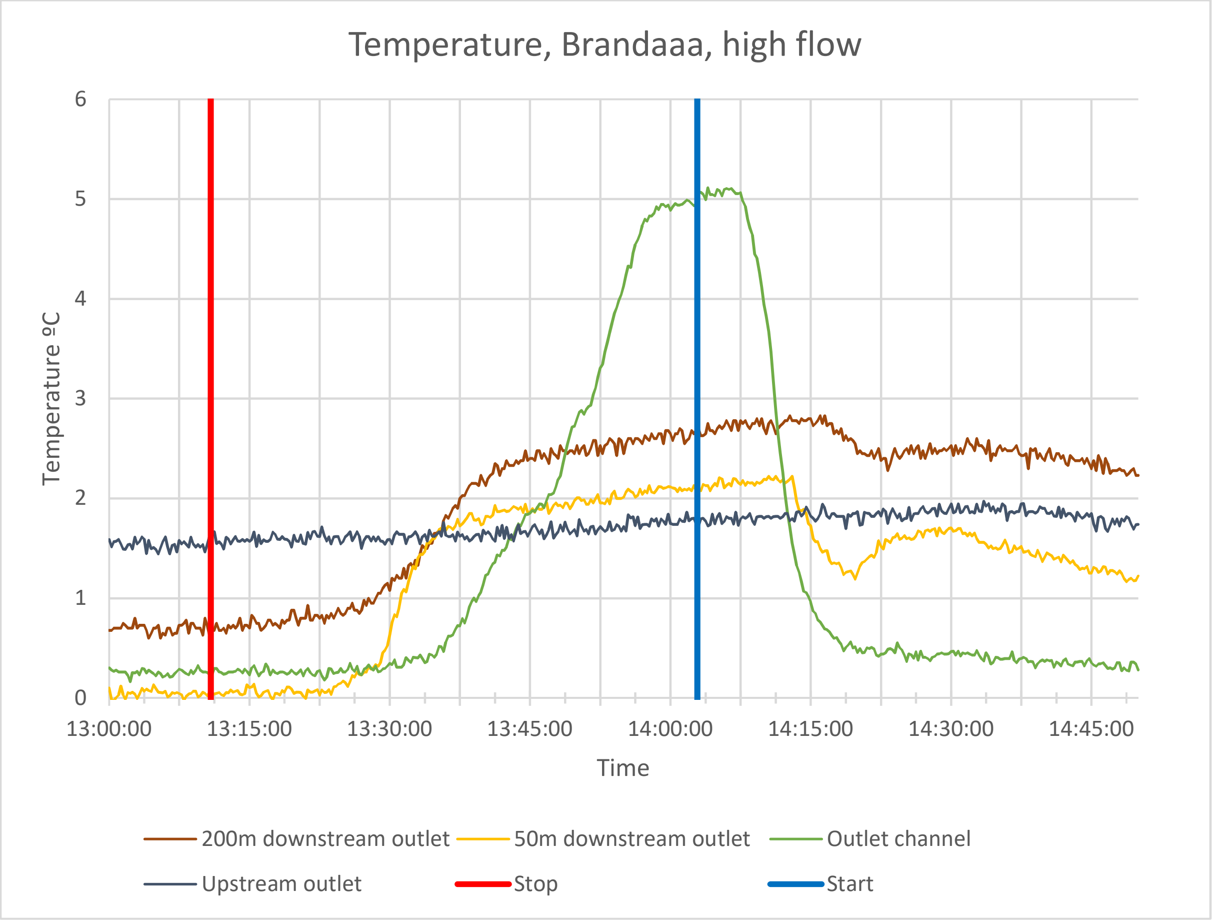

Water level change, Brandaaa, medium flow
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
Relative water level (m)
09:00:00
09:15:00
09:30:00
09:45:00
10:00:00
10:15:00
10:30:00
10:45:00
11:00:00
11:15:00
11:30:00
Time

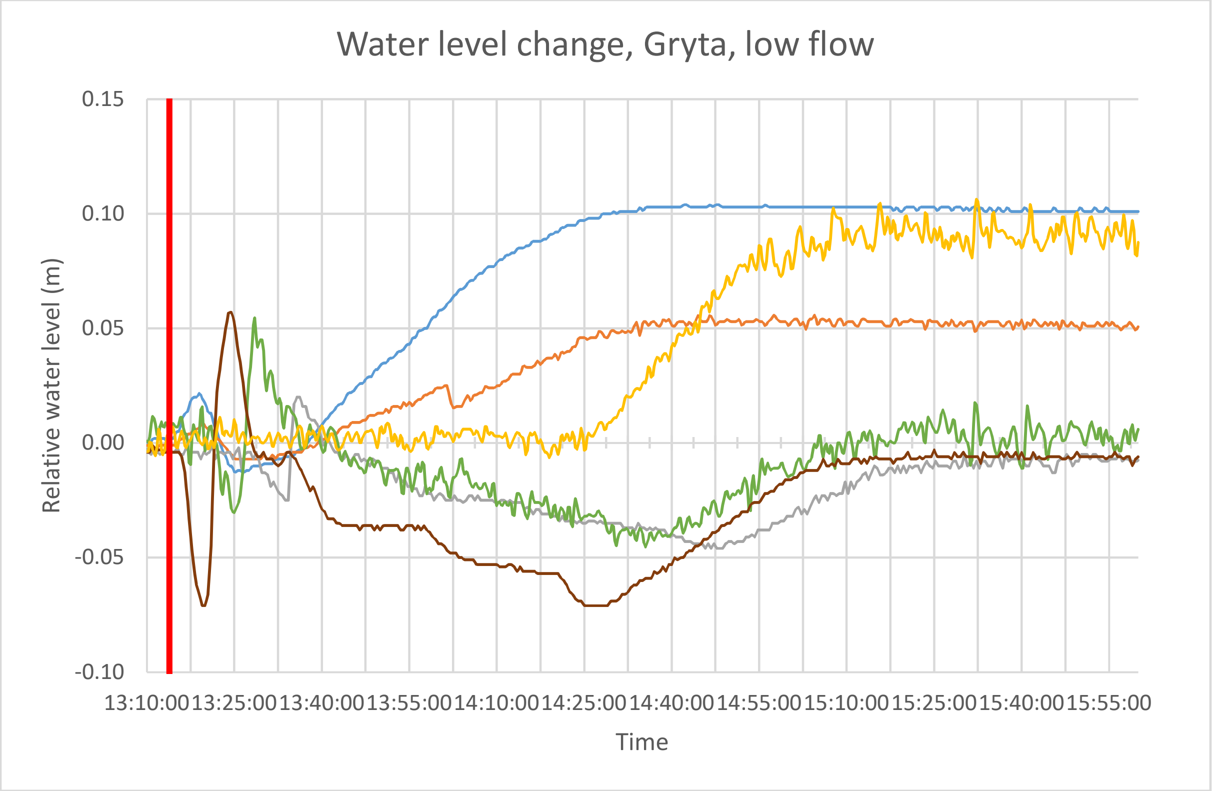

Temperature, Brandaaa, medium flow
8
7
6
5
4
3
2
1
Temperature ºC
9:00:00
9:15:00
9:30:00
9:45:00
10:00:00
10:15:00
10:30:00
10:45:00
11:00:00
11:15:00
11:30:00
Time
Intake
Downstream intake
200m downstream from intake
50m downstream from intake
Outlet channel
Upstream outlet
Stop
Start

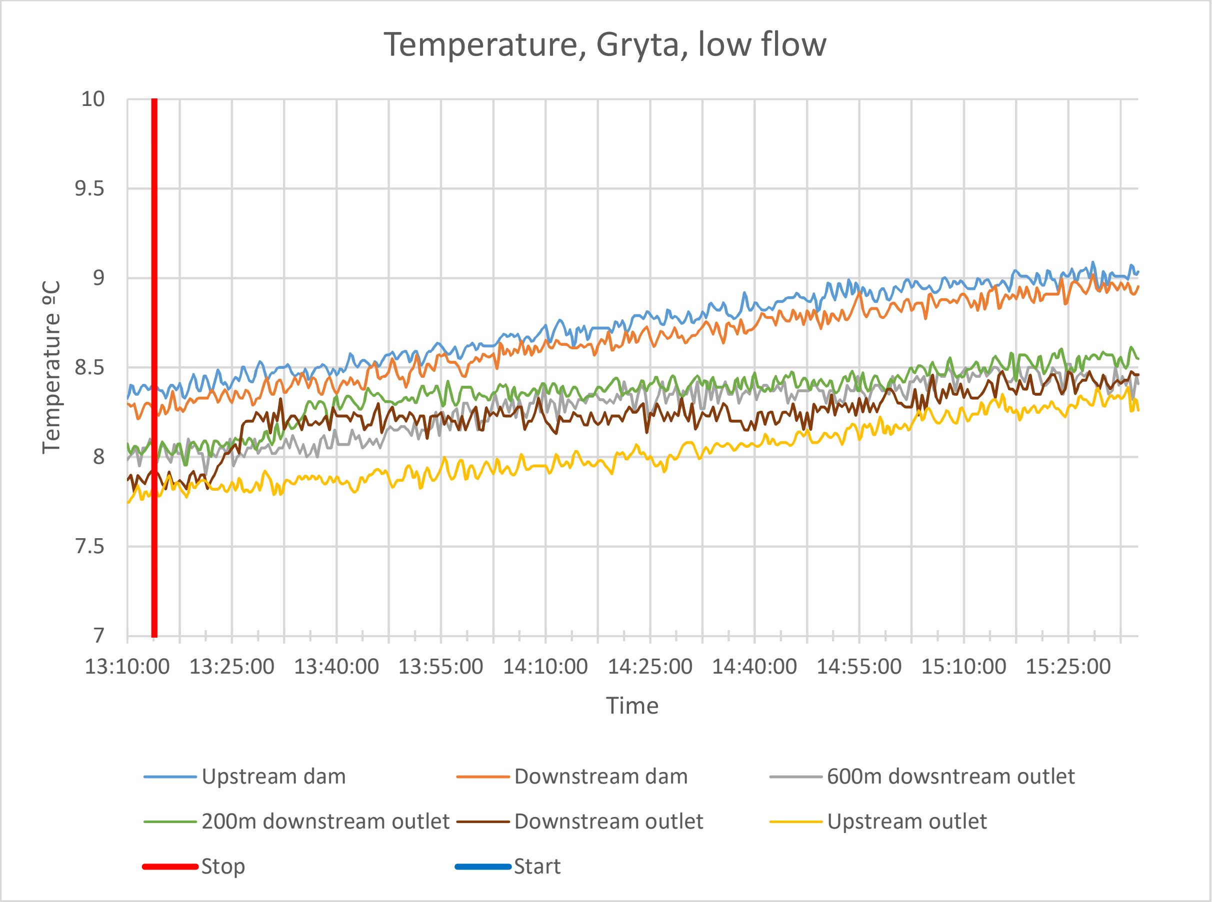

Water level change, Brandaaa, low flow
Relative water level (m)
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
11:55:00
12:10:00
12:25:00
12:40:00
Time

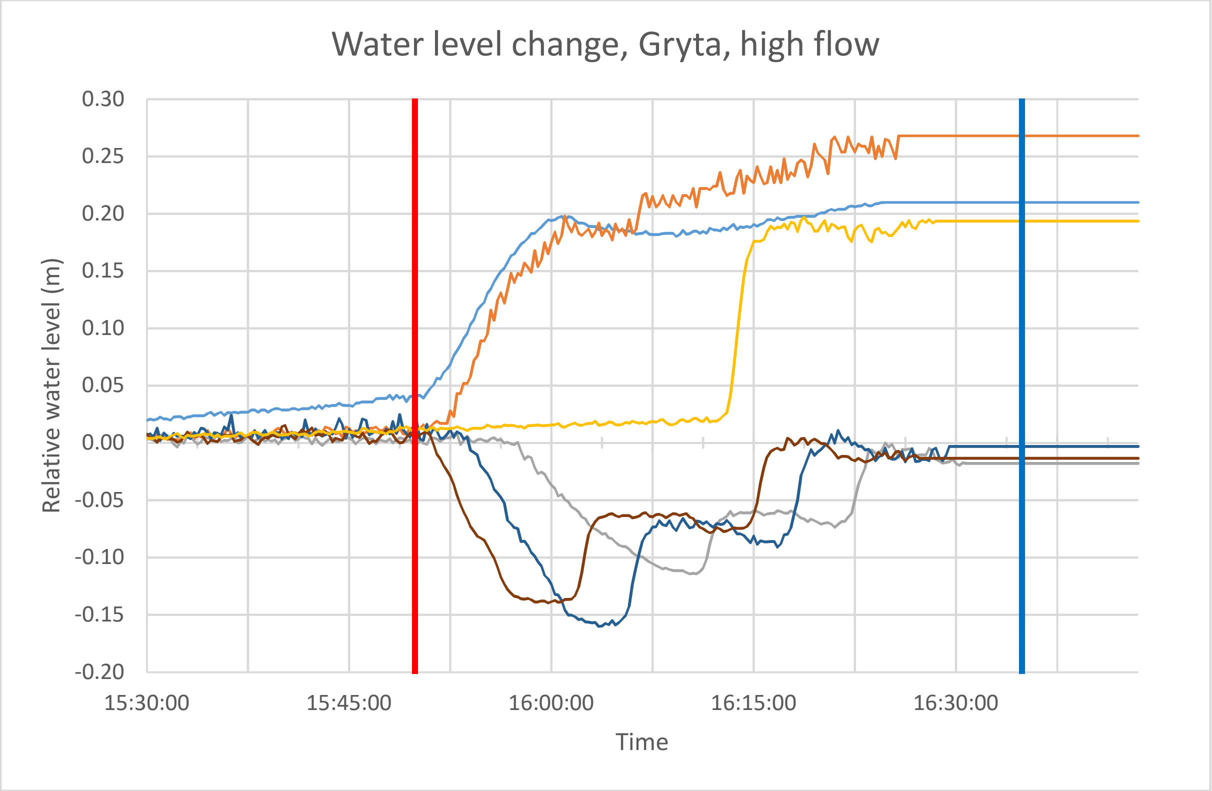

Temperature, Brandaaa, low flow
Temperature ºC
6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
11:55:00
12:10:00
12:25:00
12:40:00
Time
200m downstream from outlet
50m downstream from outlet
Outlet channel
Upstream outlet
Stop
Start

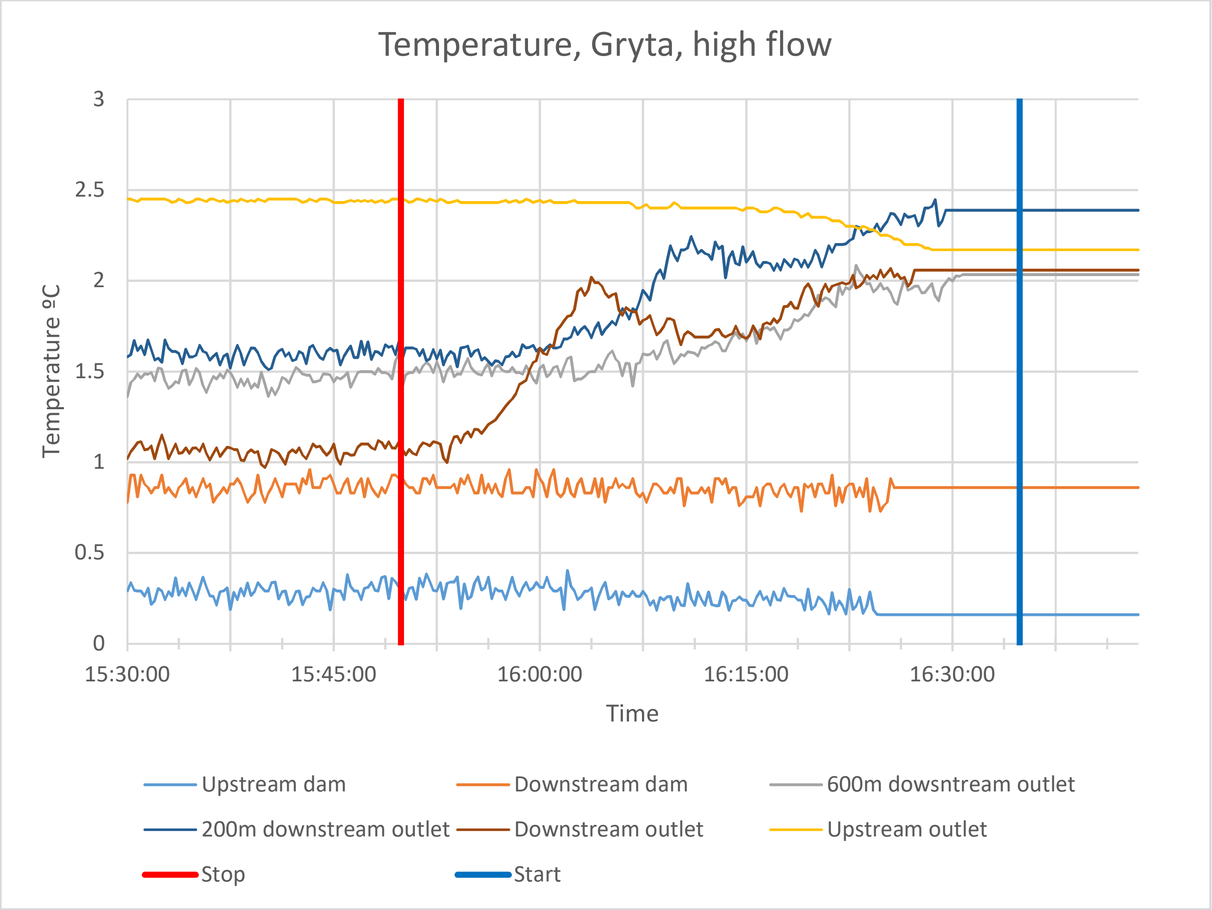

Water level change, Brandaaa, high flow
Relative water level (m)
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
13:00:00
13:15:00
13:30:00
13:45:00
14:00:00
14:15:00
14:30:00
14:45:00
Time

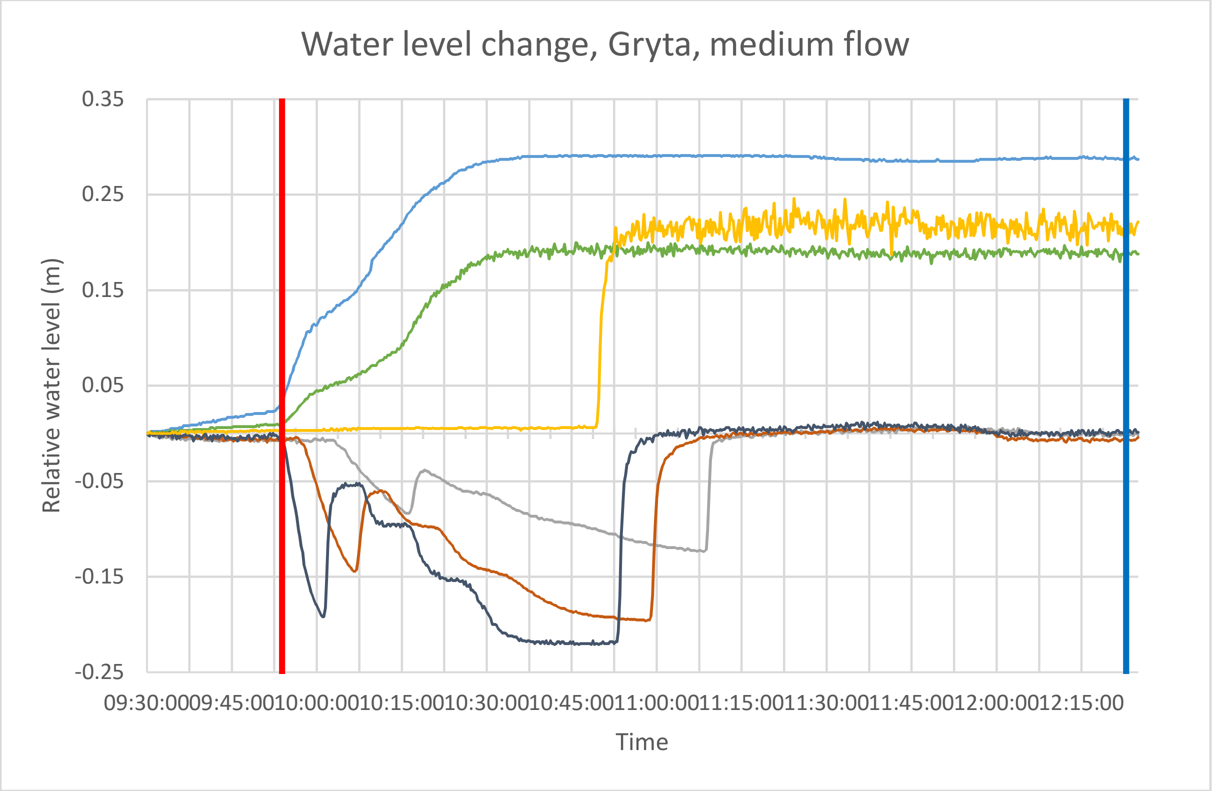

Temperature, Brandaaa, high flow
Temperature ºC
6
5
4
3
2
1
0
13:00:00
13:15:00
13:30:00
13:45:00
14:00:00
14:15:00
14:30:00
14:45:00
Time
200m downstream outlet
50m downstream outlet
Outlet channel
Upstream outlet
Stop
Start

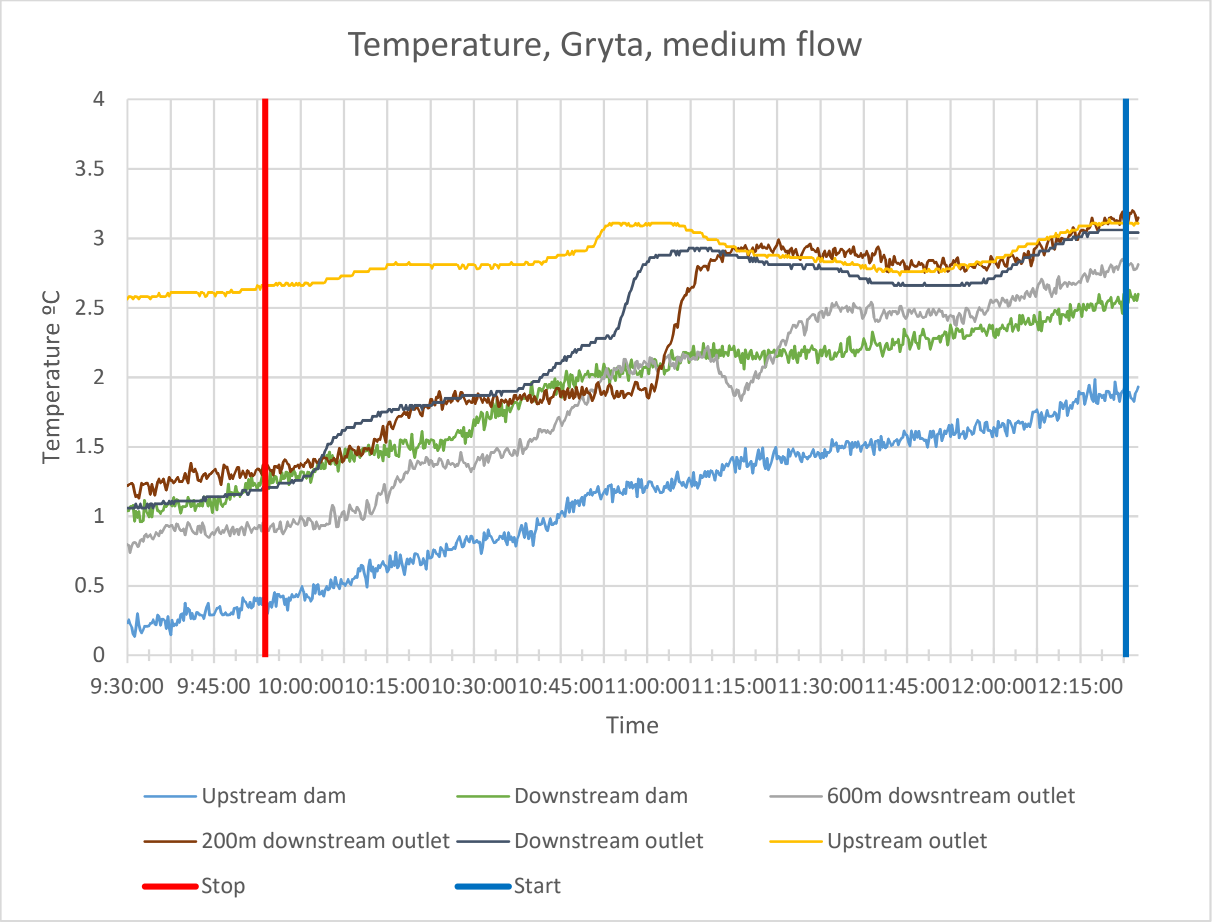

Water level change, Gryta, low flow
0.15
0.10
0.05
0.00
-0.05
-0.10
Relative water level (m)
13:10:00
13:25:00
13:40:00
13:55:00
14:10:00
14:25:00
14:40:00
14:55:00
15:10:00
15:25:00
15:40:00
15:55:00
Time

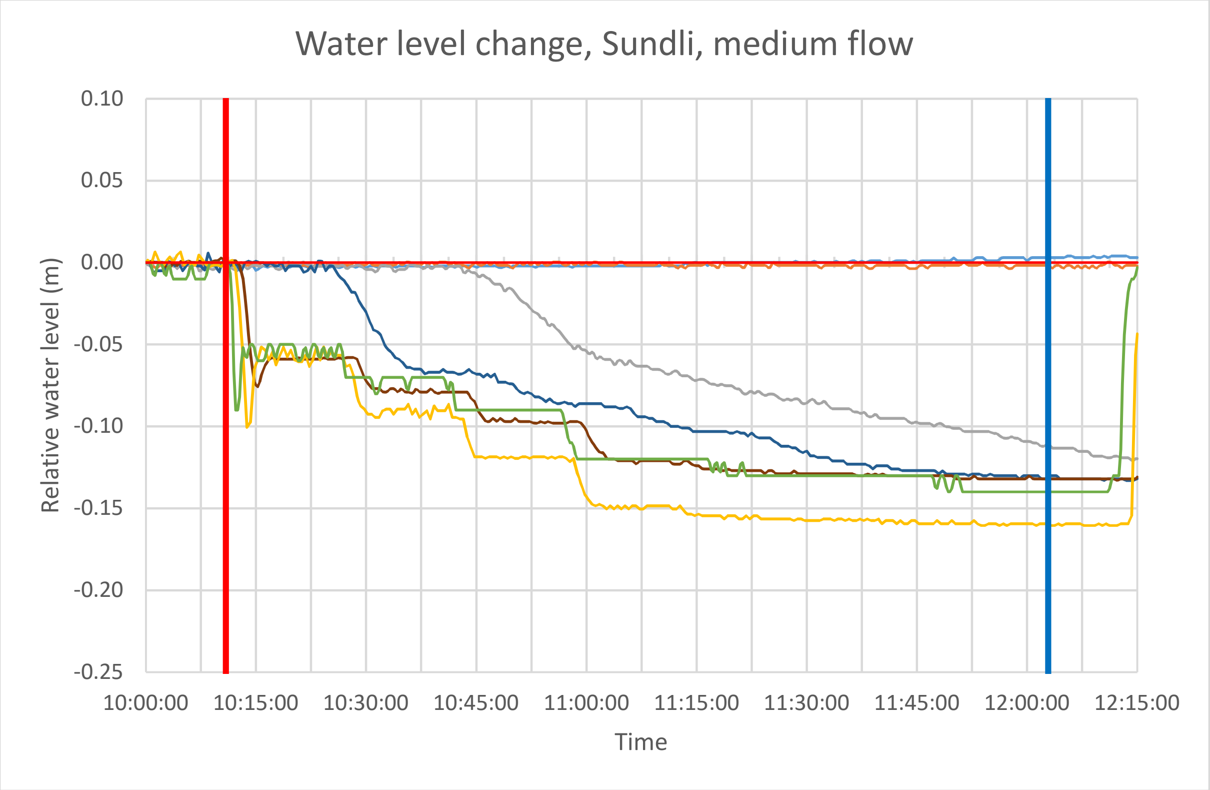

Temperature, Gryta, low flow
10
9.5
9
8.5
8
7.5
7
Temperature ºC
13:10:00
13:25:00
13:40:00
13:55:00
14:10:00
14:25:00
14:40:00
14:55:00
15:10:00
15:25:00
Time
Upstream dam
Downstream dam
600m dowsntream outlet
200m downstream outlet
Downstream outlet
Upstream outlet
Stop
Start

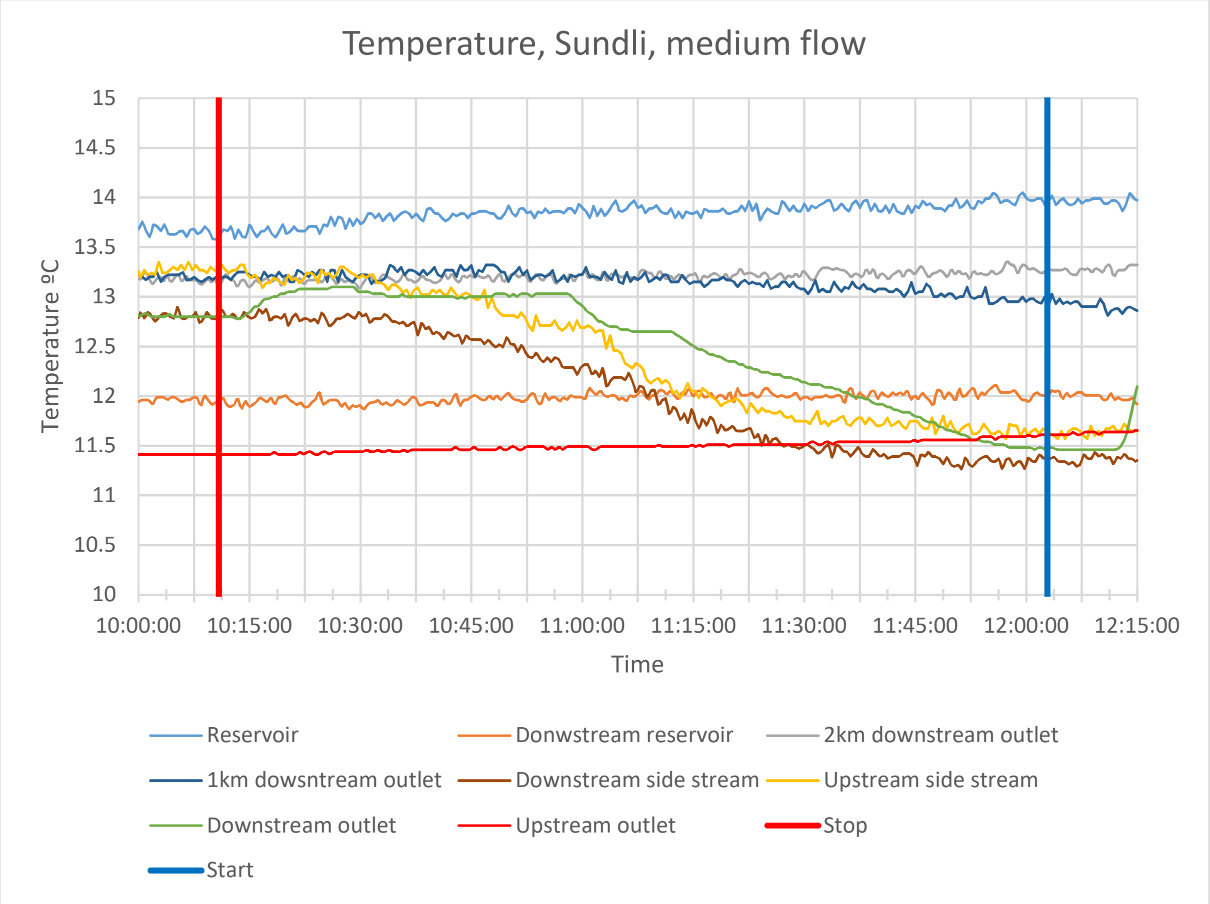

Water level change, Gryta, high flow
Relative water level (m)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
15:30:00
15:45:00
16:00:00
16:15:00
16:30:00
Time

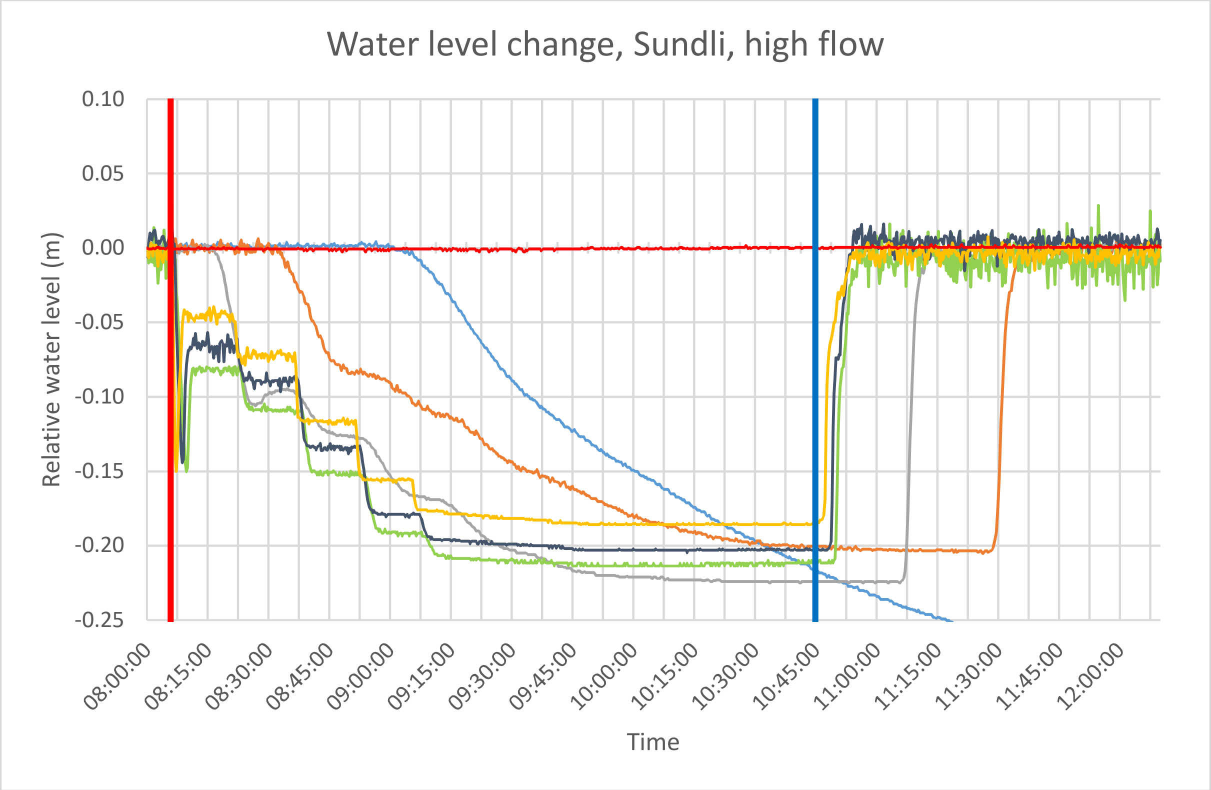

Temperature, Gryta, high flow
Temperature ºC
3
2.5
2
1.5
1
0.5
0
15:30:00
15:45:00
16:00:00
16:15:00
16:30:00
Time
Upstream dam
Downstream dam
600m downsntream outlet
200m downstream outlet
Downstream outlet
Upstream outlet
Stop
Start

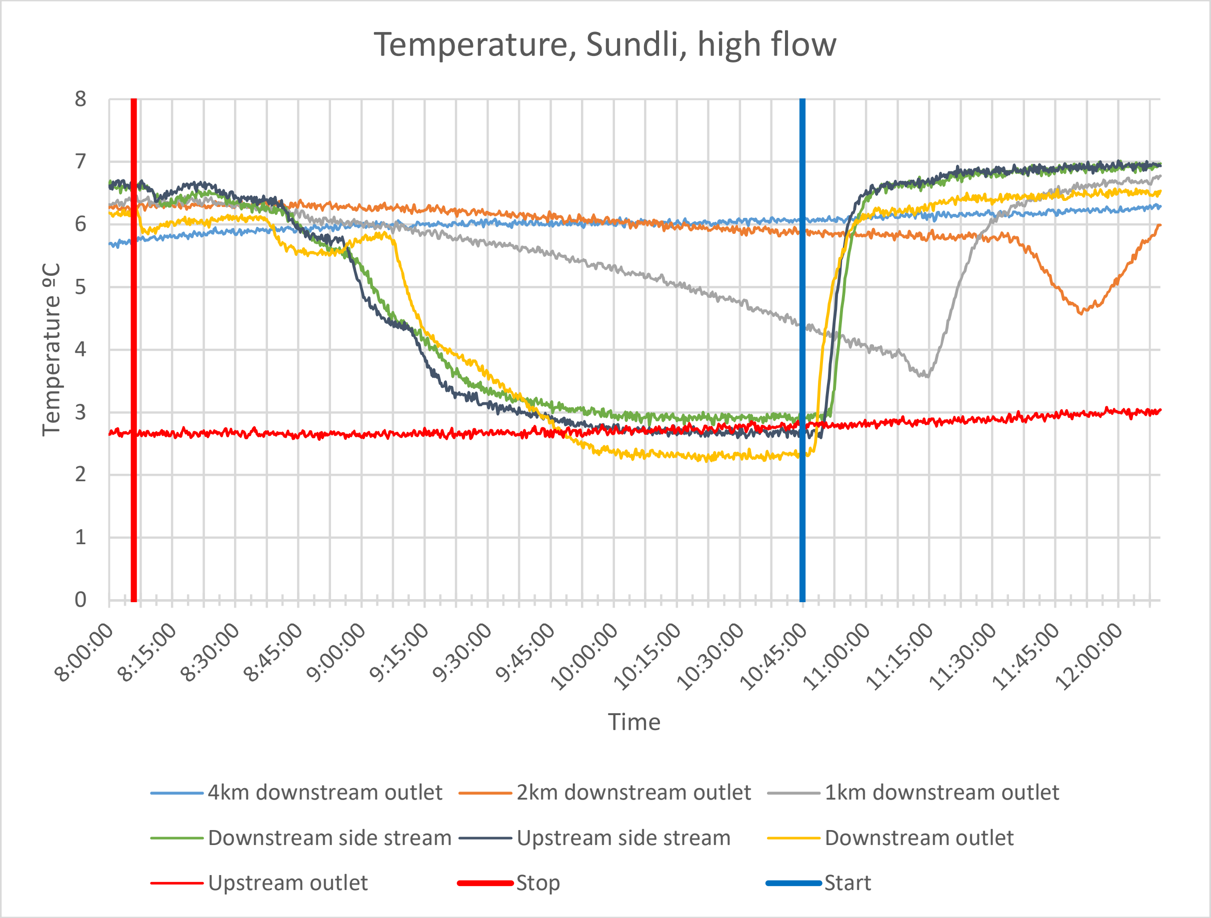

Water level change, Gryta, medium flow
Relative water level (m)
0.35
0.25
0.15
0.05
-0.05
-0.15
-0.25
09:30:00
09:45:00
10:00:00
10:15:00
10:30:00
10:45:00
11:00:00
11:15:00
11:30:00
11:45:00
12:00:00
12:15:00
Time

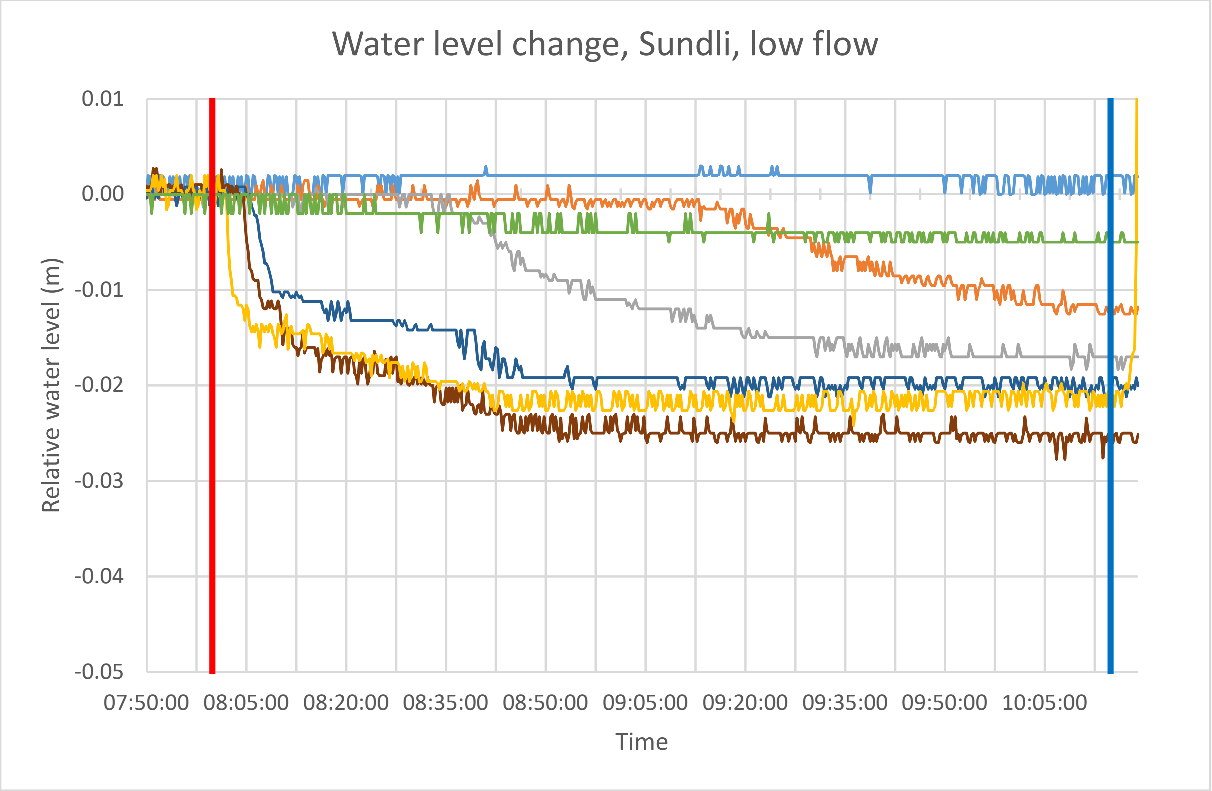

Temperature, Gryta, medium flow
Temperature ºC
4
3.5
3
2.5
2
1.5
1
0.5
0
9:30:00
9:45:00
10:00:00
10:15:00
10:30:00
10:45:00
11:00:00
11:15:00
11:30:00
11:45:00
12:00:00
12:15:00
Time
Upstream dam
Downstream dam
600m dowsntream outlet
200m downstream outlet
Downstream outlet
Upstream outlet
Stop
Start

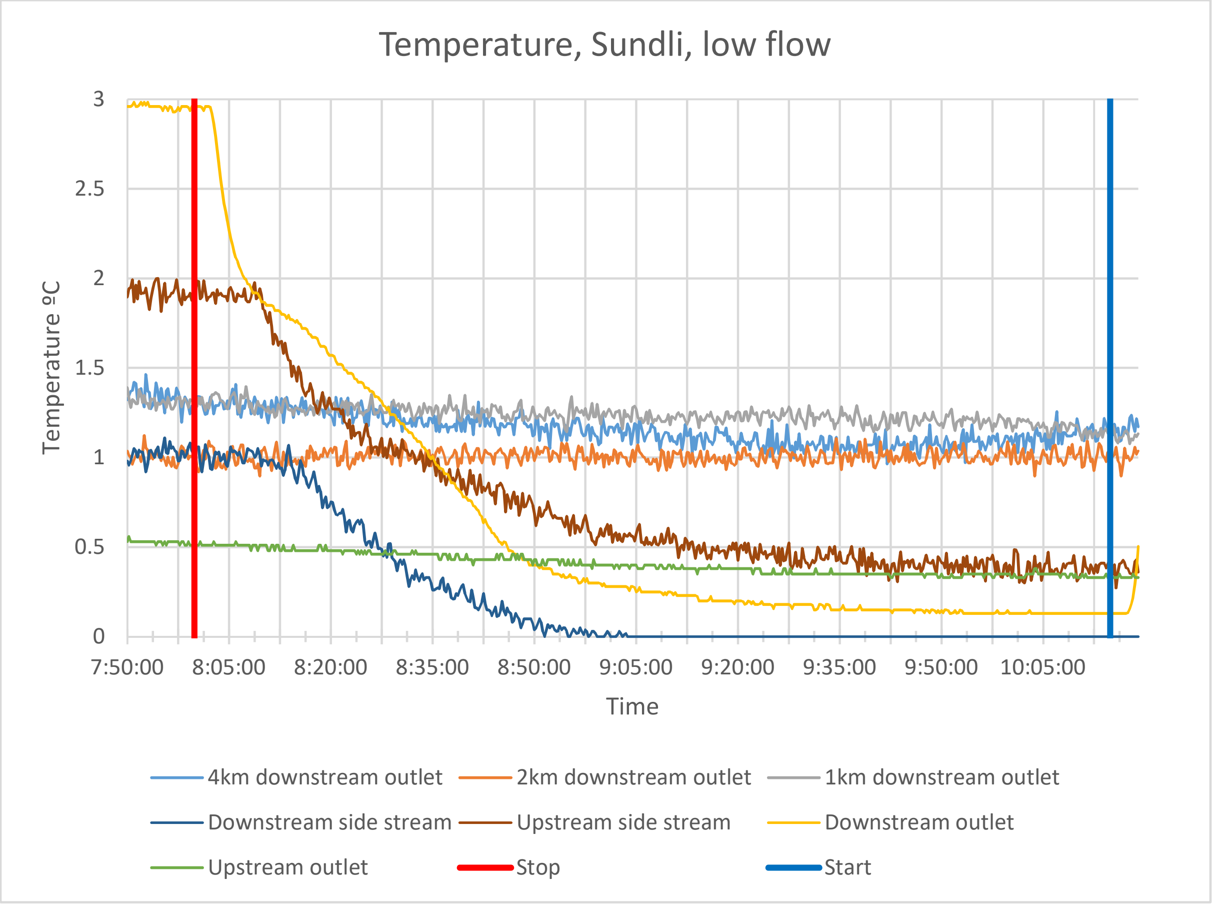

Water level change, Sundli, medium flow
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
Relative water level (m)
10:00:00
10:15:00
10:30:00
10:45:00
11:00:00
11:15:00
11:30:00
11:45:00
12:00:00
12:15:00
Time

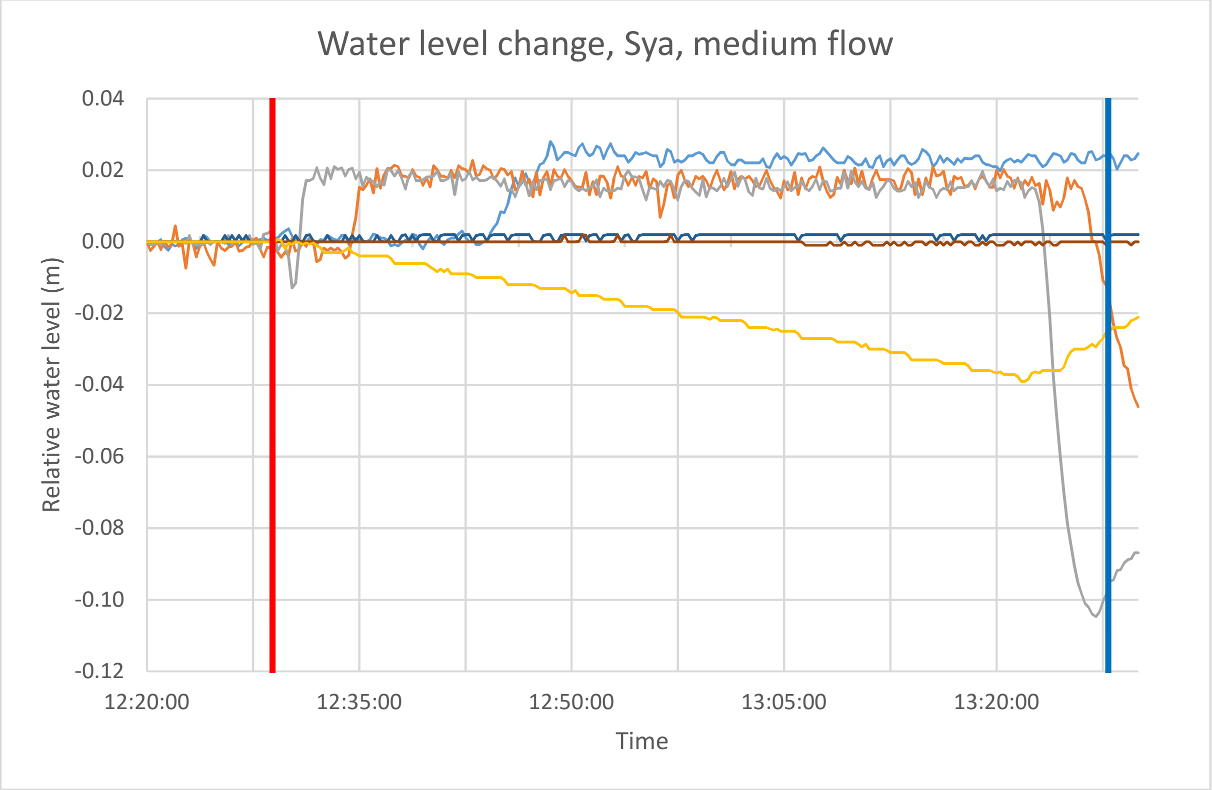

Temperature, Sundli, medium flow
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
Temperature ºC
10:00:00
10:15:00
10:30:00
10:45:00
11:00:00
11:15:00
11:30:00
11:45:00
12:00:00
12:15:00
Time
Reservoir
Donwstream reservoir
2km downstream outlet
1km dowsntream outlet
Downstream side stream
Upstream side stream
Downstream outlet
Upstream outlet
Stop
Start

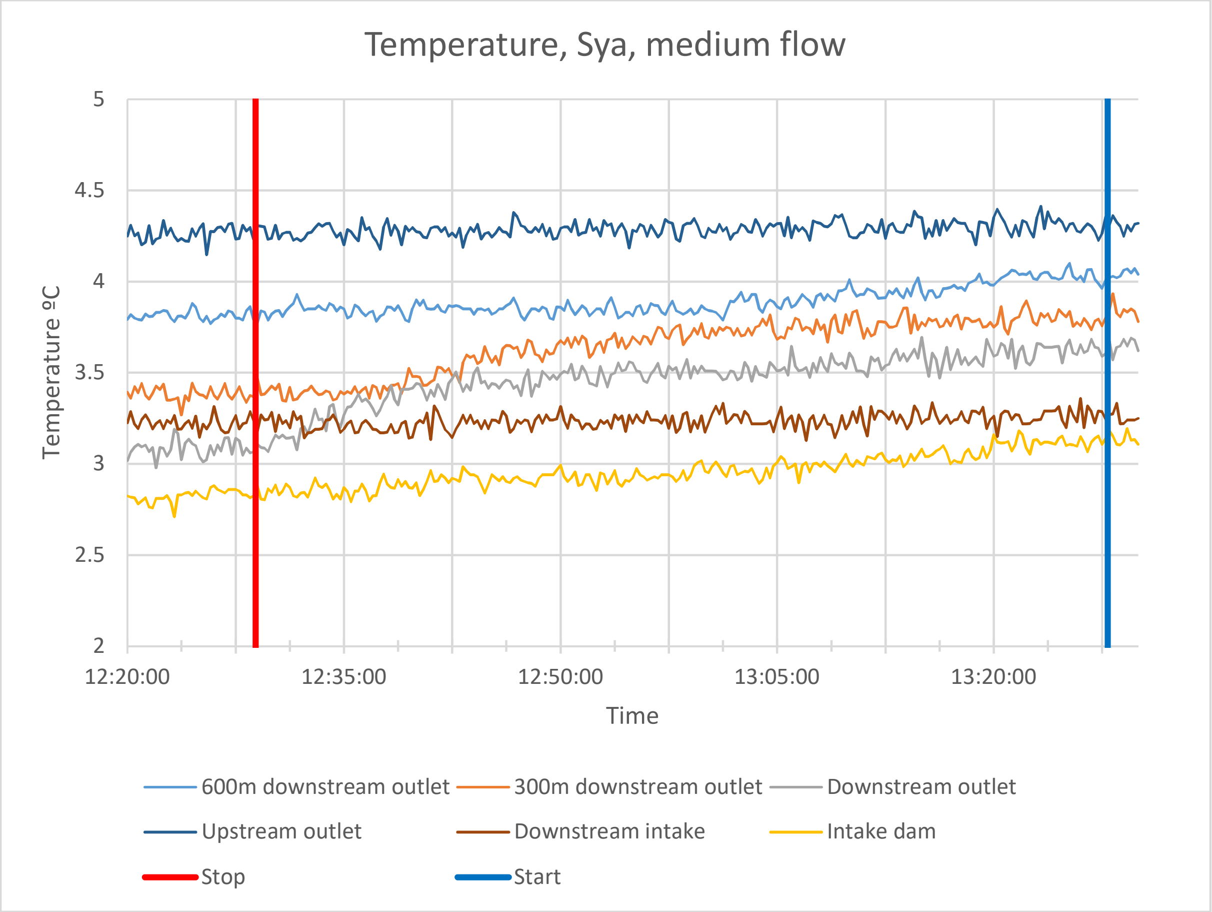

Water level change, Sundli, high flow
Relative water level (m)
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
08:00:00
08:15:00
08:30:00
08:45:00
09:00:00
09:15:00
09:30:00
09:45:00
10:00:00
10:15:00
10:30:00
10:45:00
11:00:00
11:15:00
11:30:00
11:45:00
12:00:00
Time

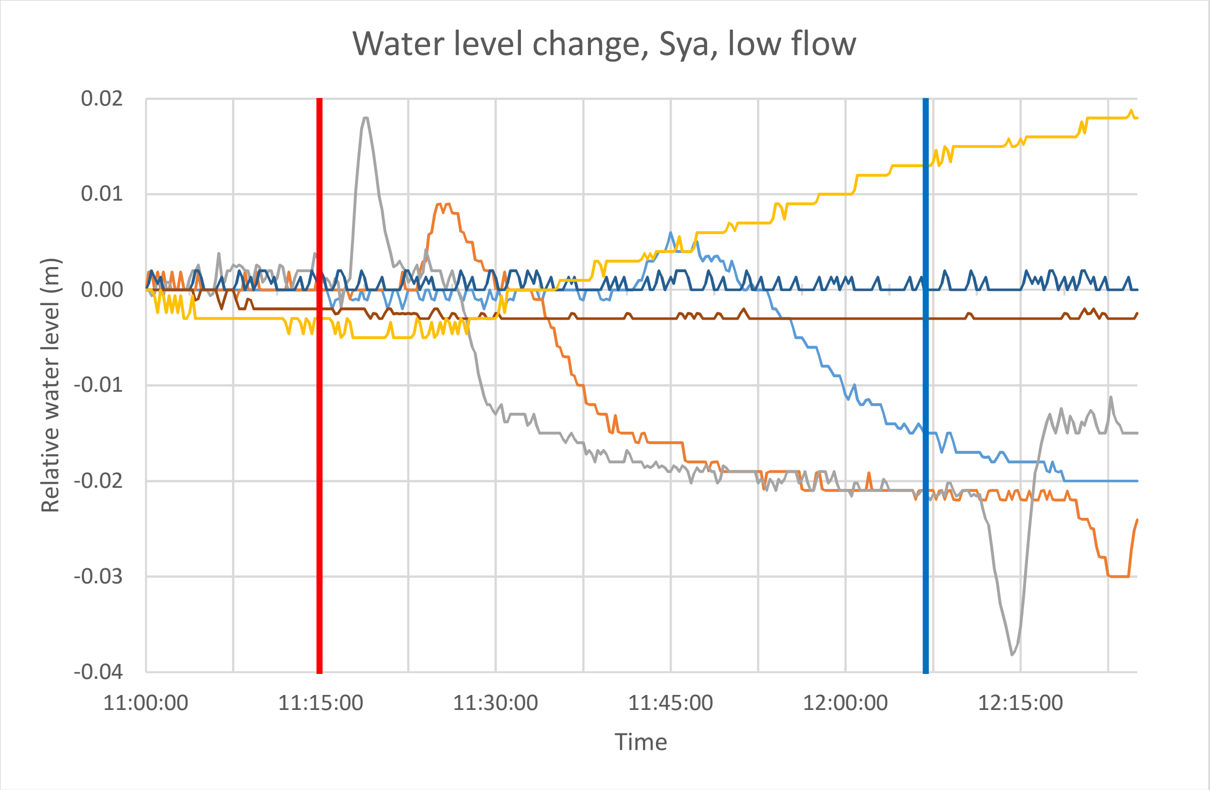

Temperature, Sundli, high flow
Temperature ºC
8
7
6
5
4
3
2
1
0
8:00:00
8:15:00
8:30:00
8:45:00
9:00:00
9:15:00
9:30:00
9:45:00
10:00:00
10:15:00
10:30:00
10:45:00
11:00:00
11:15:00
11:30:00
11:45:00
12:00:00
Time
4km downstream outlet
2km downstream outlet
1km downstream outlet
Downstream side stream
Upstream side stream
Downstream outlet
Upstream outlet
Stop
Start

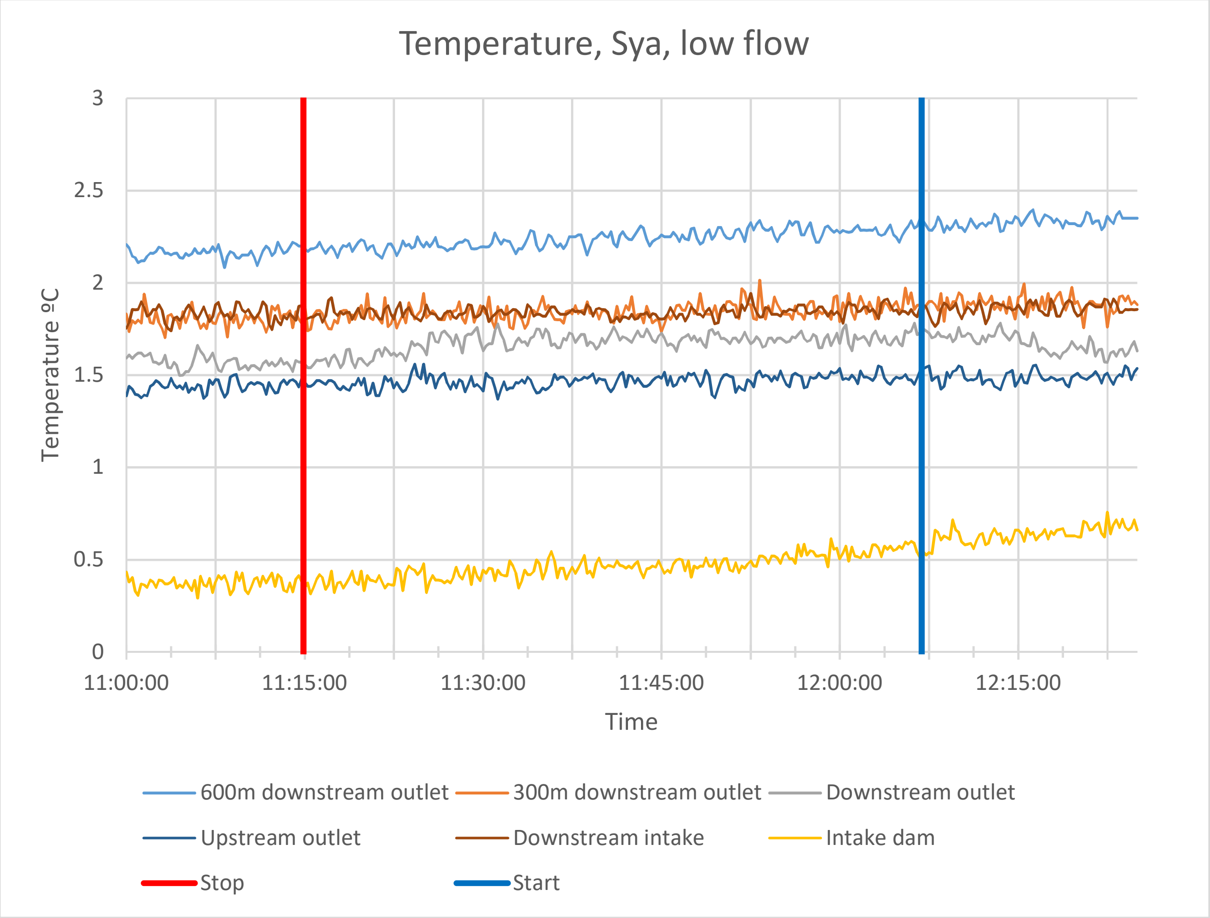

Water level change, Sundli, low flow
Relative water level (m)
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
07:50:00
08:05:00
08:20:00
08:35:00
08:50:00
09:05:00
09:20:00
09:35:00
09:50:00
10:05:00
Time

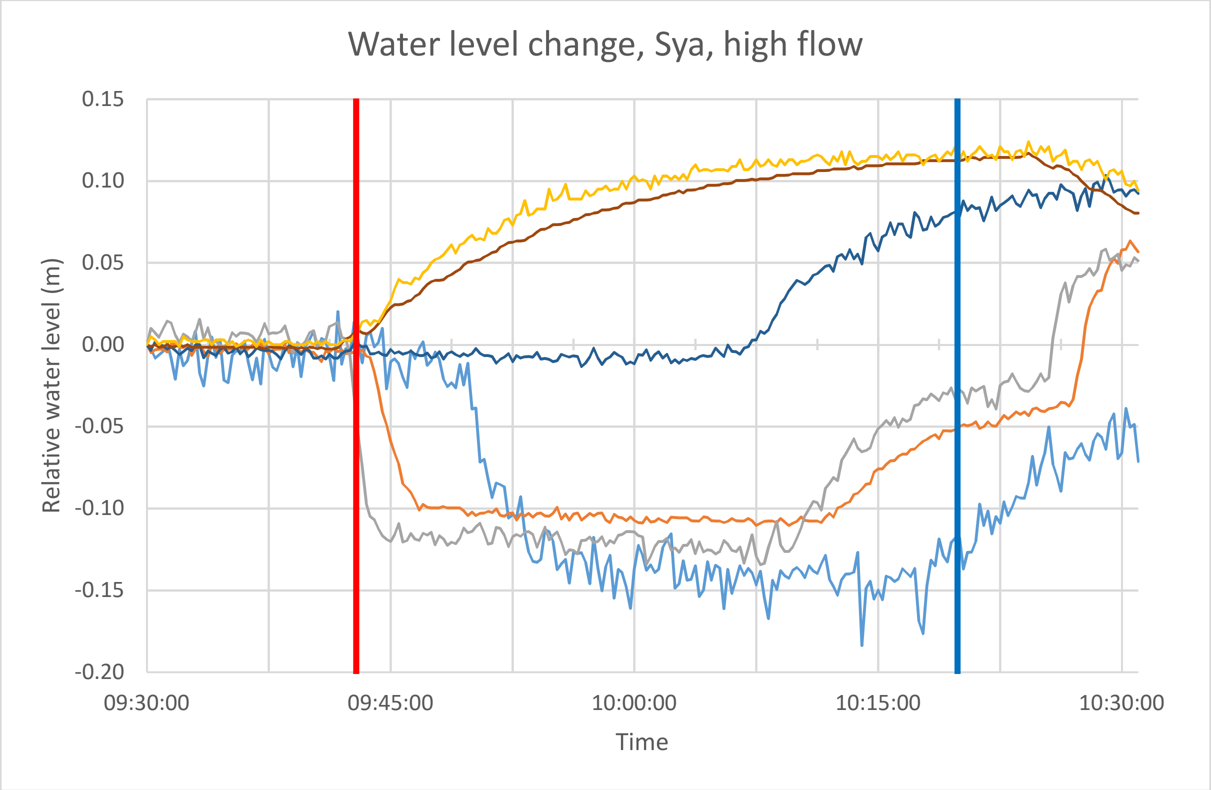

Temperature, Sundli, low flow
Temperature ºC
3
2.5
2
1.5
1
0.5
0
7:50:00
8:05:00
8:20:00
8:35:00
8:50:00
9:05:00
9:20:00
9:35:00
9:50:00
10:05:00
Time
4km downstream outlet
2km downstream outlet
1km downstream outlet
Downstream side stream
Upstream side stream
Downstream outlet
Upstream outlet
Stop
Start

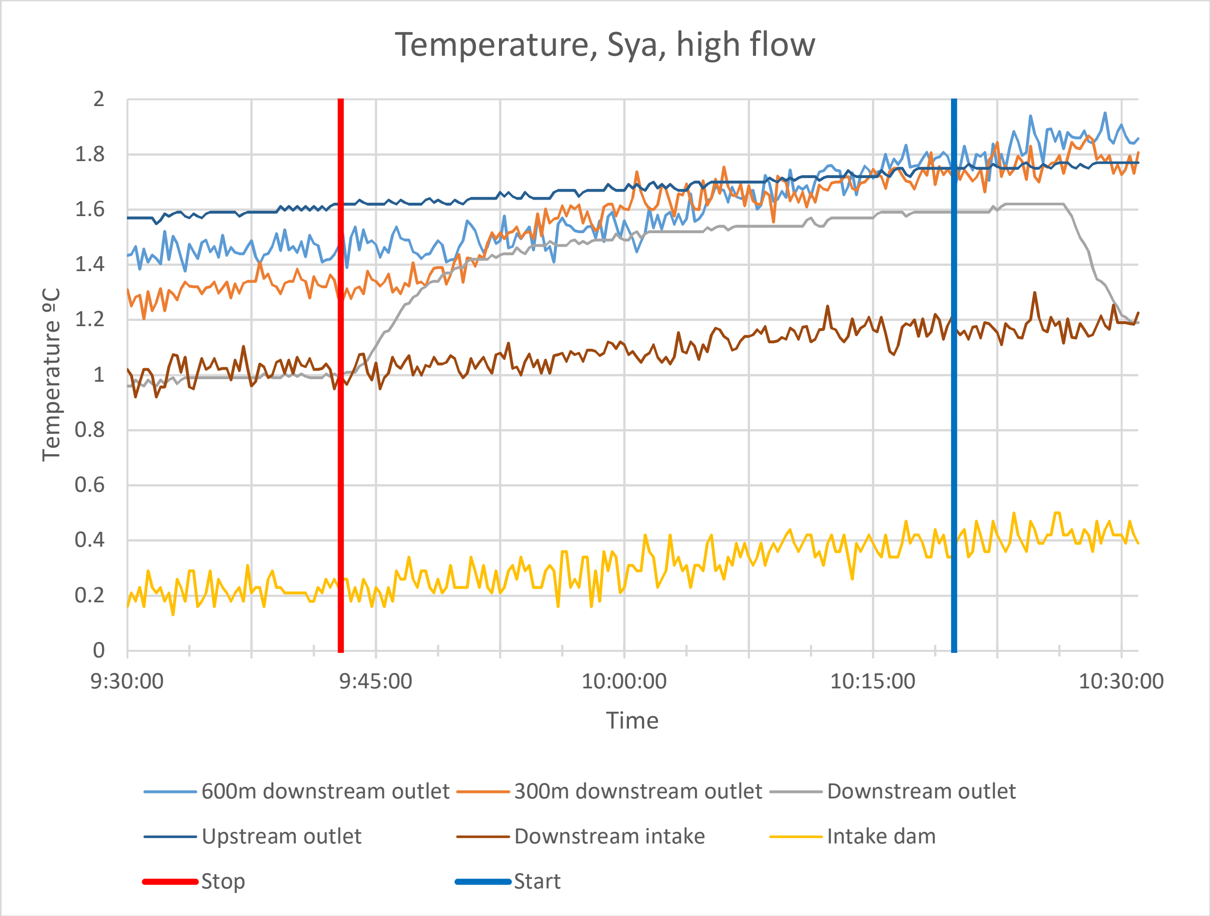

Water level change, Sya, medium flow
Relative water level (m)
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
12:20:00
12:35:00
12:50:00
13:05:00
13:20:00
Time


Temperature, Sya, medium flow
Temperature ºC
5
4.5
4
3.5
3
2.5
2
12:20:00
12:35:00
12:50:00
13:05:00
13:20:00
Time
600m downstream outlet
300m downstream outlet
Downstream outlet
Upstream outlet
Downstream intake
Intake dam
Stop
Start


Water level change, Sya, low flow
Relative water level (m)
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
11:00:00
11:15:00
11:30:00
11:45:00
12:00:00
12:15:00
Time

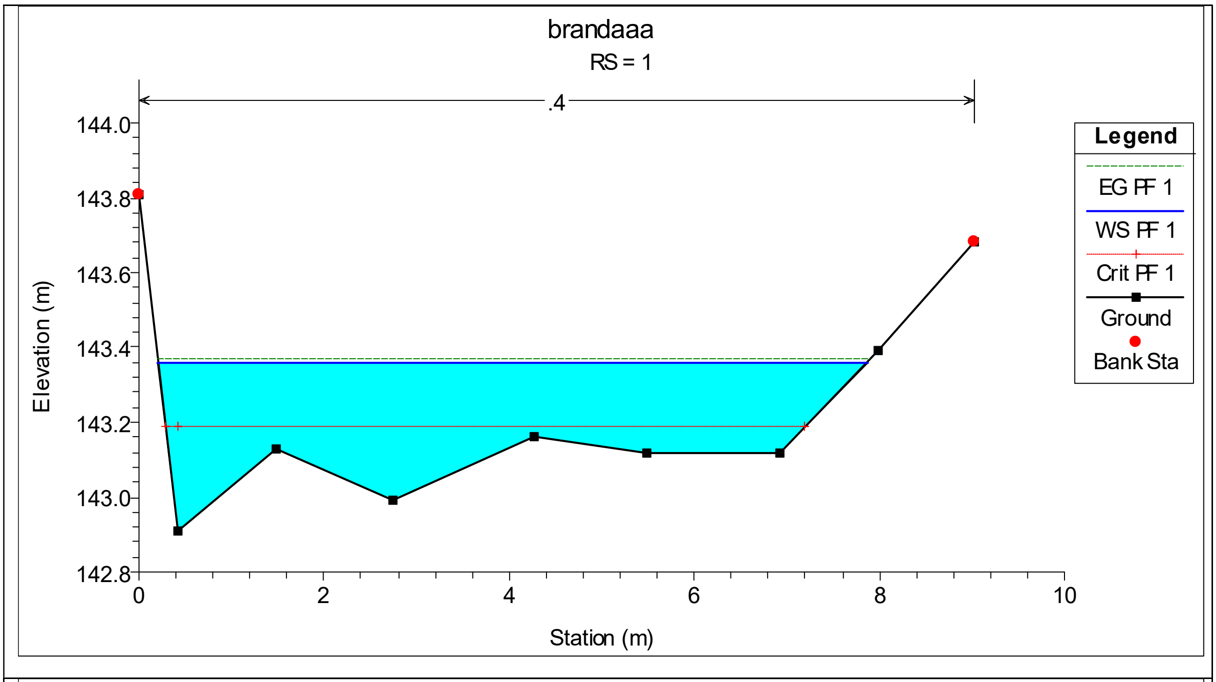

Temperature, Sya, low flow
Temperature ºC
3
2.5
2
1.5
1
0.5
0
11:00:00
11:15:00
11:30:00
11:45:00
12:00:00
12:15:00
Time
600m downstream outlet
300m downstream outlet
Downstream outlet
Upstream outlet
Downstream intake
Intake dam
Stop
Start

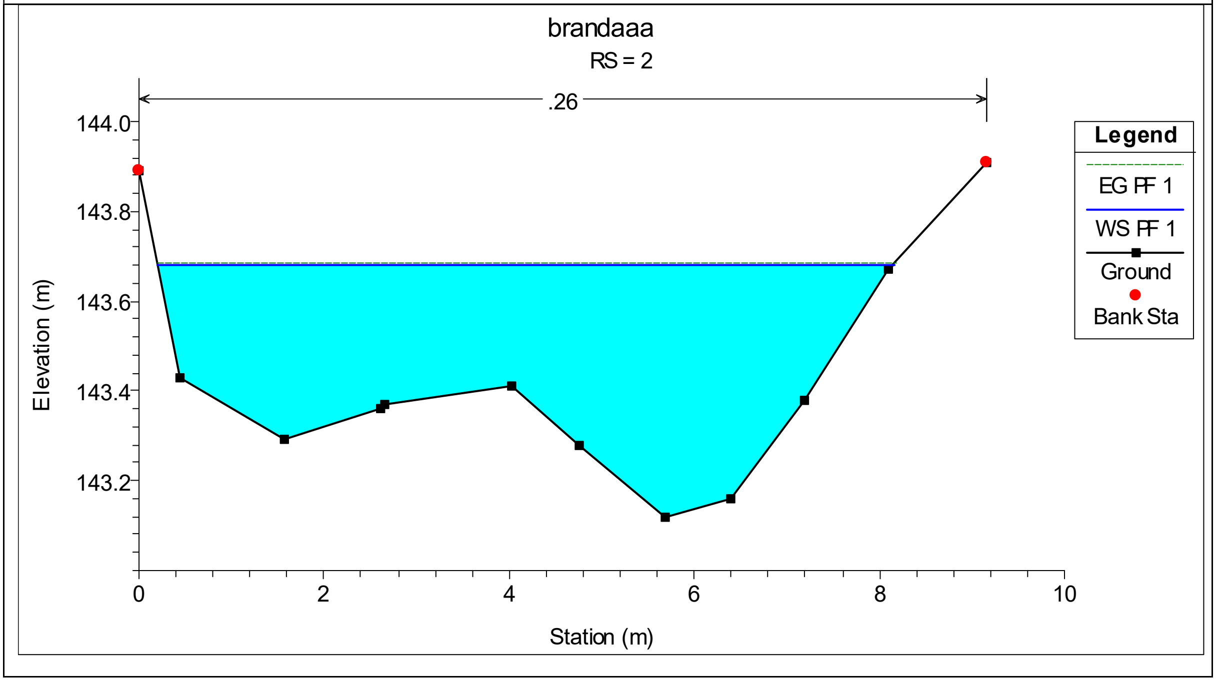

Water level change, Sya, high flow
Relative water level (m)
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
09:30:00
09:45:00
10:00:00
10:15:00
10:30:00
Time

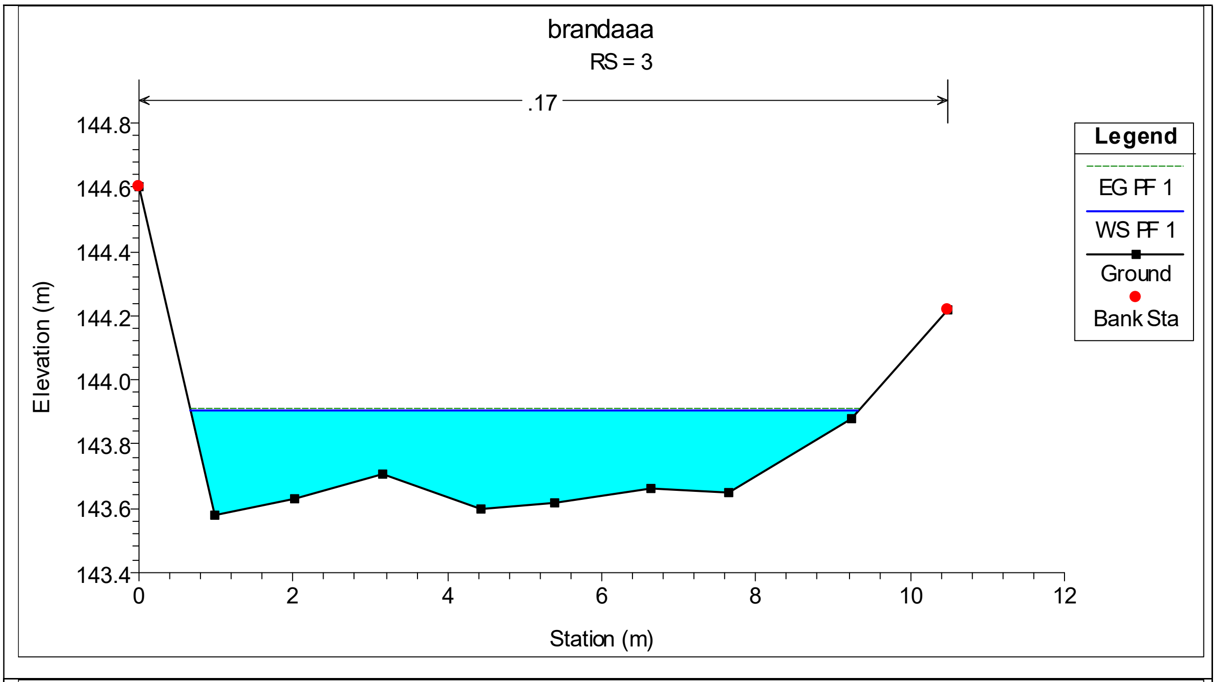

Temperature, Sya, high flow
Temperature ºC
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
9:30:00
9:45:00
10:00:00
10:15:00
10:30:00
Time
600m downstream outlet
300m downstream outlet
Downstream outlet
Upstream outlet
Downstream intake
Intake dam
Stop
Start

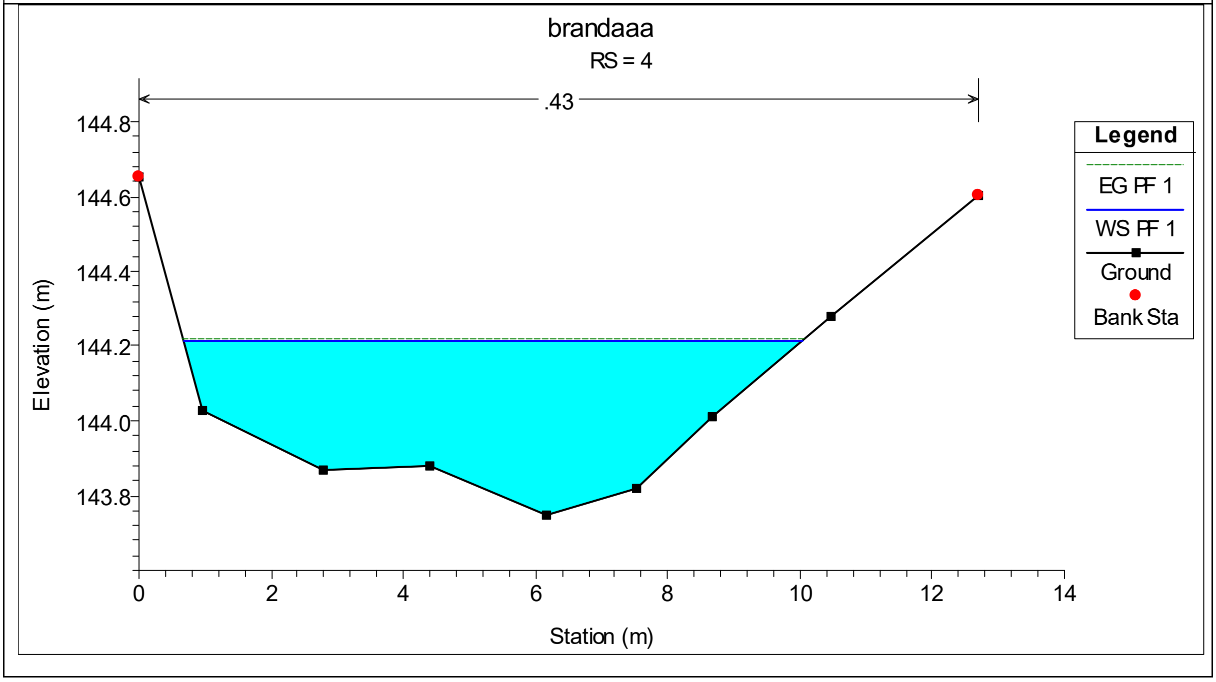
Cross sections

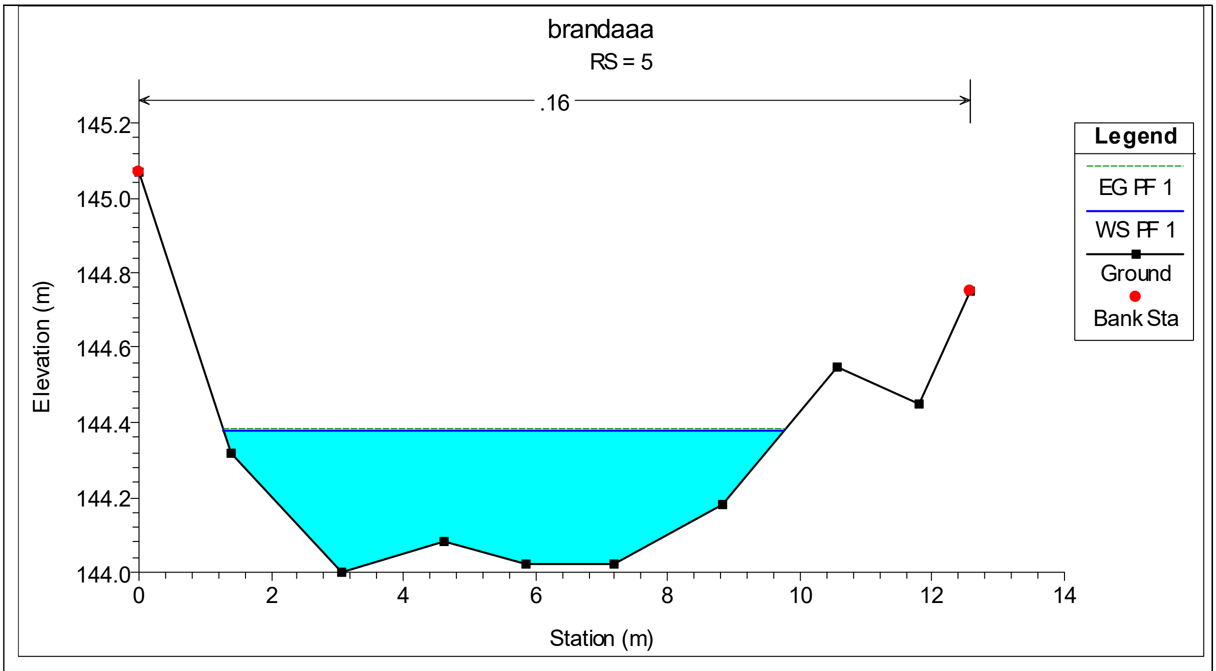
Cross sections 1 to 14 belong to the main river, while 15 to 18 are part of the outlet channel.

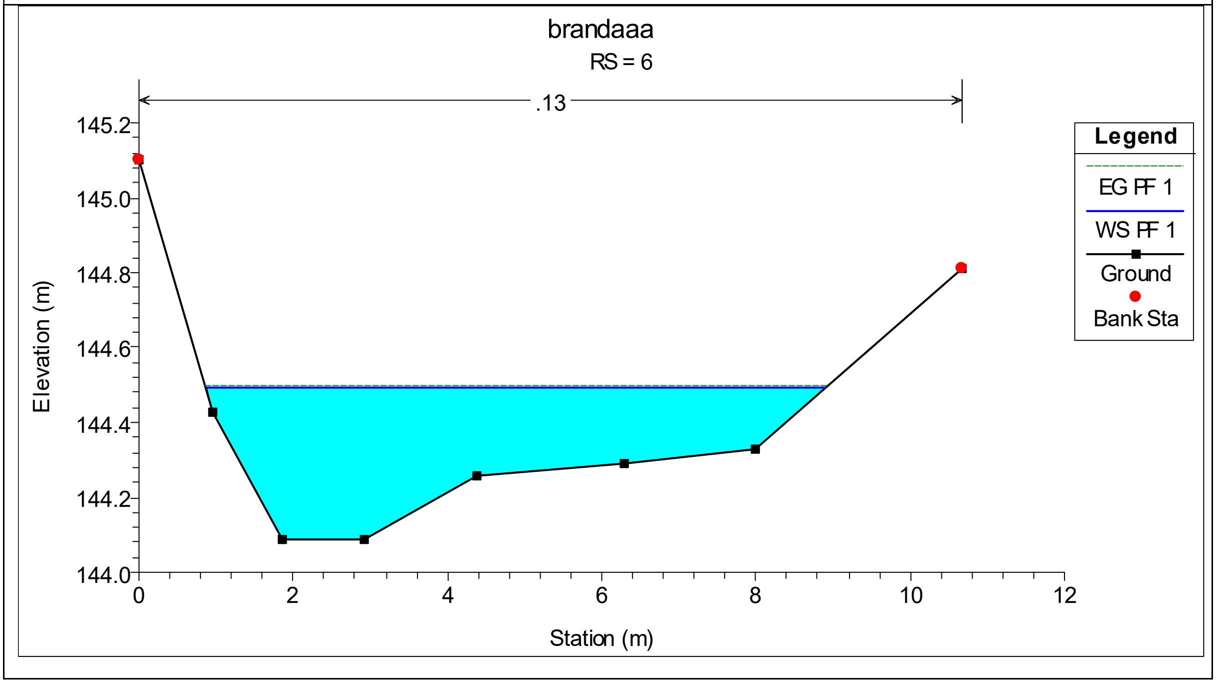


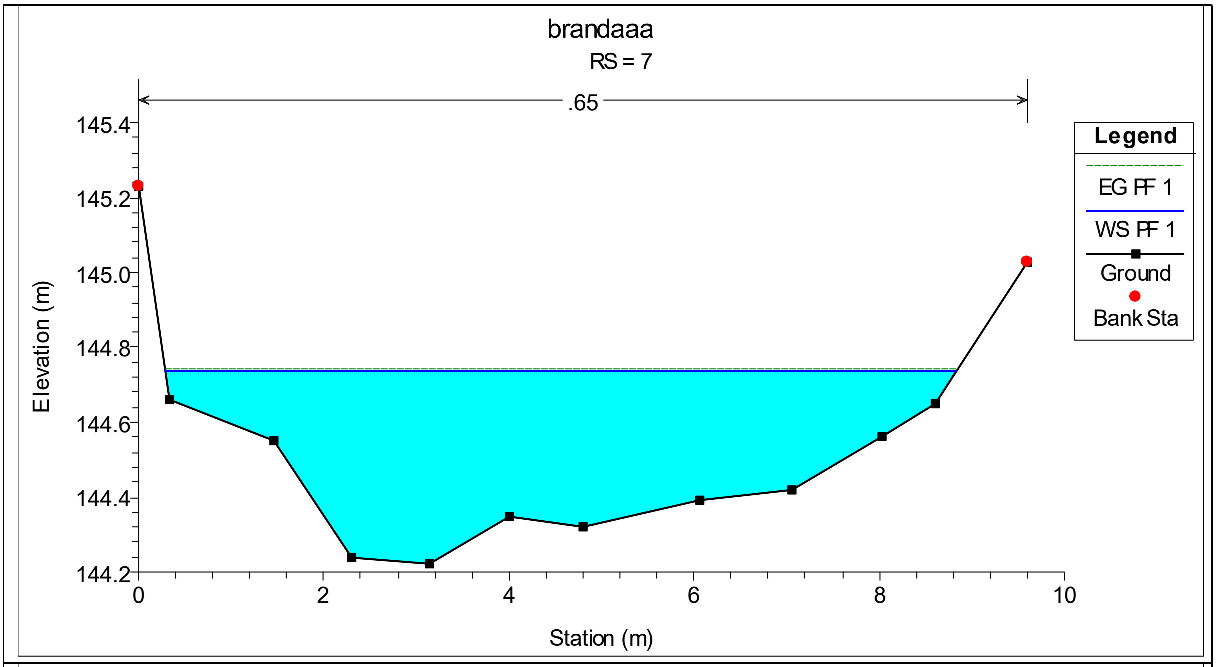


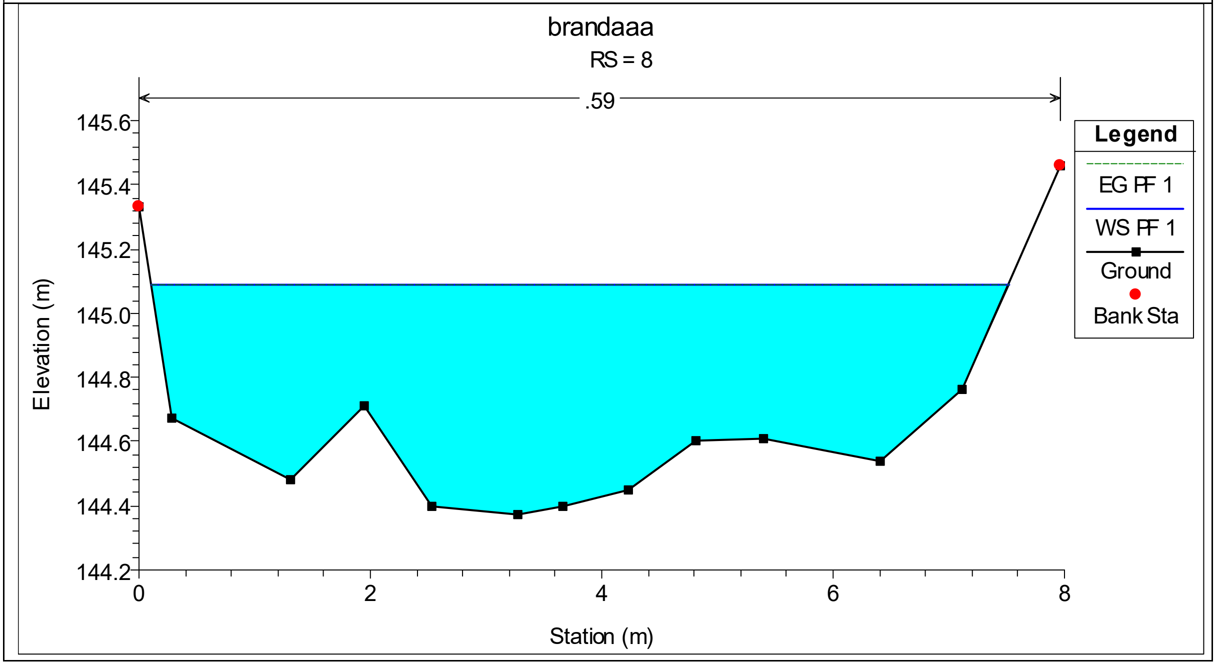

brandaaa
RS = 3
.17
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
144.8
144.6
144.4
144.2
144.0
143.8
143.6
143.4
0
2
4
6
8
10
12
Station (m)

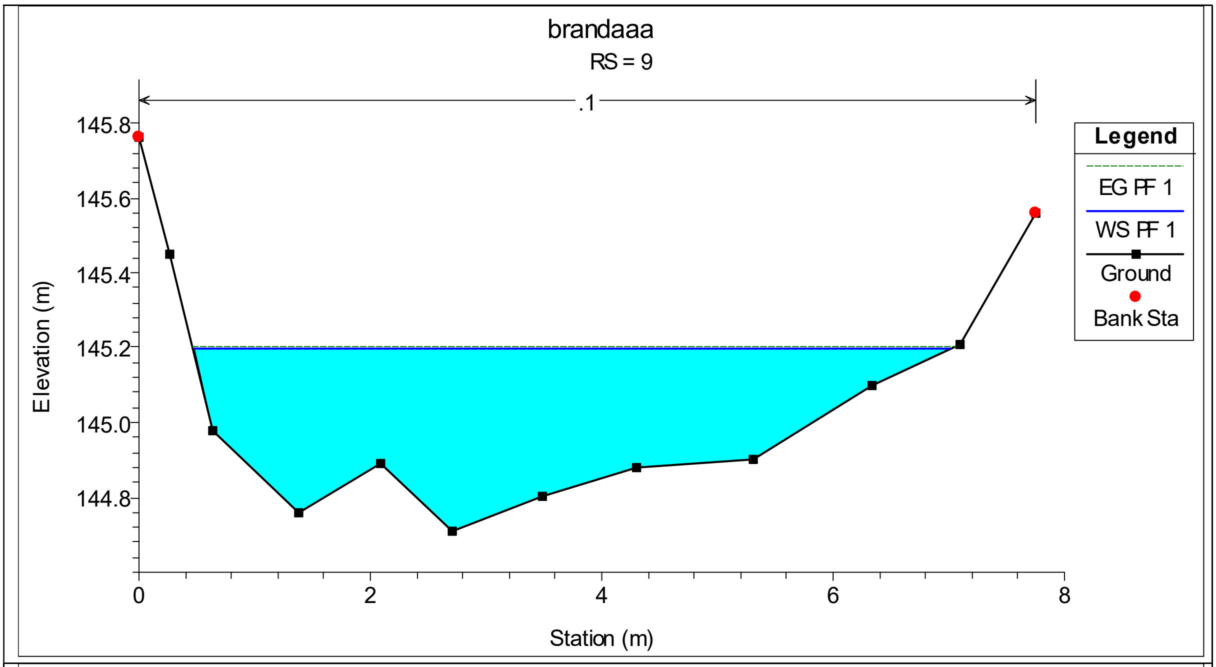

brandaaa
RS = 4
.43
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
144.8
144.6
144.4
144.2
144.0
143.8
0
2
4
6
8
10
12
14
Station (m)

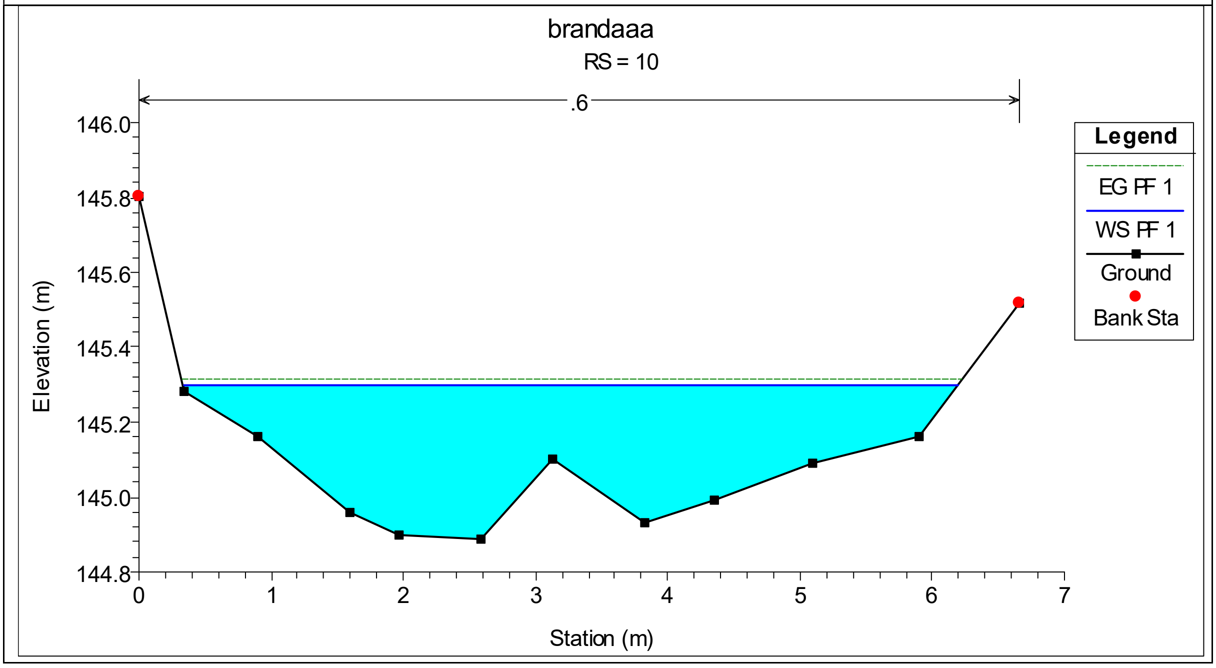

brandaaa
RS = 5
.16
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
145.2
145.0
144.8
144.6
144.4
144.2
144.0
0
2
4
6
8
10
12
14
Station (m)

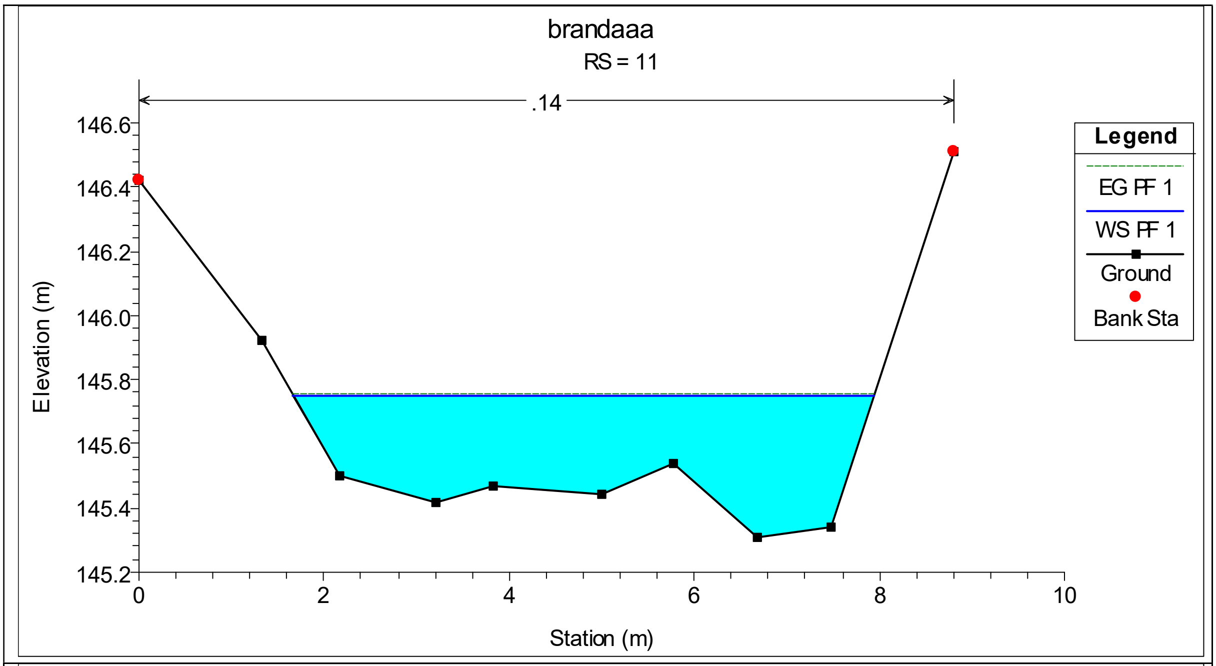

brandaaa
RS = 6
.13
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
145.2
145.0
144.8
144.6
144.4
144.2
144.0
0
2
4
6
8
10
12
Station (m)

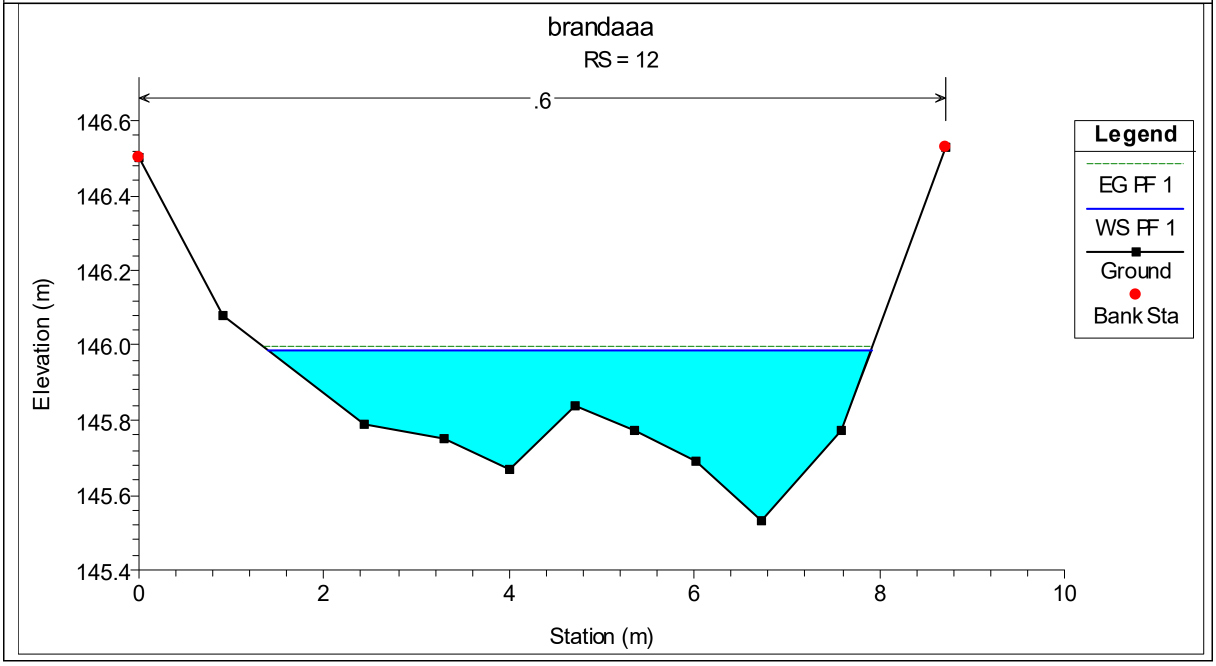

brandaaa
RS = 7
.65
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
145.4
145.2
145.0
144.8
144.6
144.4
144.2
0
2
4
6
8
10
Station (m)

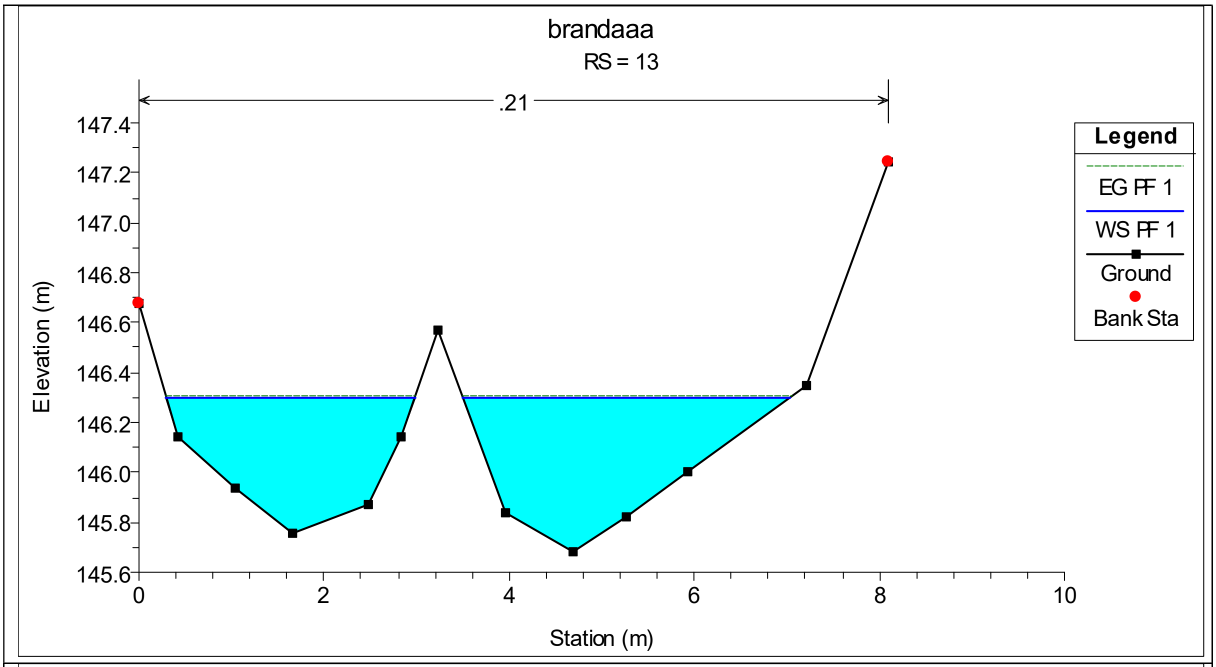

brandaaa
RS = 8
.59
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
145.6
145.4
145.2
145.0
144.8
144.6
144.4
144.2
0
2
4
6
8
Station (m)

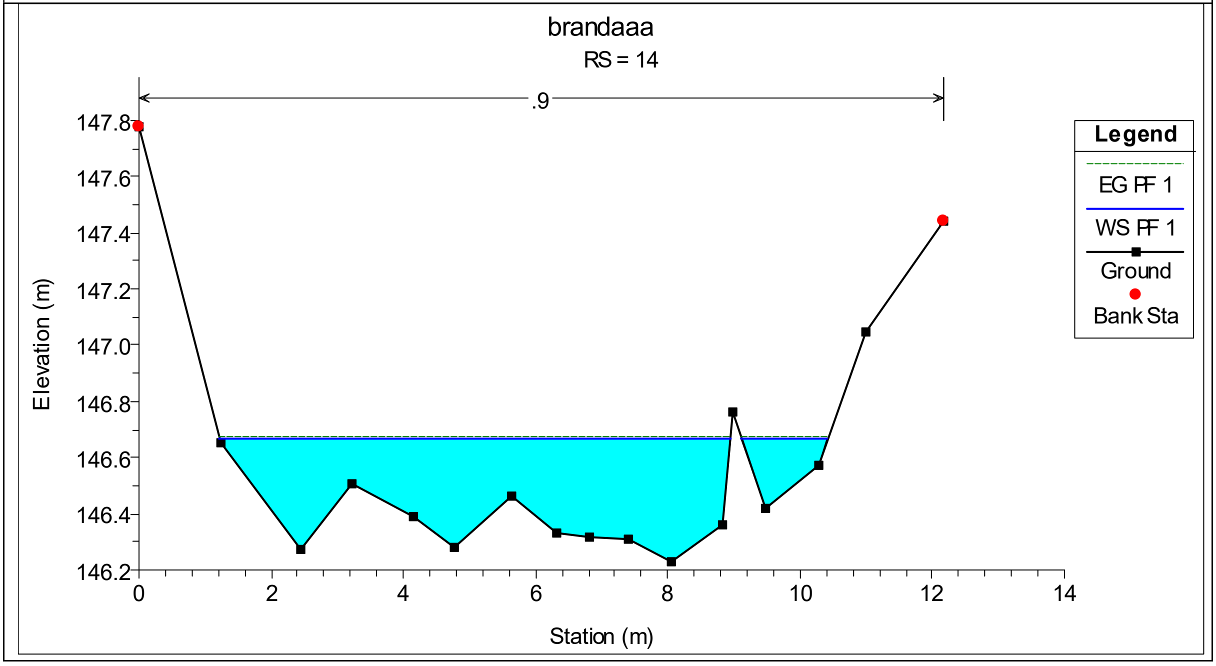

brandaaa
RS = 9
.1
Elevation (m)
145.8
145.6
145.4
145.2
145.0
144.8
0
2
4
6
8
Station (m)
Legend
EG PF 1
WS PF 1
Ground
Bank Sta

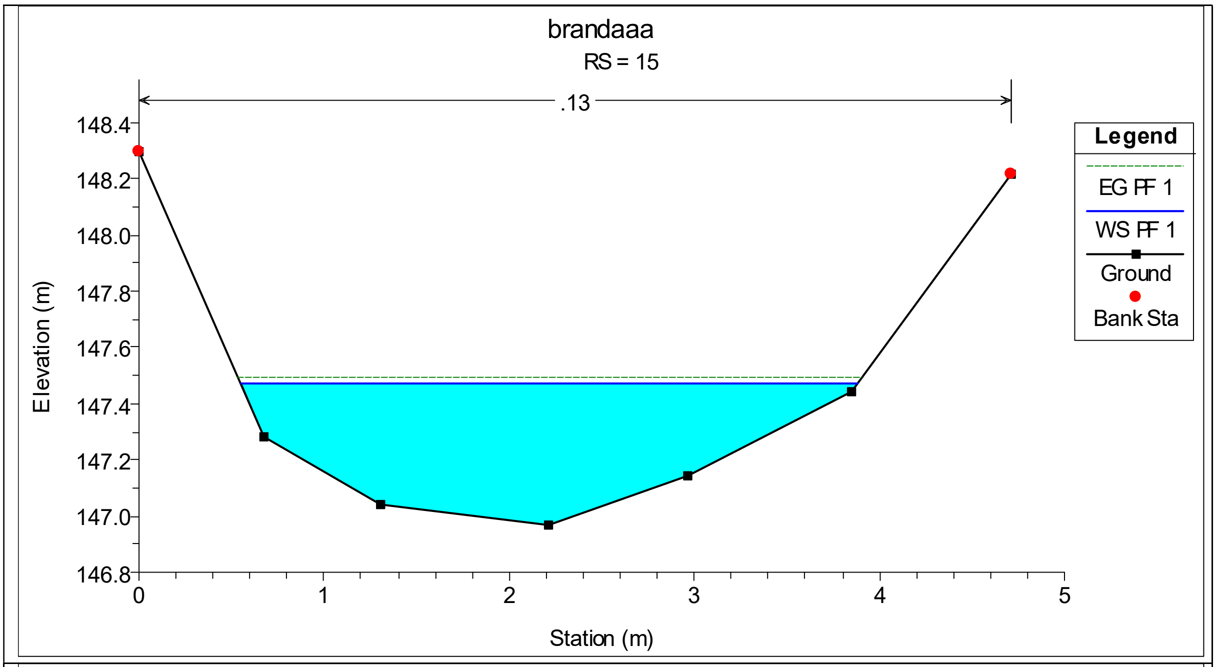

brandaaa
RS = 10
.6
Elevation (m)
146.0
145.8
145.6
145.4
145.2
145.0
144.8
0
1
2
3
4
5
6
7
Station (m)
Legend
EG PF 1
WS PF 1
Ground
Bank Sta

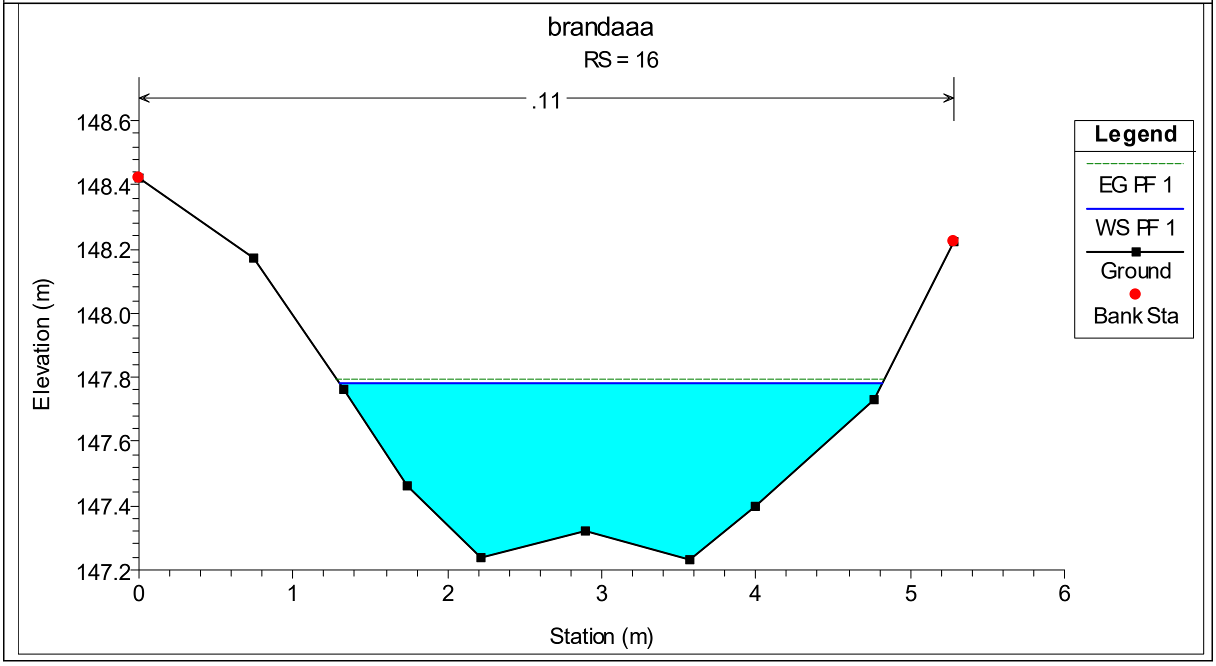

brandaaa
RS = 11
.14
Elevation (m)
146.6
146.4
146.2
146.0
145.8
145.6
145.4
145.2
0
2
4
6
8
10
Station (m)
Legend
EG PF 1
WS PF 1
Ground
Bank Sta

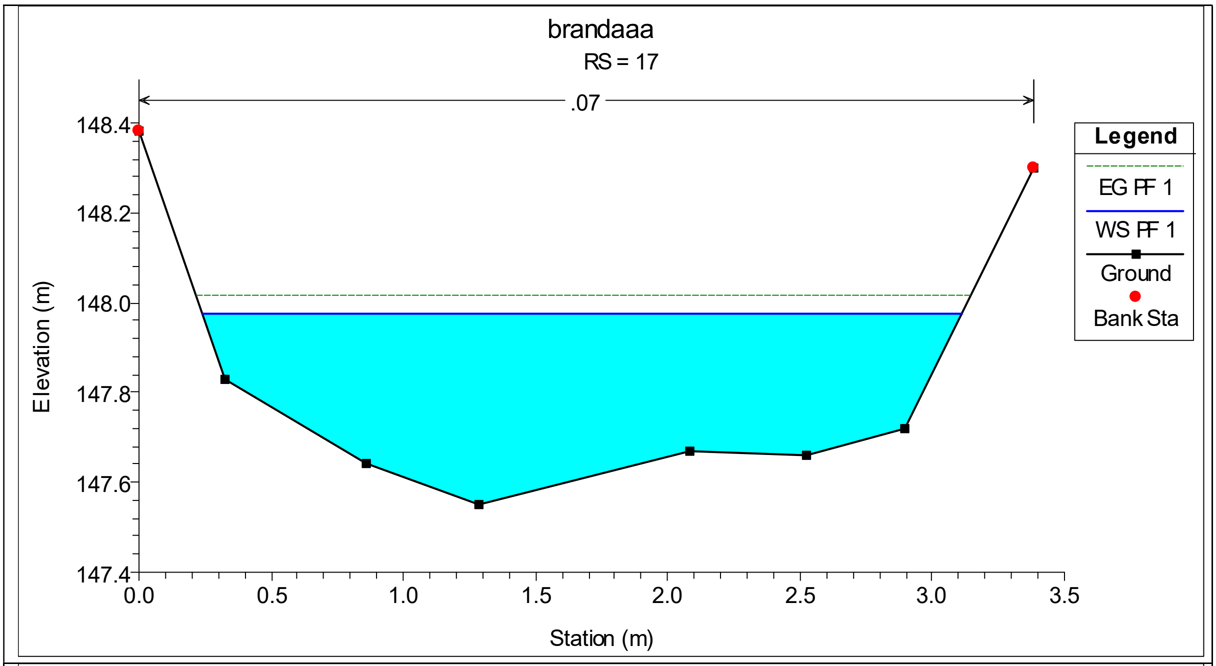

brandaaa
RS = 12
.6
Elevation (m)
146.6
146.4
146.2
146.0
145.8
145.6
145.4
0
2
4
6
8
10
Station (m)
Legend
EG PF 1
WS PF 1
Ground
Bank Sta

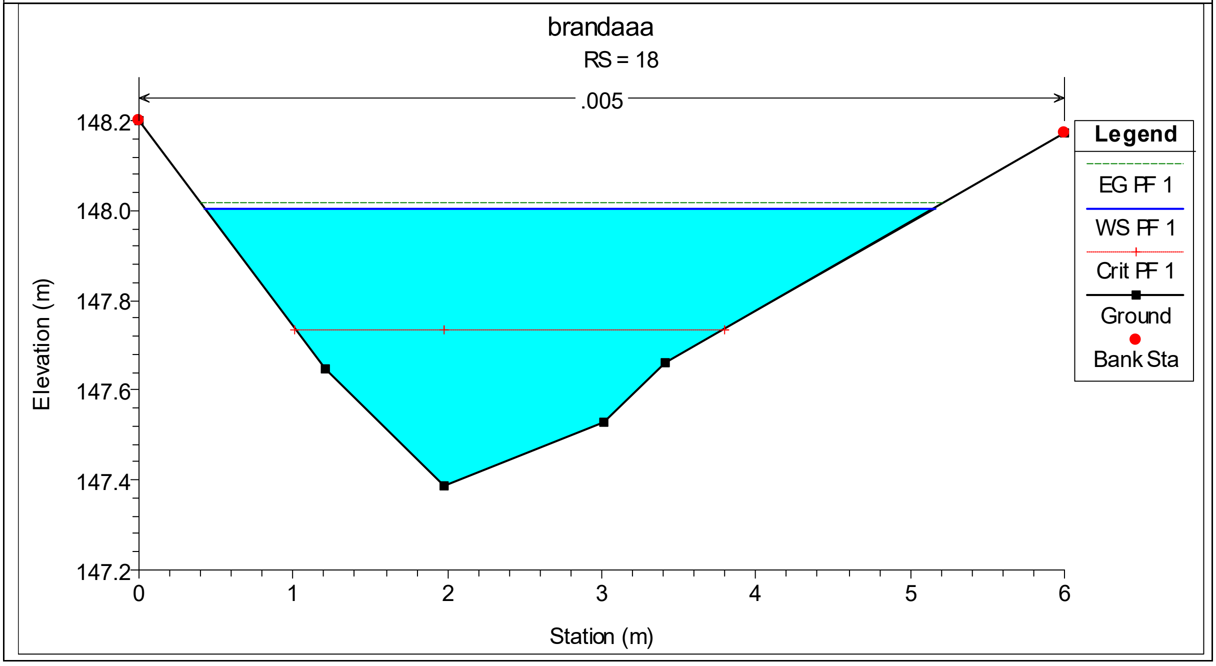

brandaaa
RS = 13
.21
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
147.4
147.2
147.0
146.8
146.6
146.4
146.2
146.0
145.8
145.6
0
2
4
6
8
10
Station (m)


brandaaa
RS = 14
.9
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
147.8
147.6
147.4
147.2
147.0
146.8
146.6
146.4
146.2
0
2
4
6
8
10
12
14
Station (m)

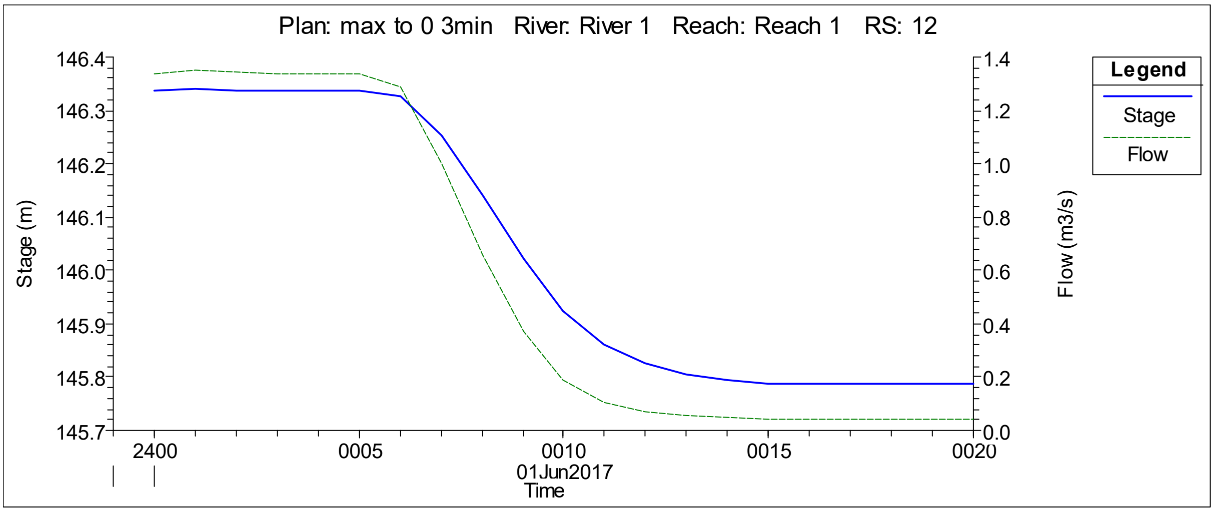

brandaaa
RS = 15
.13
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
148.4
148.2
148.0
147.8
147.6
147.4
147.2
147.0
146.8
0
1
2
3
4
5
Station (m)

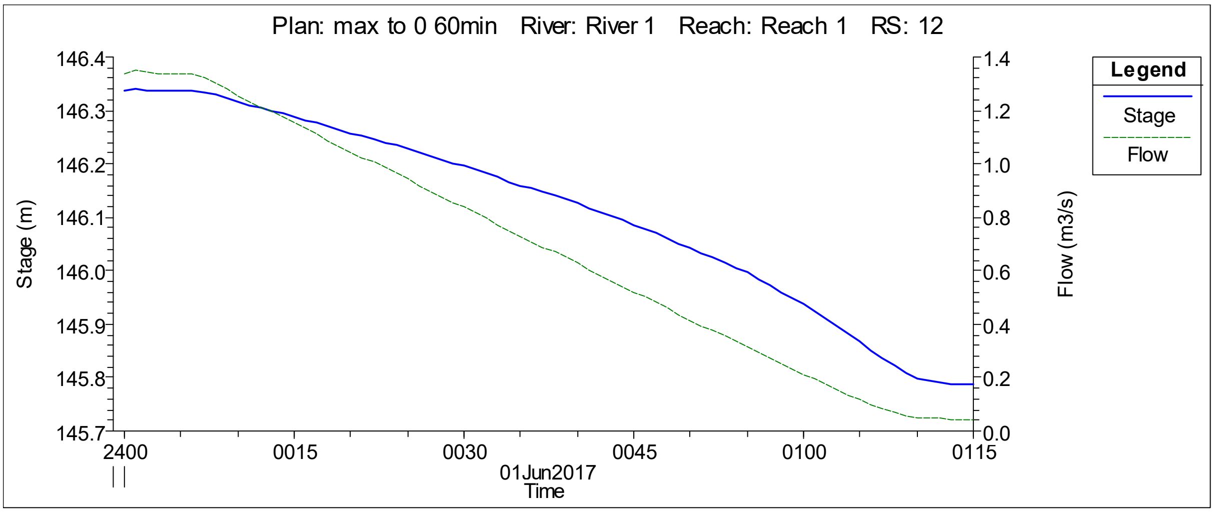

brandaaa
RS = 16
.11
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
148.6
148.4
148.2
148.0
147.8
147.6
147.4
147.2
0
1
2
3
4
5
6
Station (m)

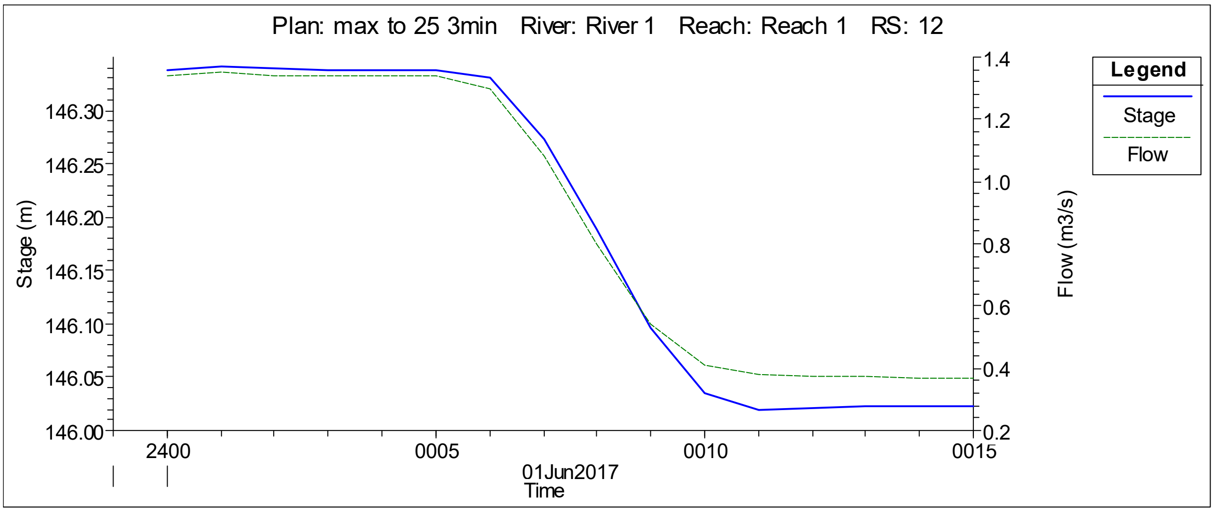

brandaaa
RS = 17
.07
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
Elevation (m)
148.4
148.2
148.0
147.8
147.6
147.4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Station (m)

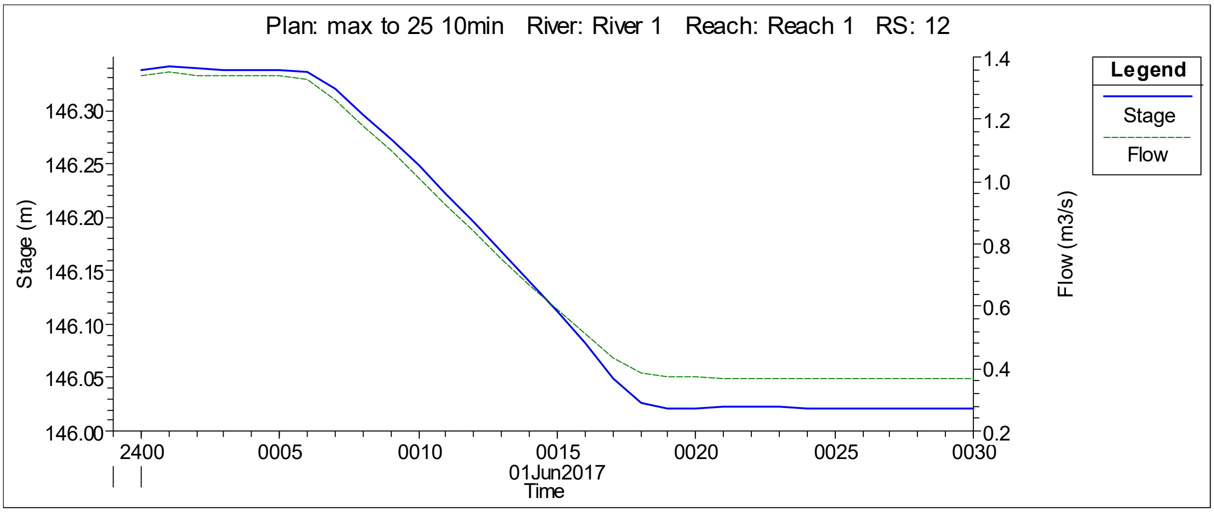

brandaaa
RS = 18
.005
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
Bank Sta
Elevation (m)
148.2
148.0
147.8
147.6
147.4
147.2
0
1
2
3
4
5
6
Station (m)

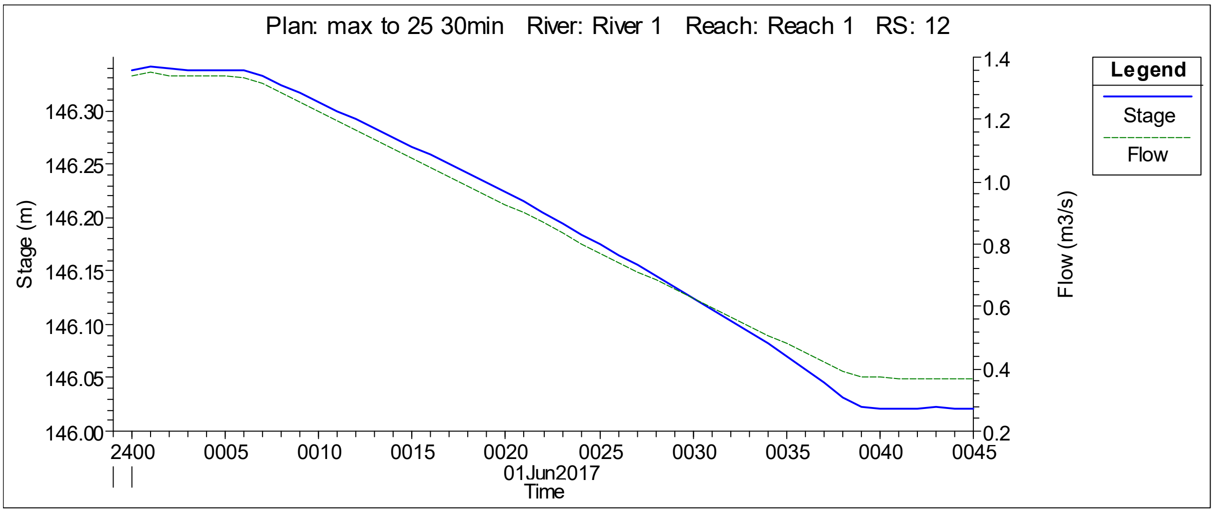
Modelling results

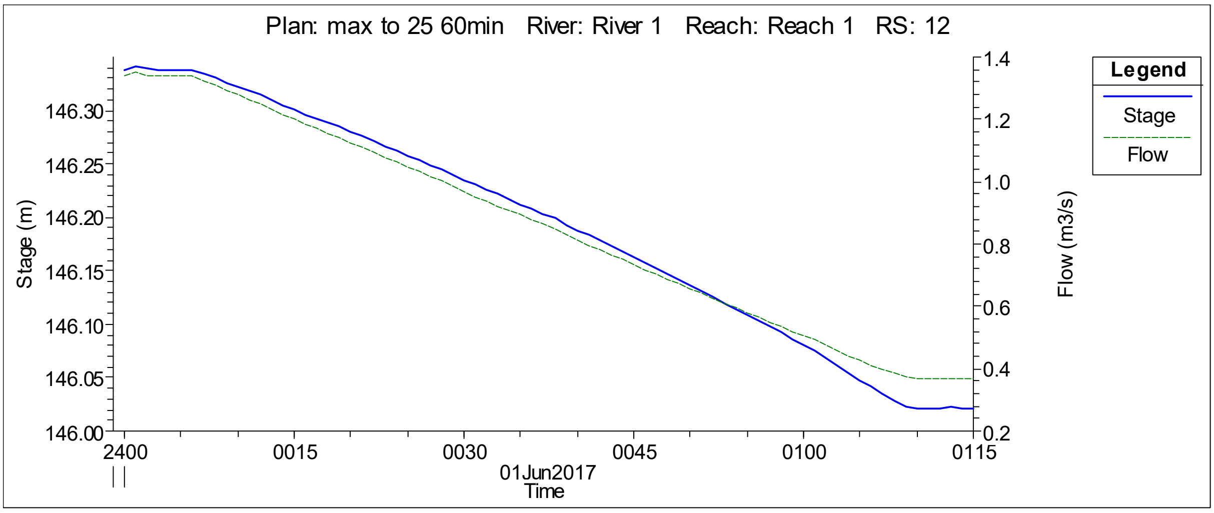


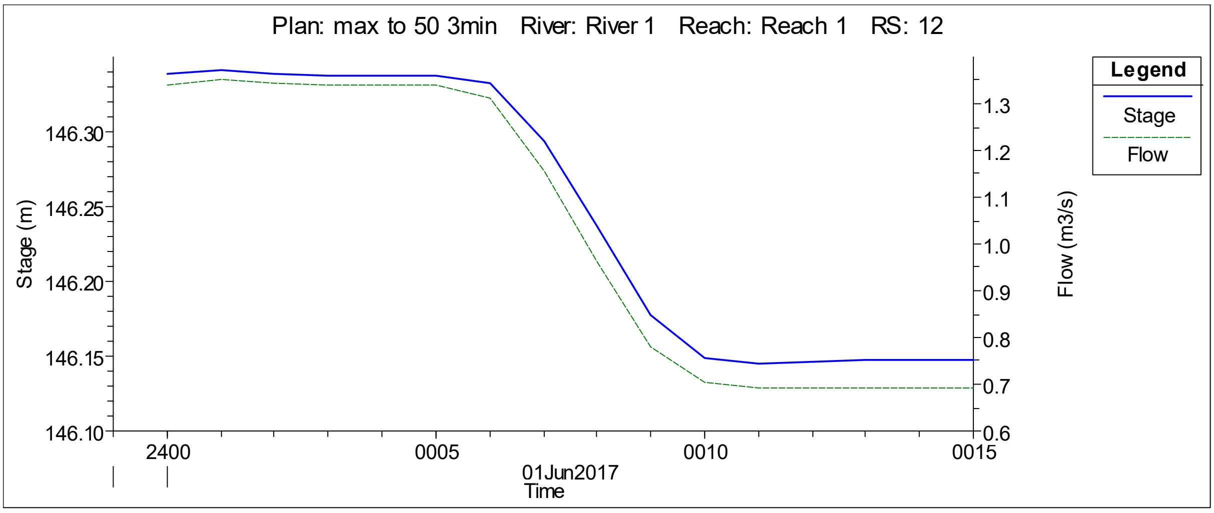


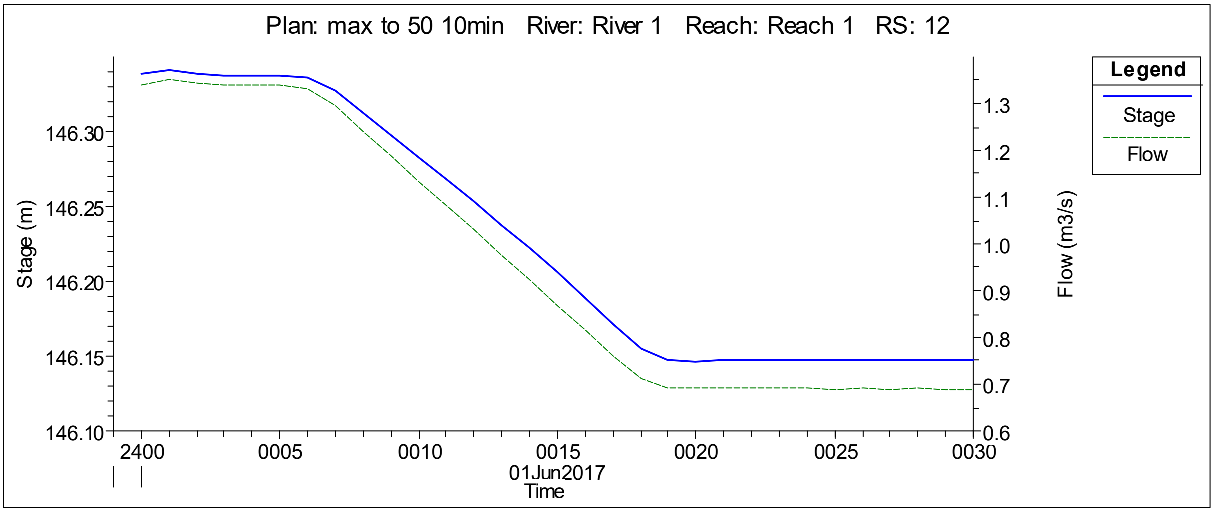


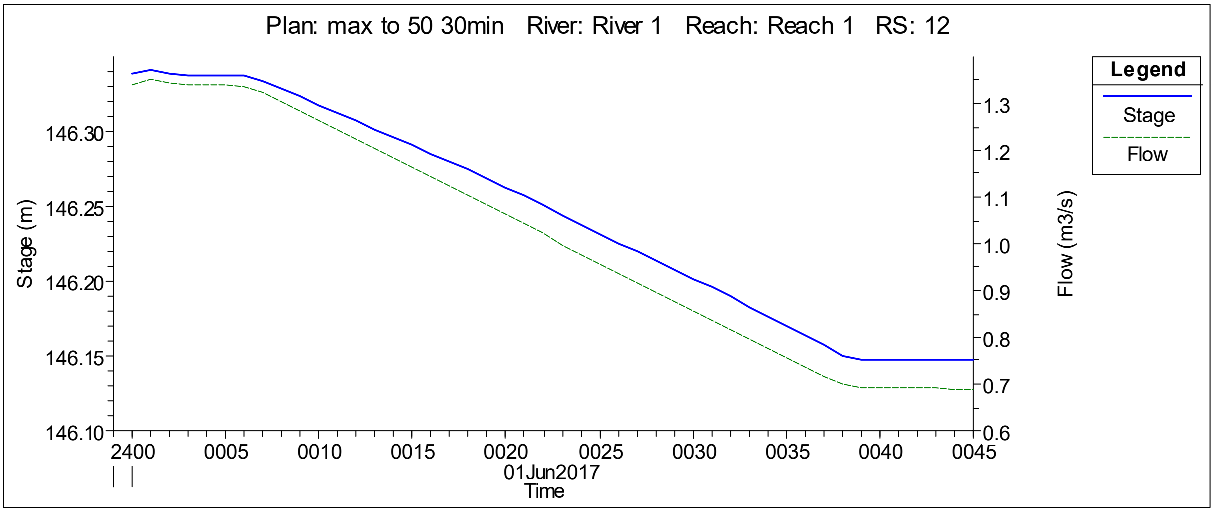

Plan: max to 25 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.30
146.25
146.20
146.15
146.10
146.05
146.00
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Flow (m3/s)
Legend
Stage
Flow

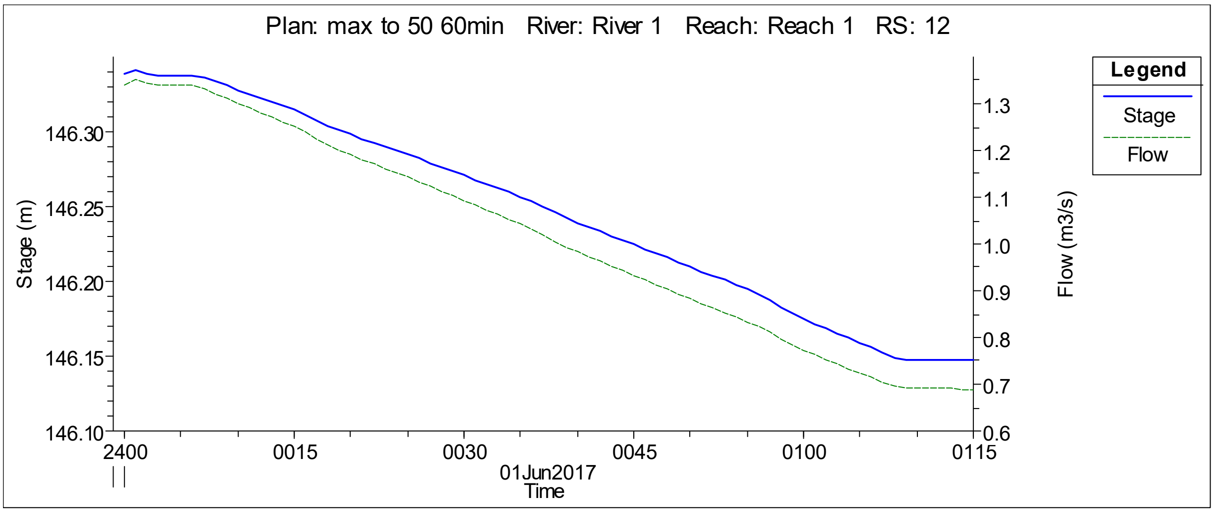

Plan: max to 25 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.30
146.25
146.20
146.15
146.10
146.05
146.00
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Flow (m3/s)
Legend
Stage
Flow

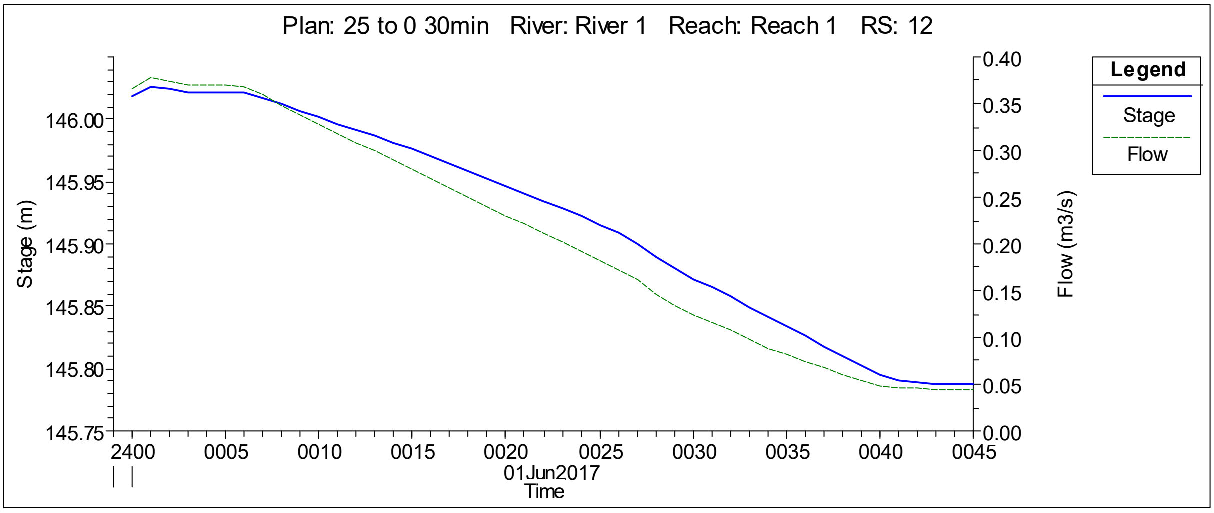

Plan: max to 25 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.30
146.25
146.20
146.15
146.10
146.05
146.00
2400
0015
0030
0045
0100
0115
01Jun2017
Time
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Flow (m3/s)
Legend
Stage
Flow

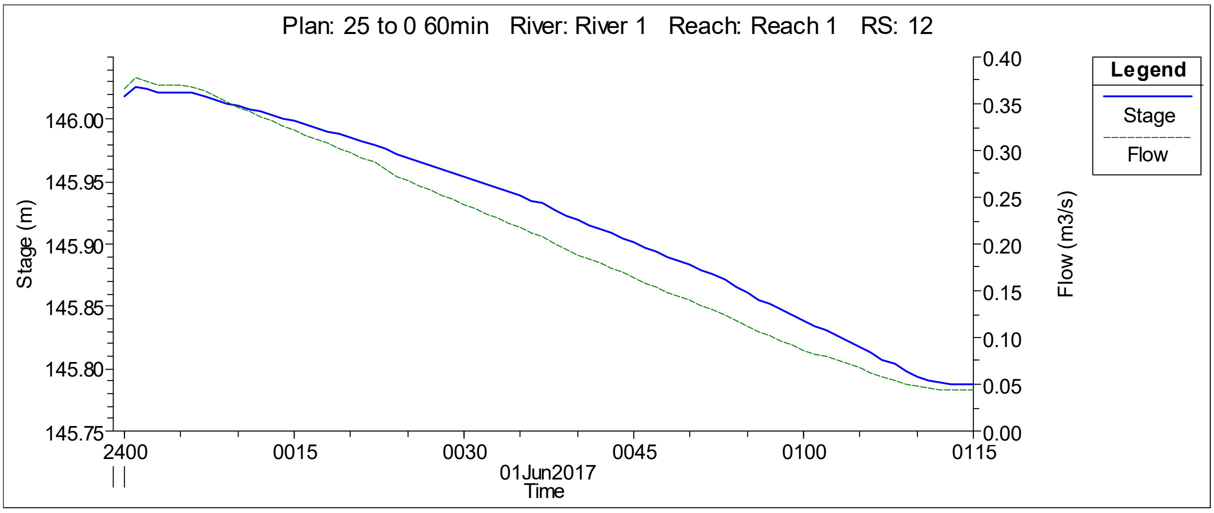

Plan: max to 50 3min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.30
146.25
146.20
146.15
146.10
Flow (m3/s)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

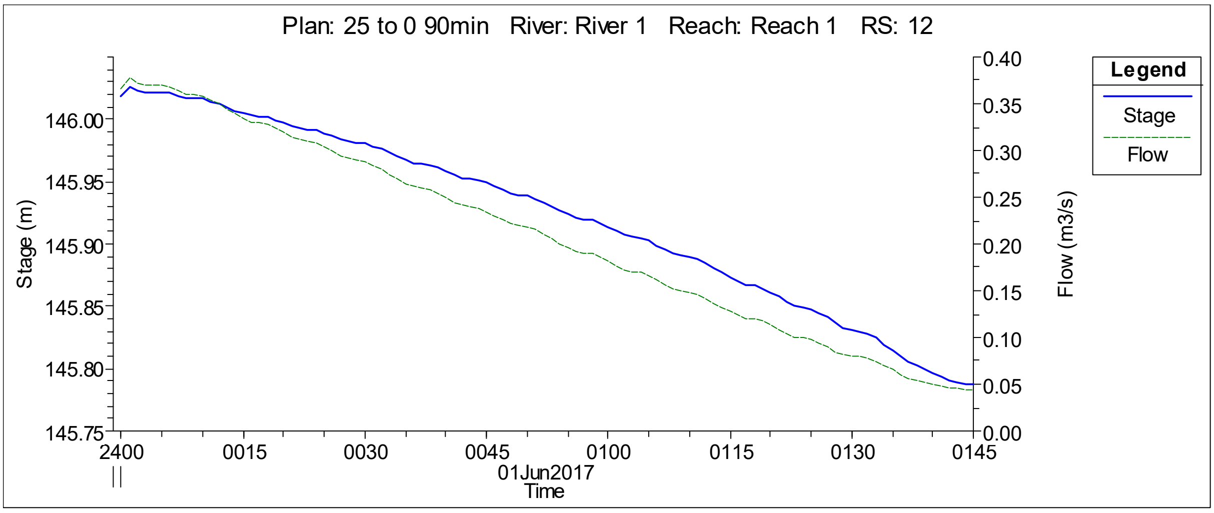

Plan: max to 50 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.30
146.25
146.20
146.15
146.10
Flow (m3/s)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

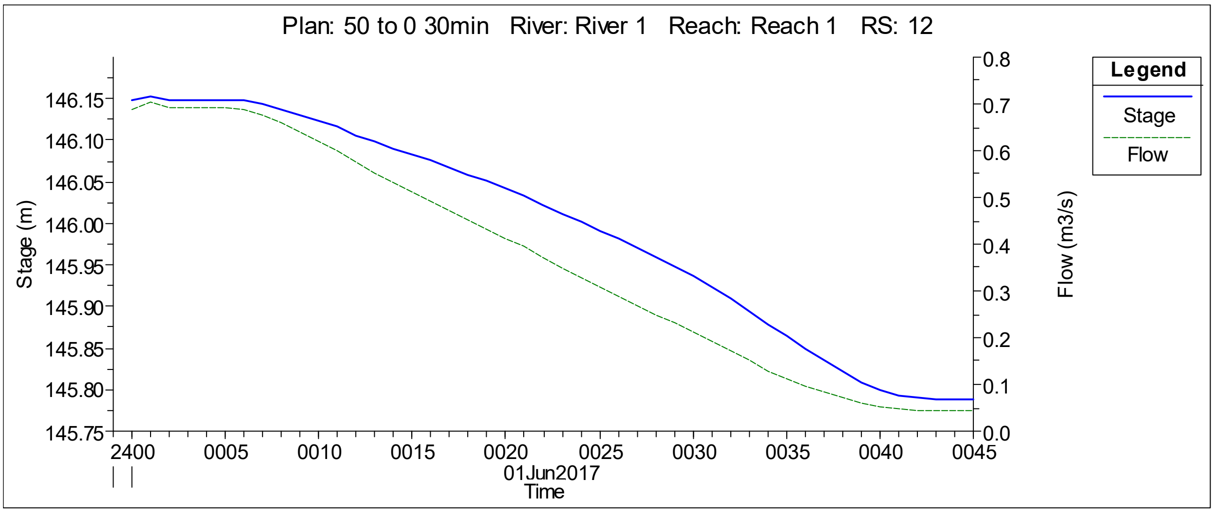

Plan: max to 50 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.30
146.25
146.20
146.15
146.10
Flow (m3/s)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

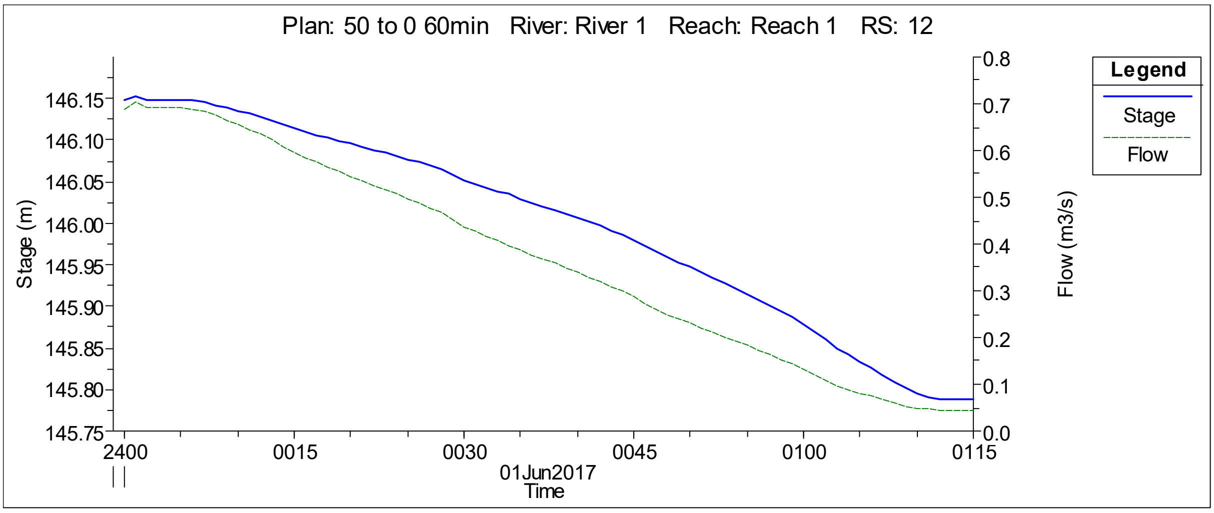

Plan: max to 50 60min River: River 1 Reach: Reach 1 RS: 12
Legend
Stage
Flow
Stage (m)
146.30
146.25
146.20
146.15
146.10
Flow (m3/s)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
2400
0015
0030
0045
0100
0115
01Jun2017
Time

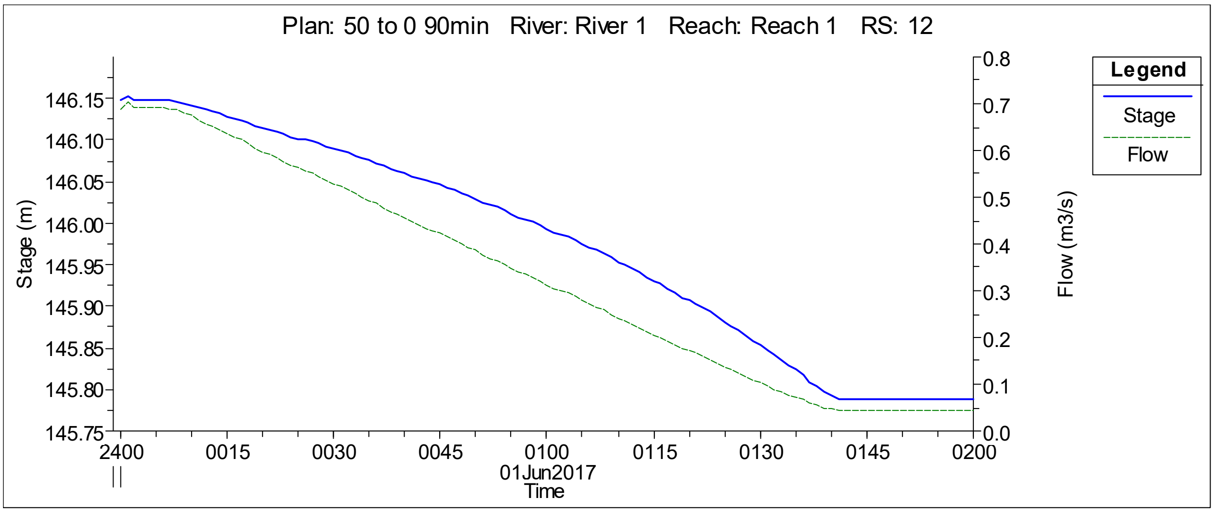

Plan: 25 to 0 30min River: River 1 Reach: Reach 1 RS: 12
Legend
Stage
Flow
Stage (m)
146.00
145.95
145.90
145.85
145.80
145.75
Flow (m3/s)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time

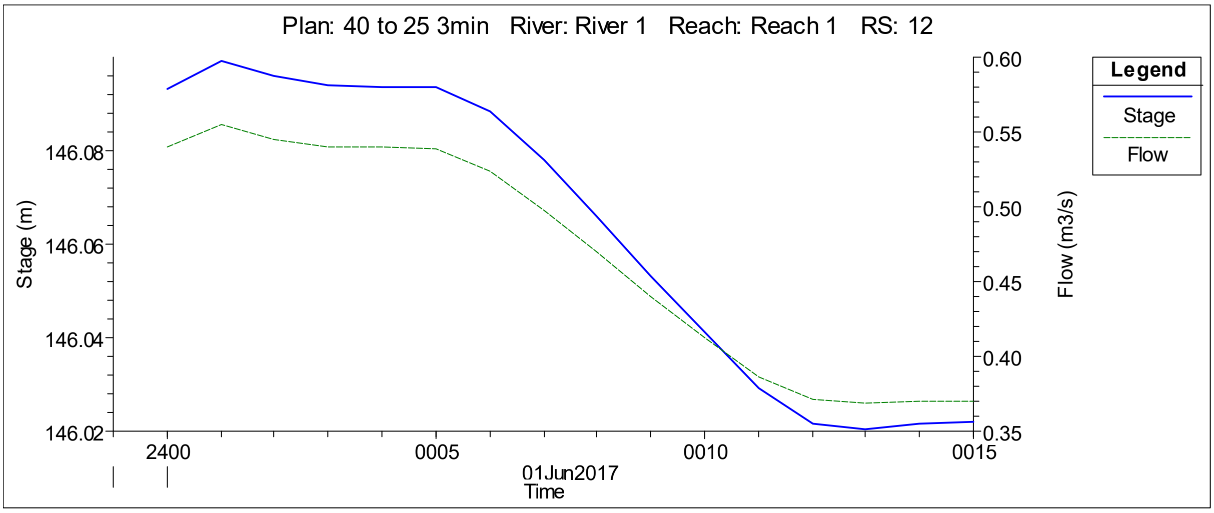

Plan: 25 to 0 60min River: River 1 Reach: Reach 1 RS: 12
Legend
Stage
Flow
Stage (m)
146.00
145.95
145.90
145.85
145.80
145.75
Flow (m3/s)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2400
0015
0030
0045
0100
0115
01Jun2017
Time

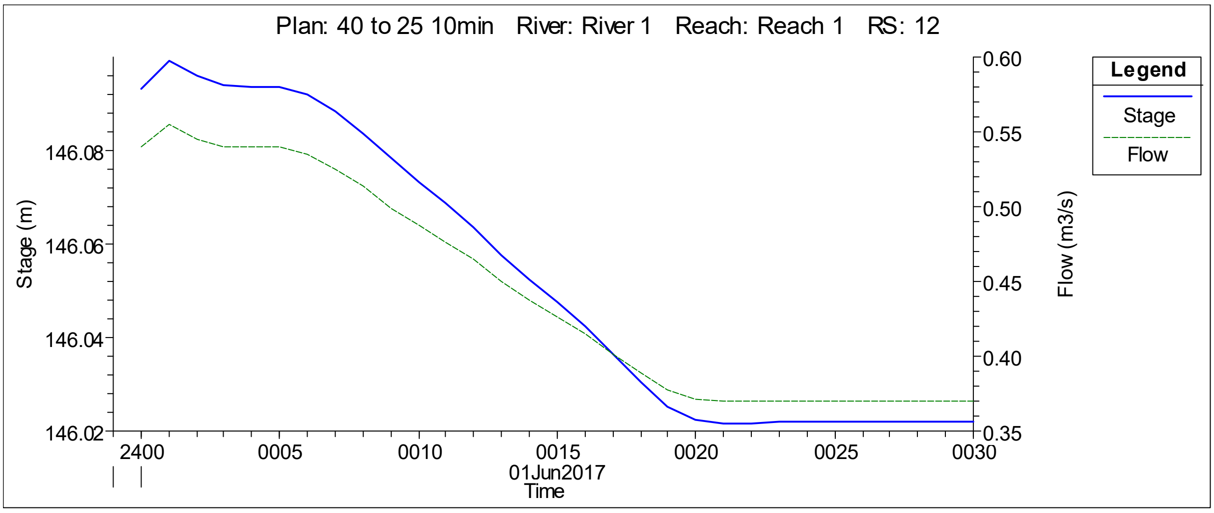

Plan: 25 to 0 90min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.00
145.95
145.90
145.85
145.80
145.75
Flow (m3/s)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2400
0015
0030
0045
0100
0115
0130
0145
01Jun2017
Time
Legend
Stage
Flow

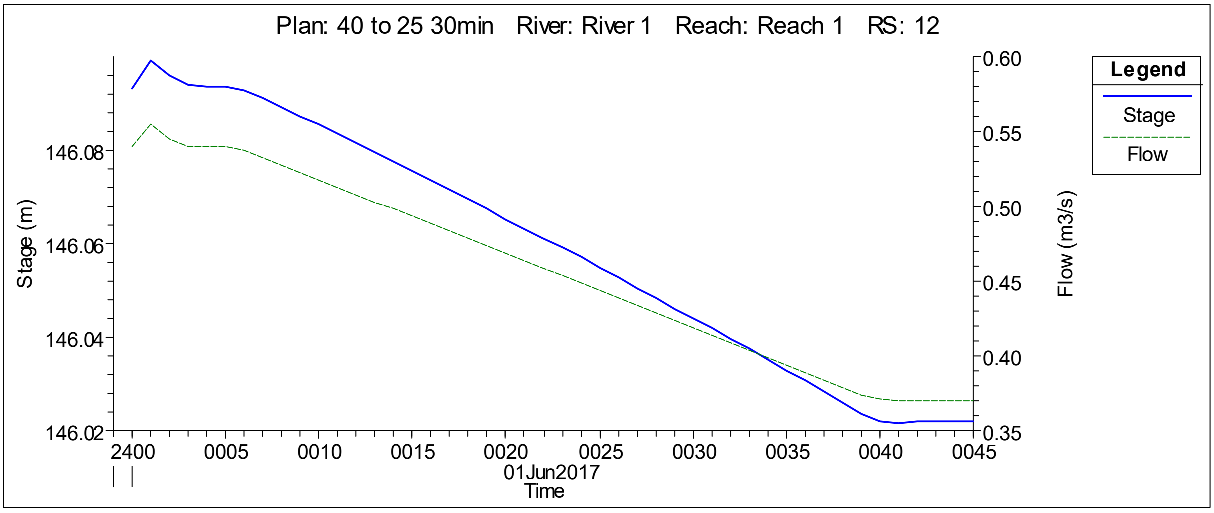

Plan: 50 to 0 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.15
146.10
146.05
146.00
145.95
145.90
145.85
145.80
145.75
Flow (m3/s)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

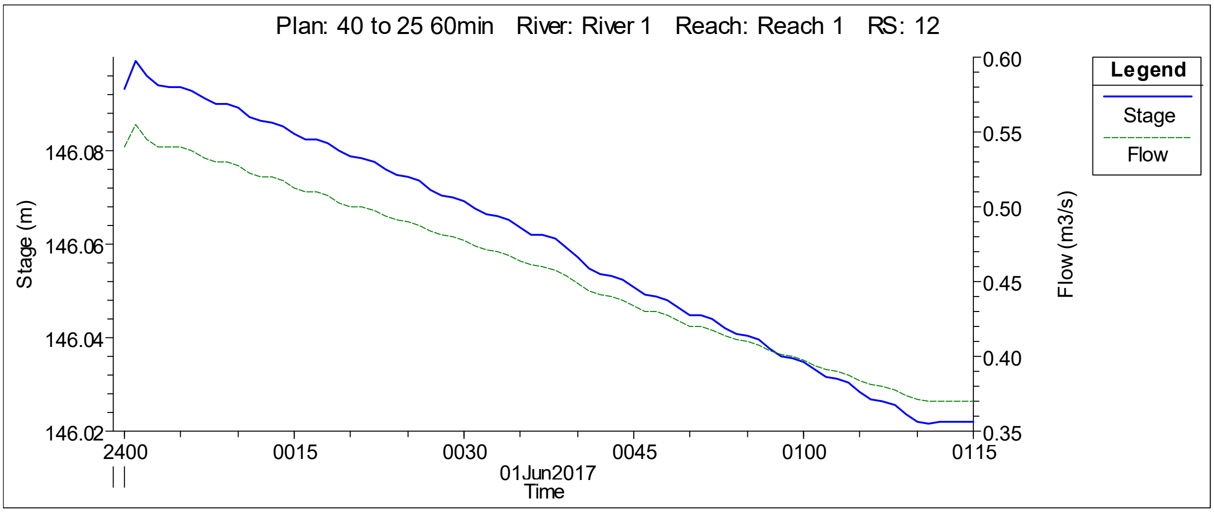

Plan: 50 to 0 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.15
146.10
146.05
146.00
145.95
145.90
145.85
145.80
145.75
Flow (m3/s)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow

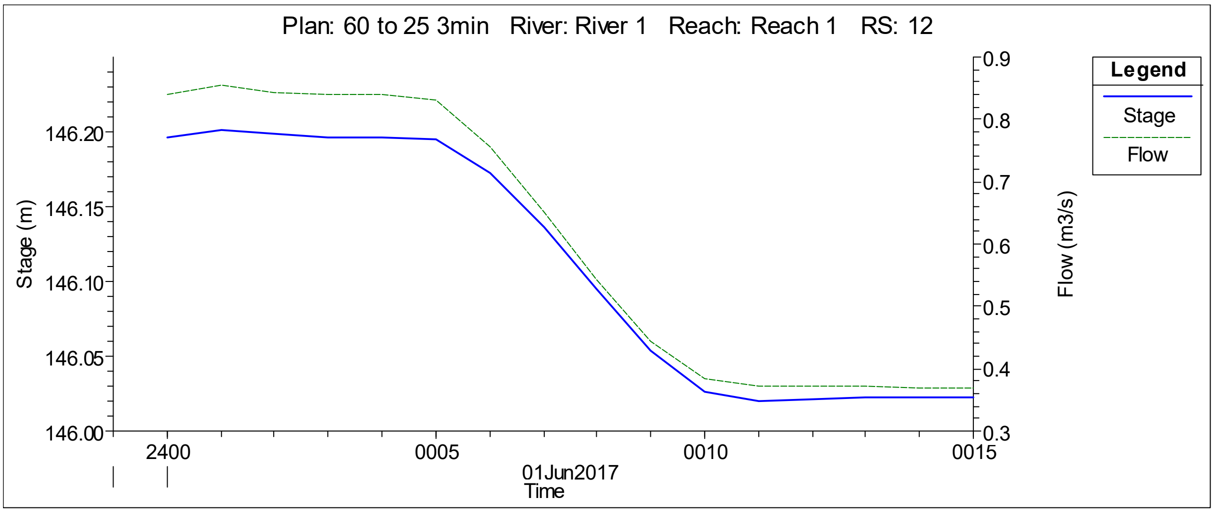

Plan: 50 to 0 90min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.15
146.10
146.05
146.00
145.95
145.90
145.85
145.80
145.75
Flow (m3/s)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2400
0015
0030
0045
0100
0115
0130
0145
0200
01Jun2017
Time
Legend
Stage
Flow

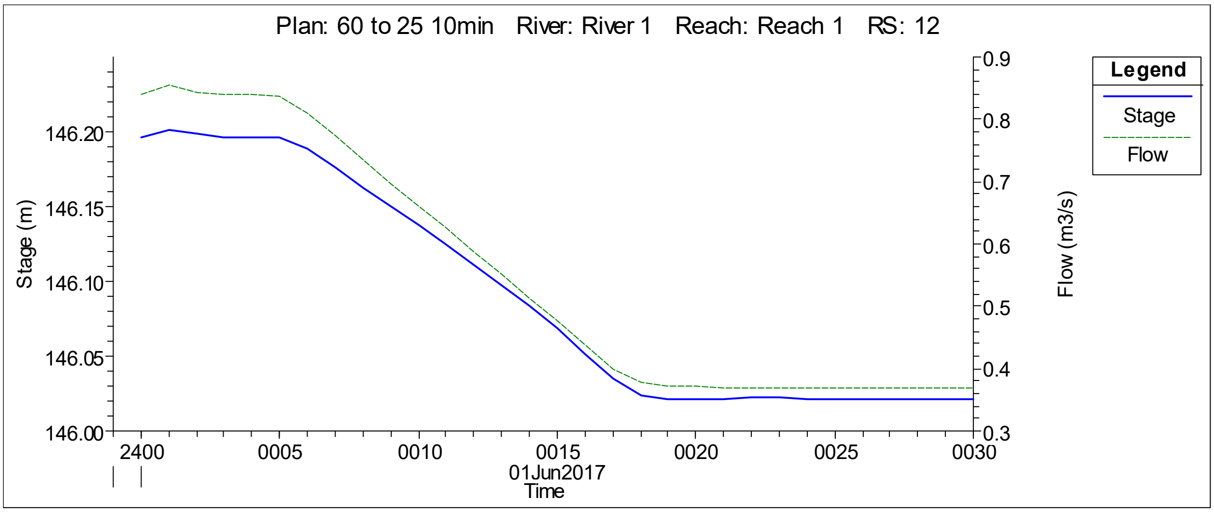

Plan: 40 to 25 3min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.08
146.06
146.04
146.02
Flow (m3/s)
0.60
0.55
0.50
0.45
0.40
0.35
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

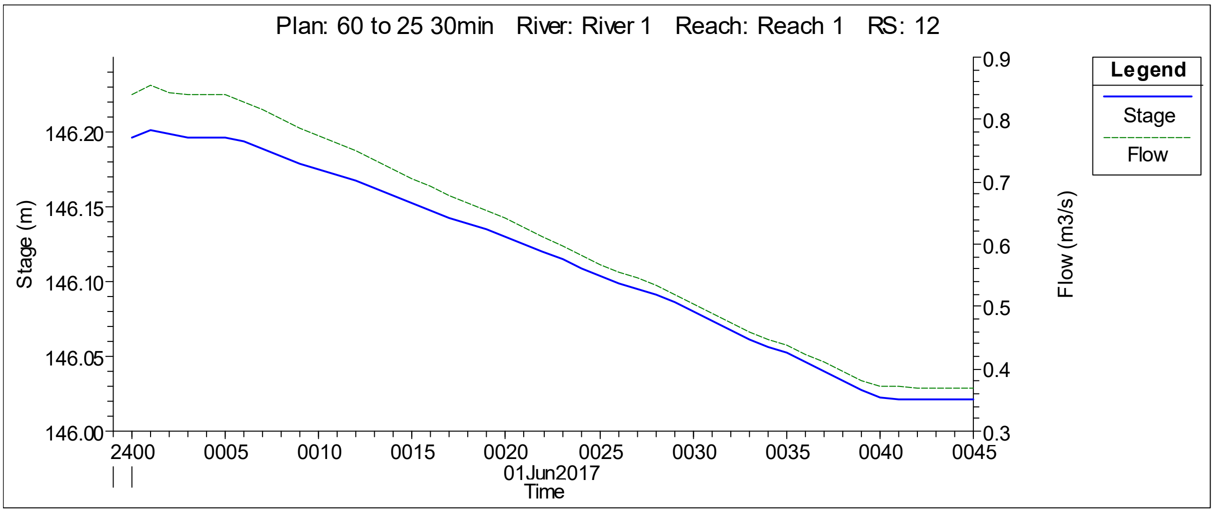

Plan: 40 to 25 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.08
146.06
146.04
146.02
Flow (m3/s)
0.60
0.55
0.50
0.45
0.40
0.35
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

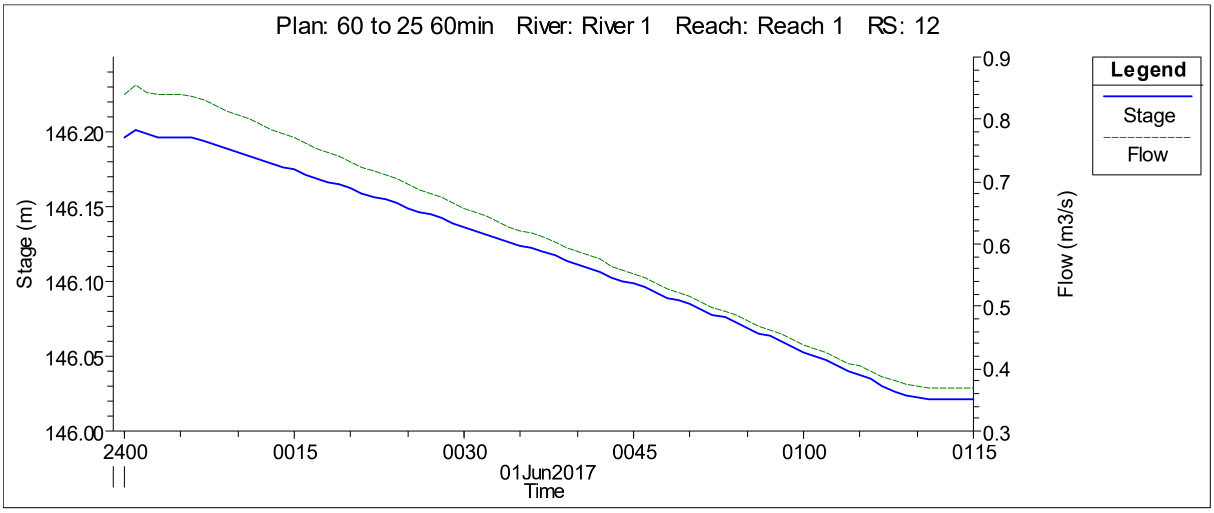

Plan: 40 to 25 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.08
146.06
146.04
146.02
Flow (m3/s)
0.60
0.55
0.50
0.45
0.40
0.35
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

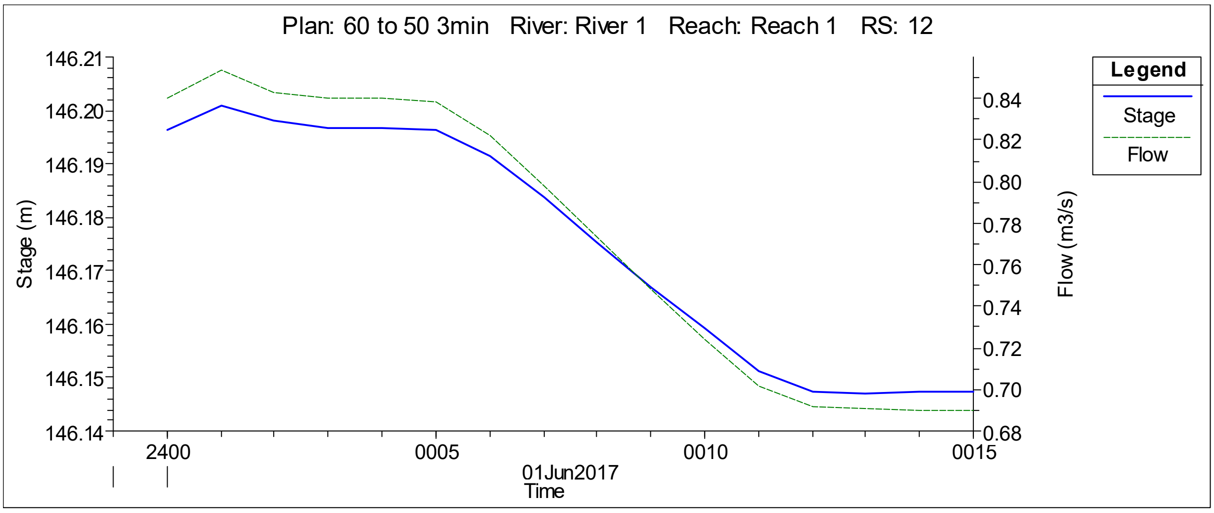

Plan: 40 to 25 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.08
146.06
146.04
146.02
Flow (m3/s)
0.60
0.55
0.50
0.45
0.40
0.35
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow

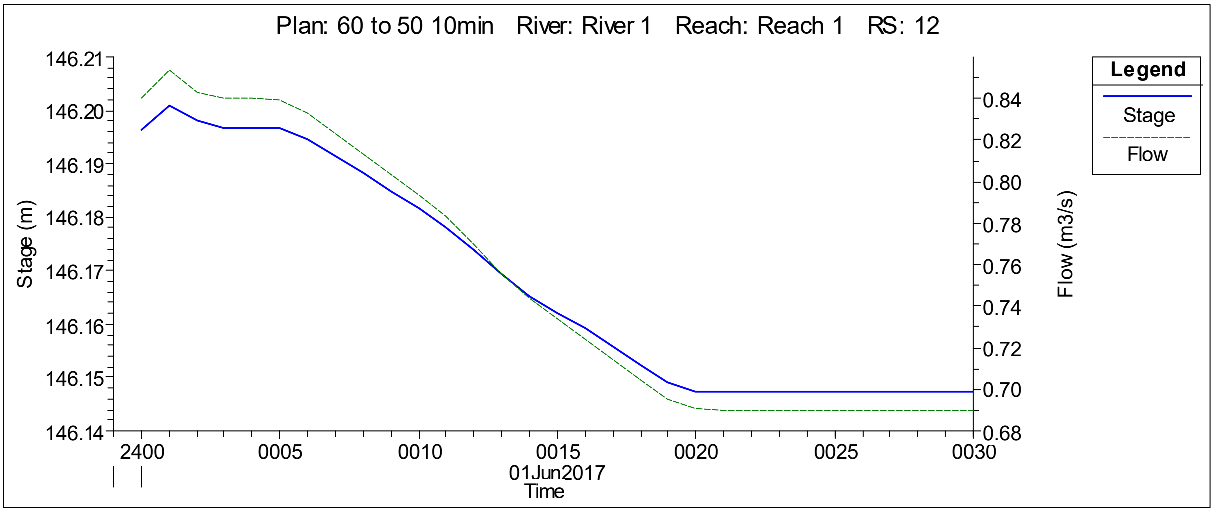

Plan: 60 to 25 3min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.20
146.15
146.10
146.05
146.00
Flow (m3/s)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

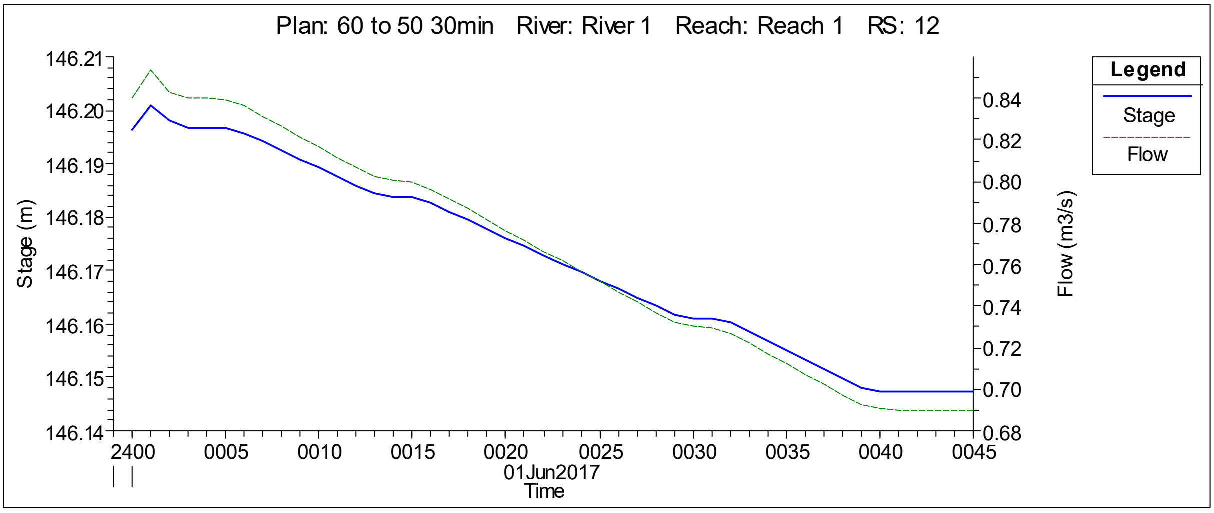

Plan: 60 to 25 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.20
146.15
146.10
146.05
146.00
Flow (m3/s)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

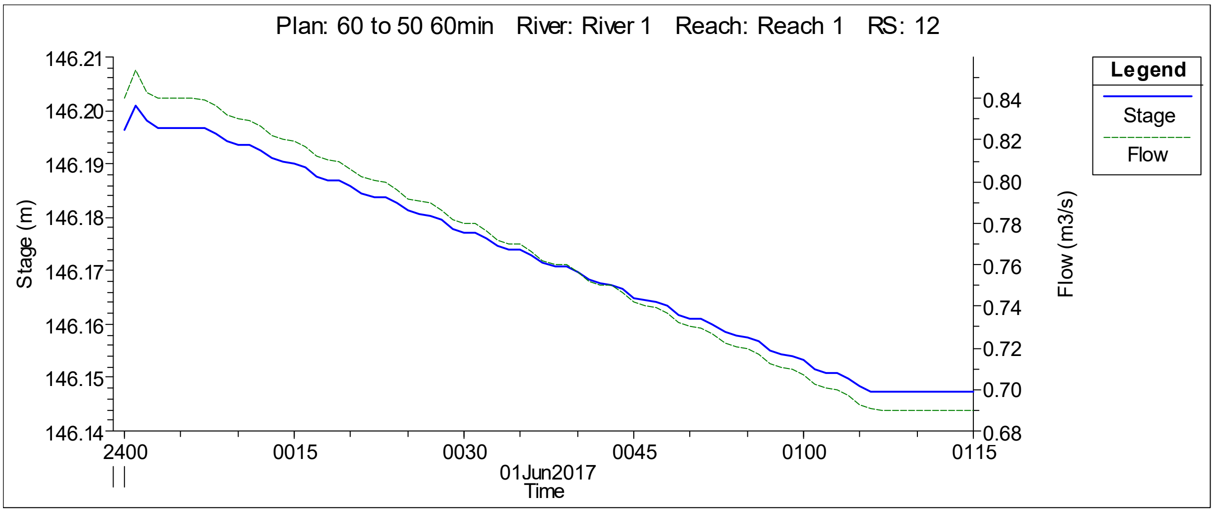

Plan: 60 to 25 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.20
146.15
146.10
146.05
146.00
Flow (m3/s)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

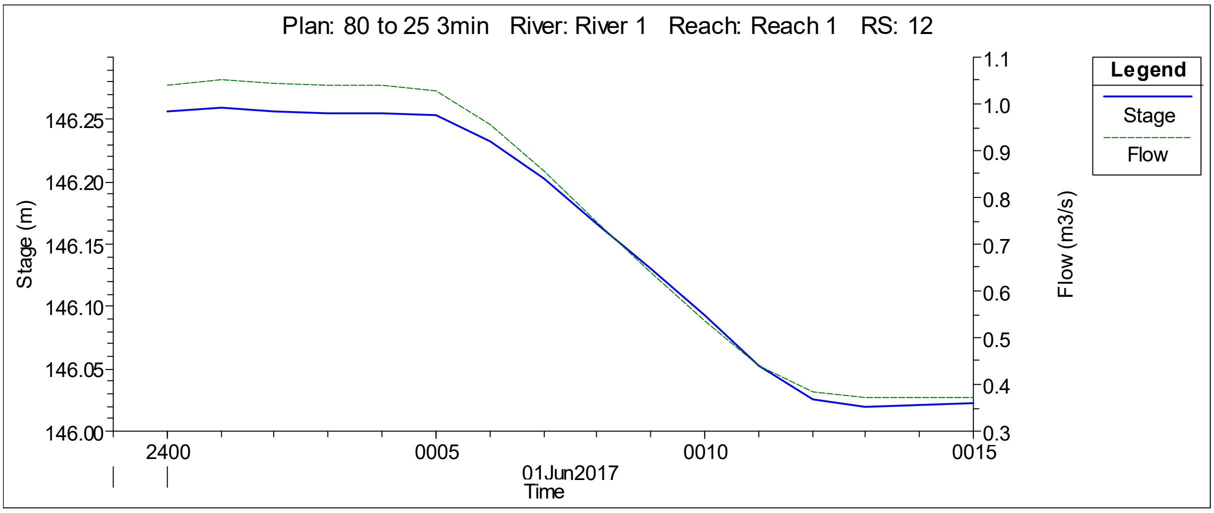

Plan: 60 to 25 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.20
146.15
146.10
146.05
146.00
Flow (m3/s)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow

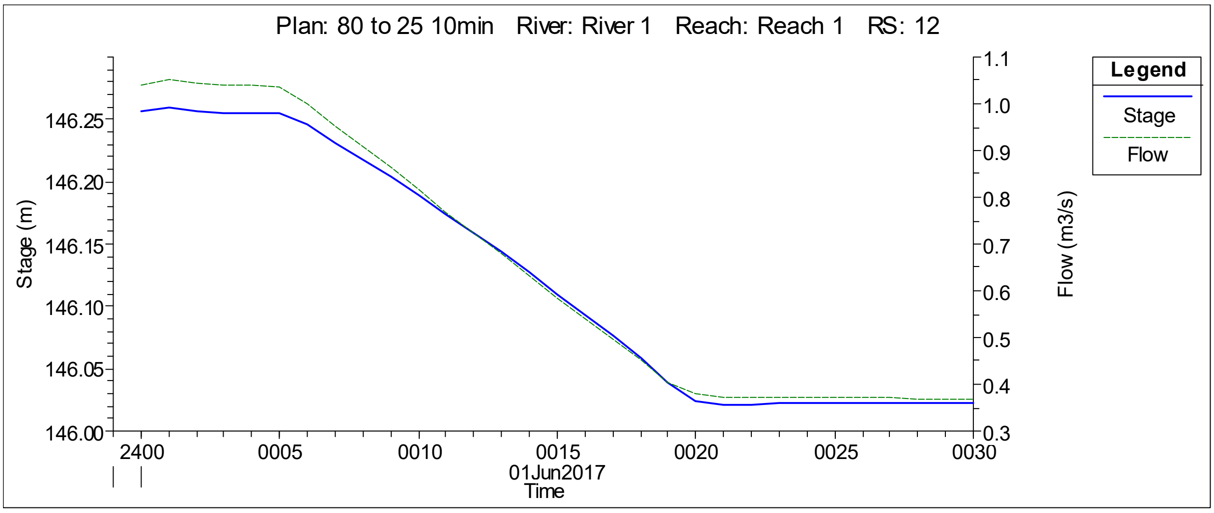

Plan: 60 to 50 3min River: River 1 Reach: Reach 1 RS: 12
146.21
146.20
146.19
146.18
146.17
146.16
146.15
146.14
Stage (m)
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
Flow (m3/s)
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

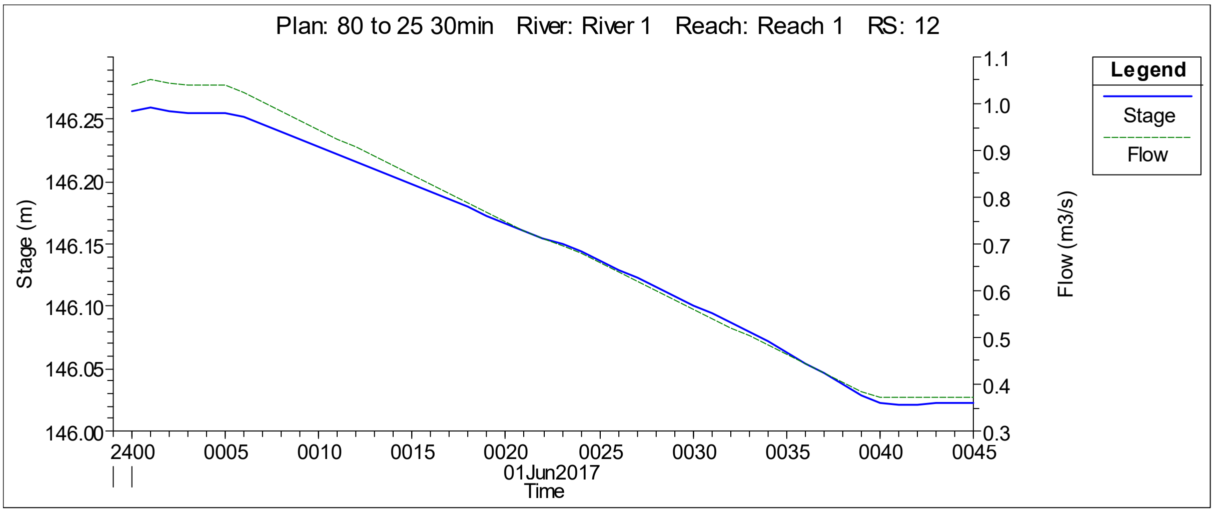

Plan: 60 to 50 10min River: River 1 Reach: Reach 1 RS: 12
146.21
146.20
146.19
146.18
146.17
146.16
146.15
146.14
Stage (m)
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
Flow (m3/s)
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

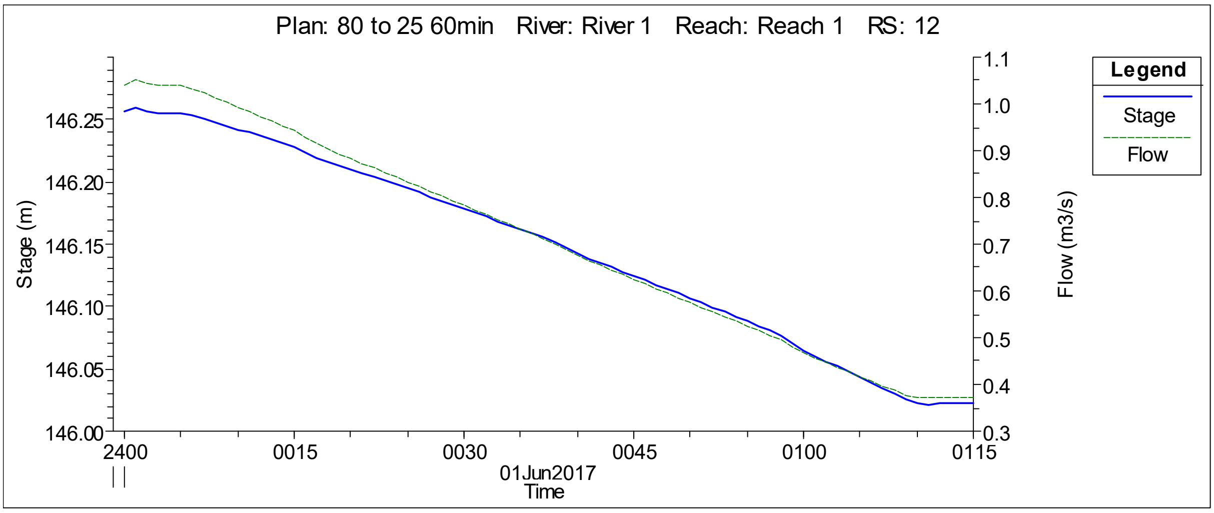

Plan: 60 to 50 30min River: River 1 Reach: Reach 1 RS: 12
146.21
146.20
146.19
146.18
146.17
146.16
146.15
146.14
Stage (m)
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
Flow (m3/s)
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

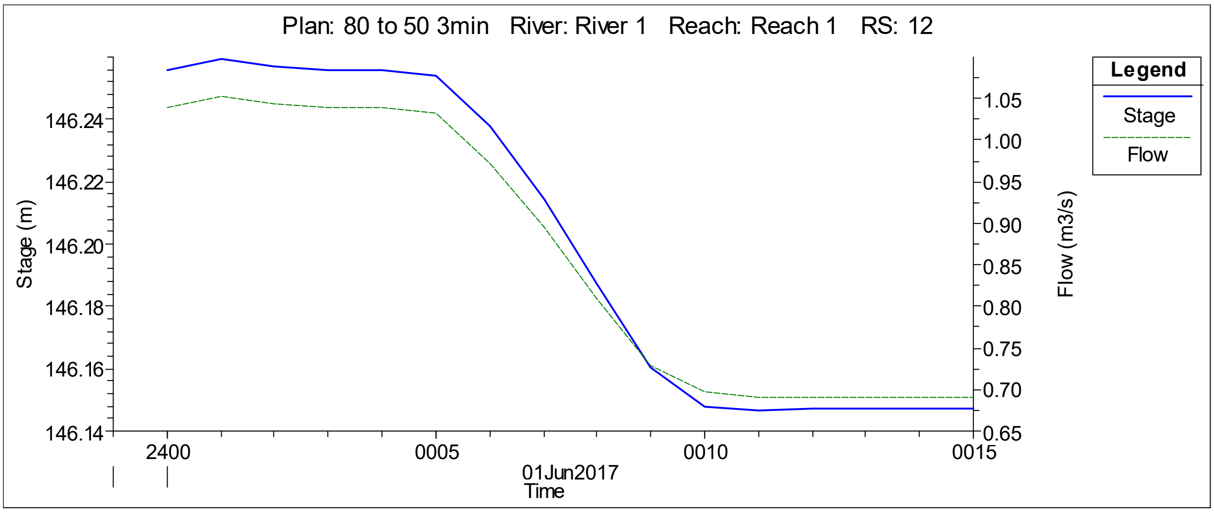

Plan: 60 to 50 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.21
146.20
146.19
146.18
146.17
146.16
146.15
146.14
Flow (m3/s)
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow

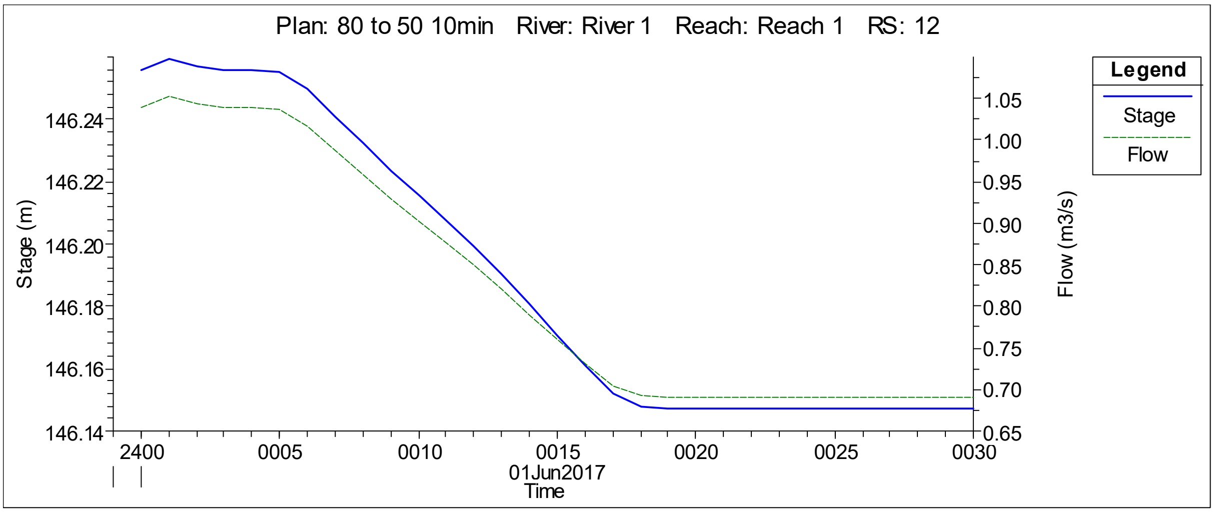

Plan: 80 to 25 3min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.25
146.20
146.15
146.10
146.05
146.00
Flow (m3/s)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

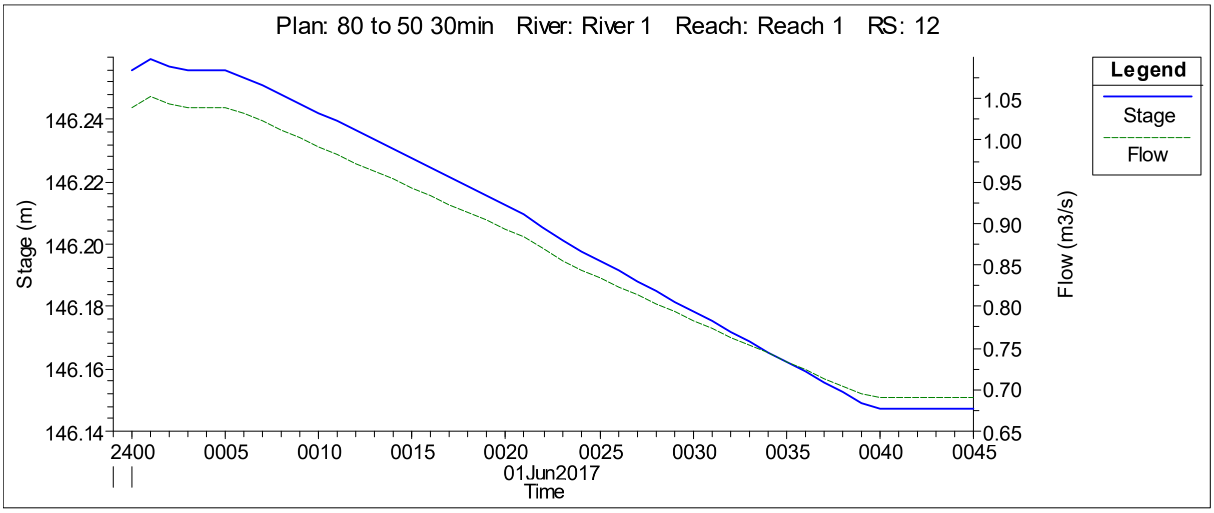

Plan: 80 to 25 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.25
146.20
146.15
146.10
146.05
146.00
Flow (m3/s)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

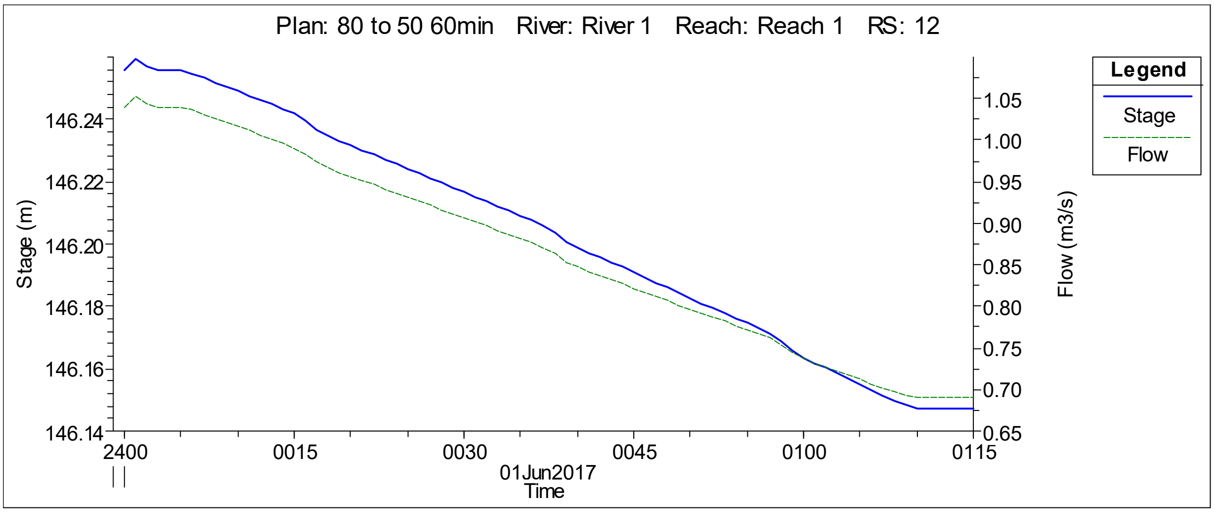

Plan: 80 to 25 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.00
146.05
146.10
146.15
146.20
146.25
Flow (m3/s)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

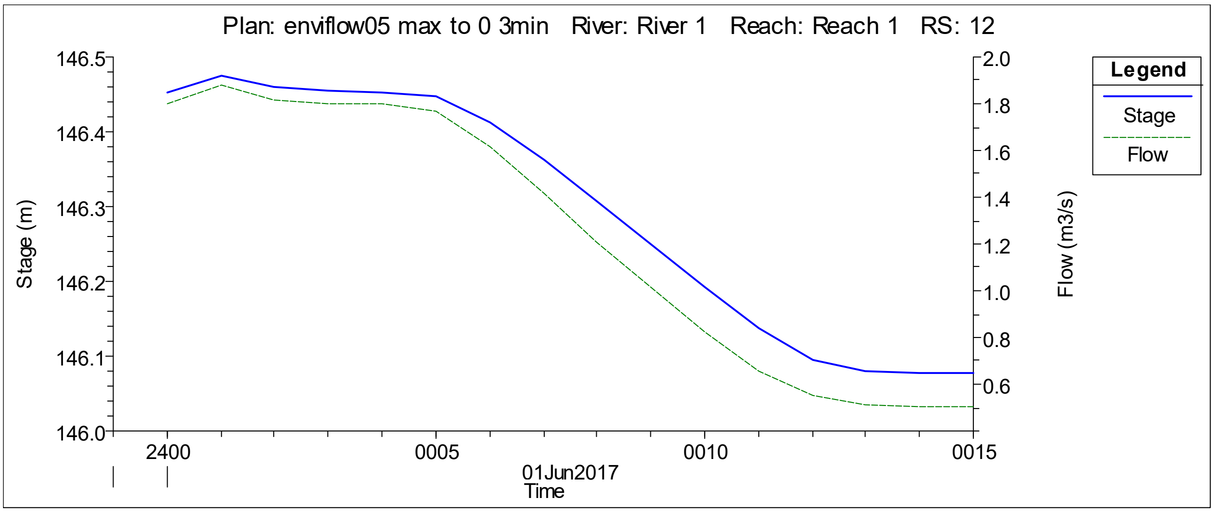

Plan: 80 to 25 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.00
146.05
146.10
146.15
146.20
146.25
Flow (m3/s)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow

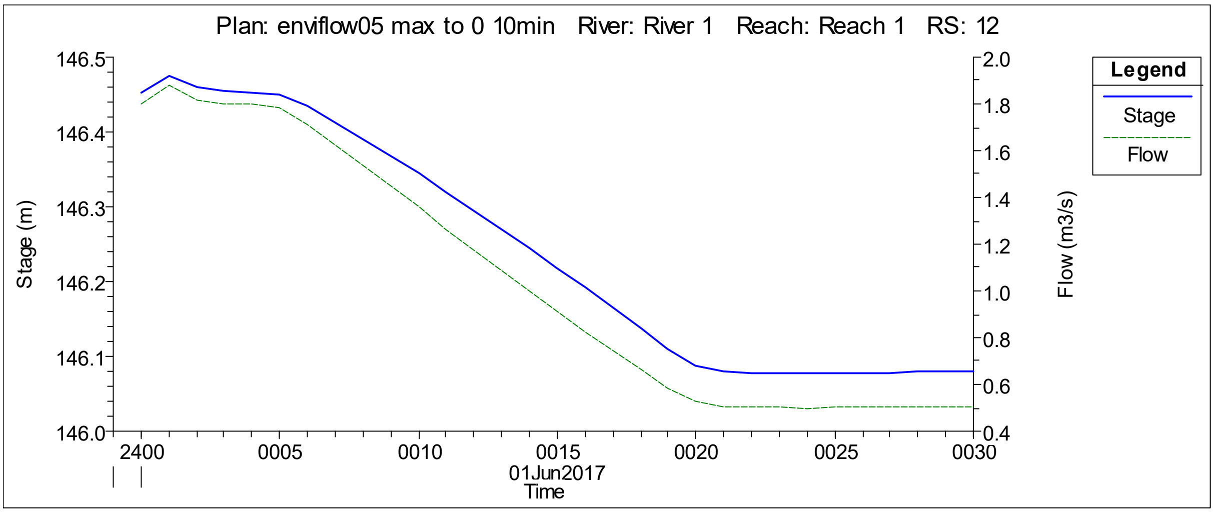

Plan: 80 to 50 3min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.14
146.16
146.18
146.20
146.22
146.24
Flow (m3/s)
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

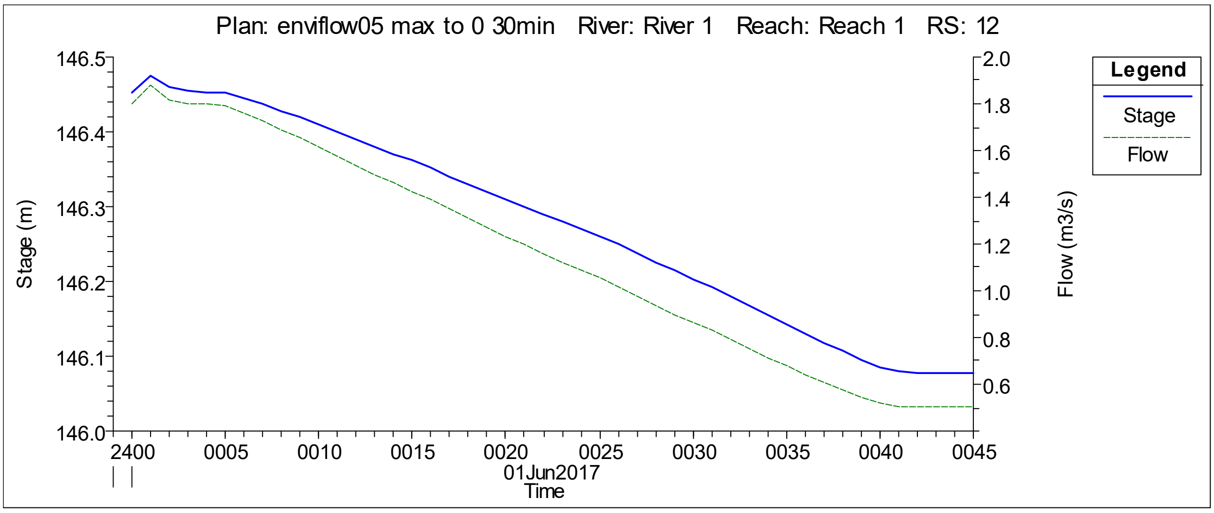

Plan: 80 to 50 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.24
146.22
146.20
146.18
146.16
146.14
Flow (m3/s)
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

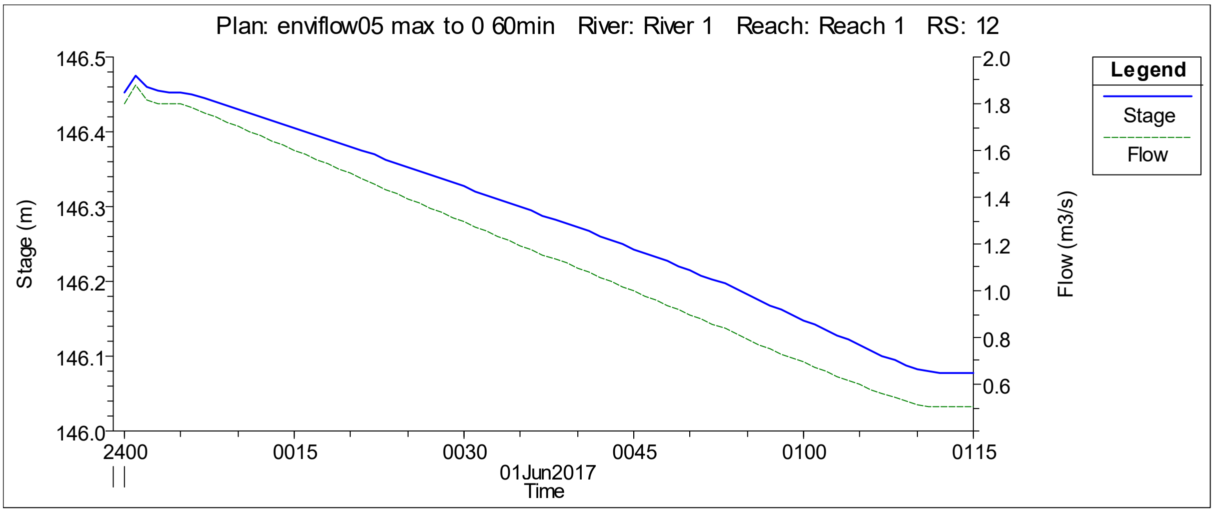

Plan: 80 to 50 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.24
146.22
146.20
146.18
146.16
146.14
Flow (m3/s)
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

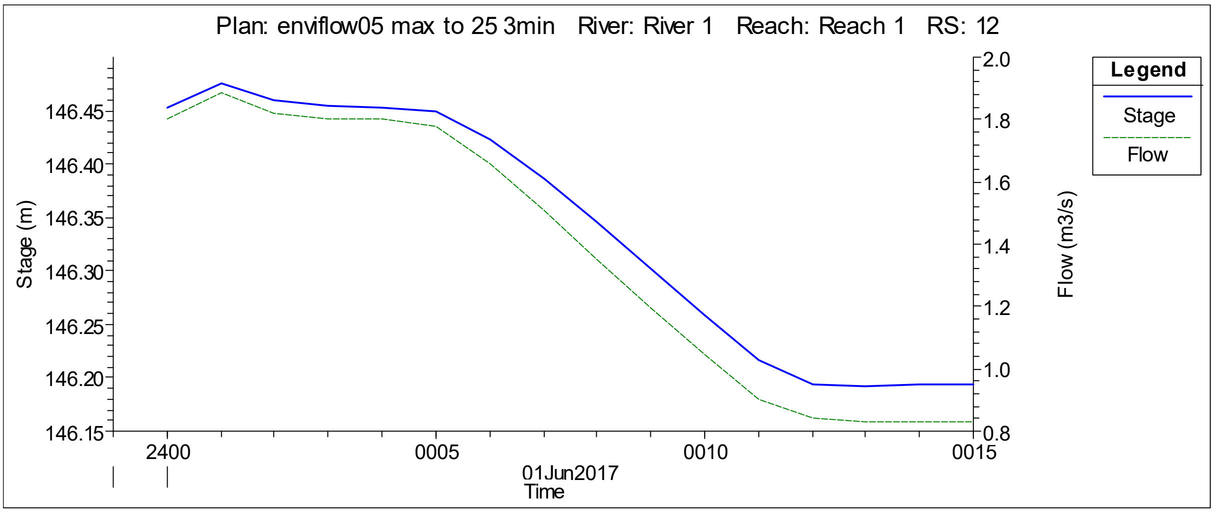

Plan: 80 to 50 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.24
146.22
146.20
146.18
146.16
146.14
Flow (m3/s)
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow

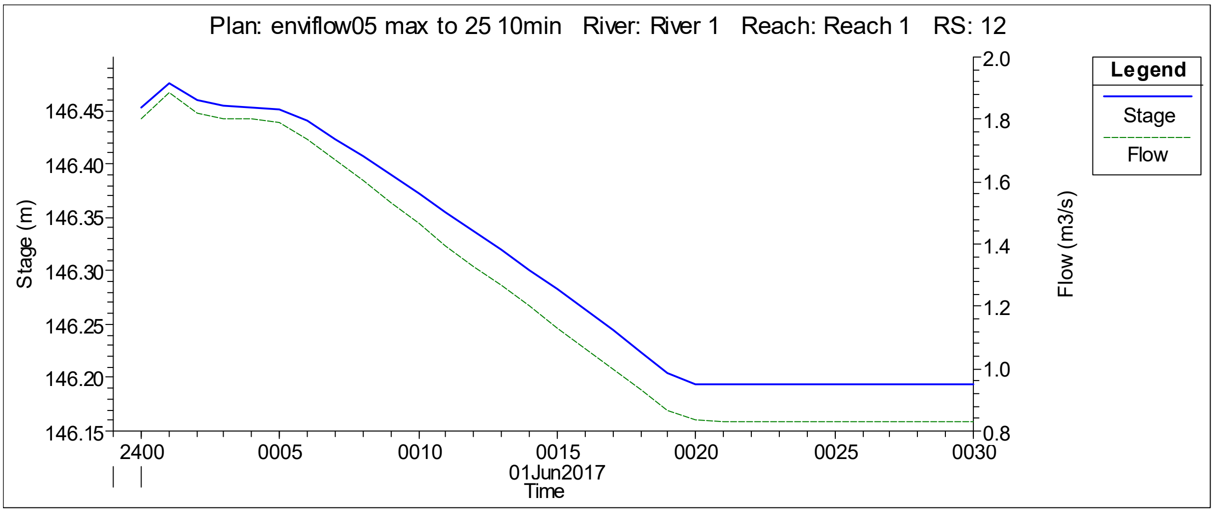

Plan: enviflow05 max to 0 3min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.5
146.4
146.3
146.2
146.1
146.0
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

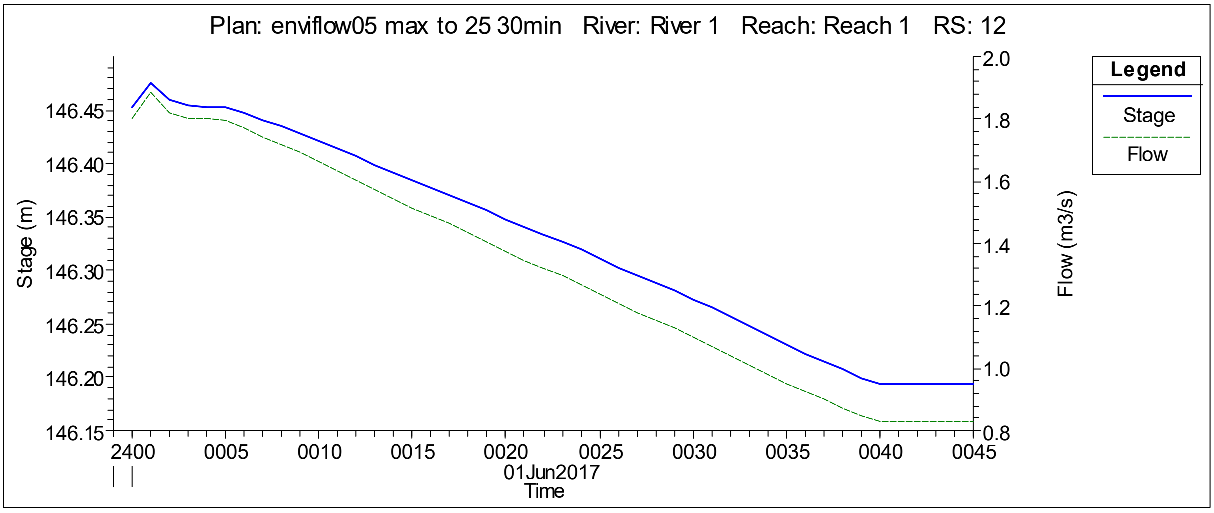

Plan: enviflow05 max to 0 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.5
146.4
146.3
146.2
146.1
146.0
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

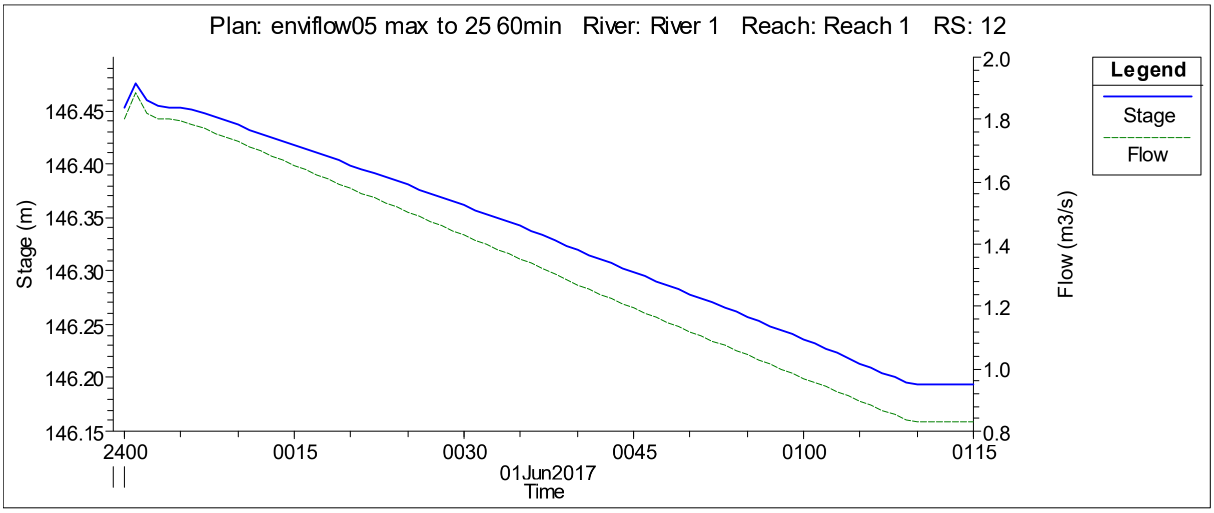

Plan: enviflow05 max to 0 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.5
146.4
146.3
146.2
146.1
146.0
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

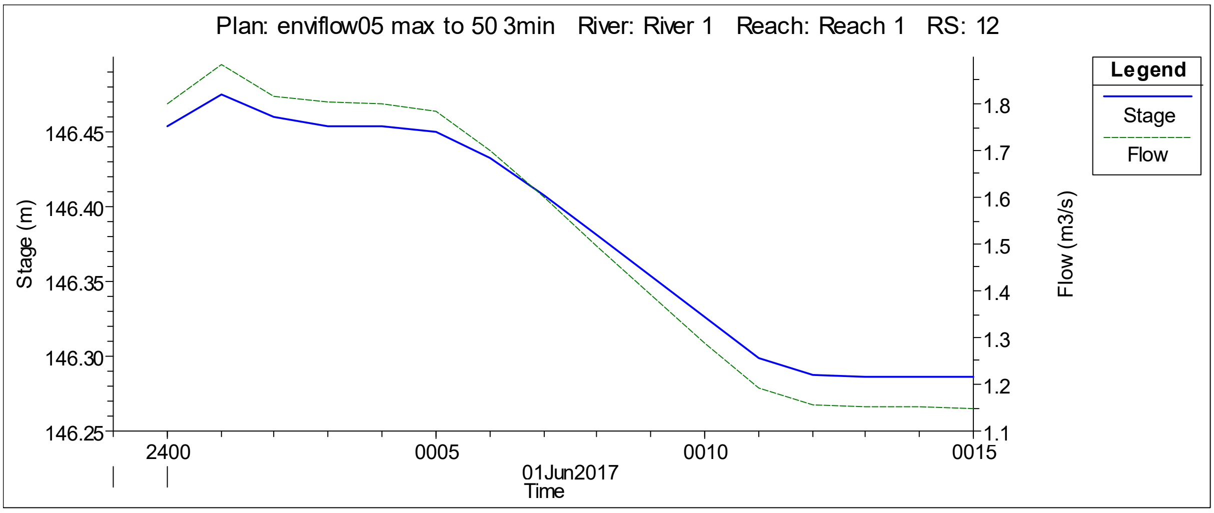

Plan: enviflow05 max to 0 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.5
146.4
146.3
146.2
146.1
146.0
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow

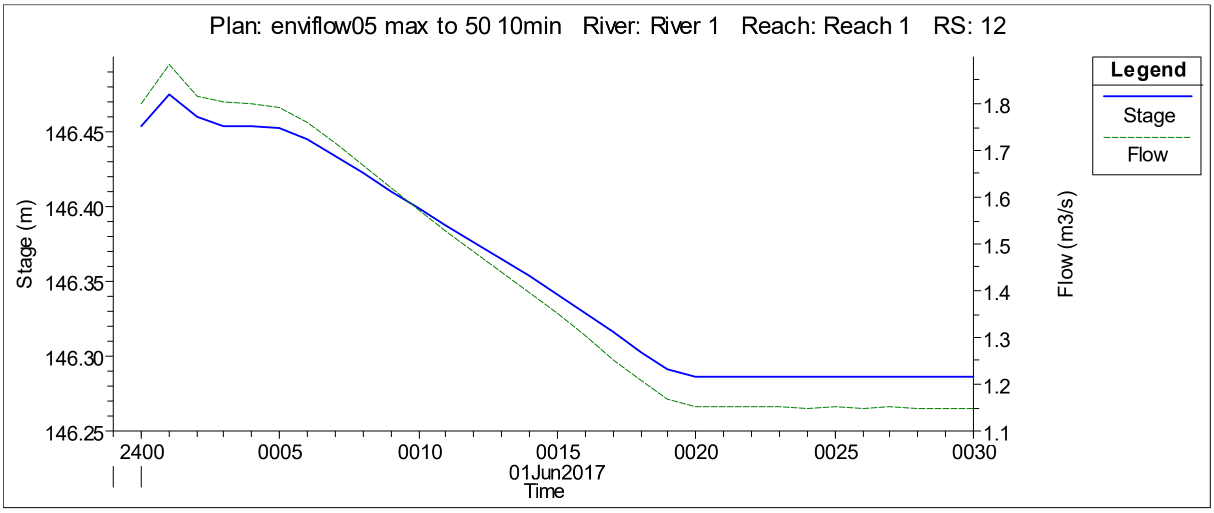

Plan: enviflow05 max to 25 3min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.45
146.40
146.35
146.30
146.25
146.20
146.15
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

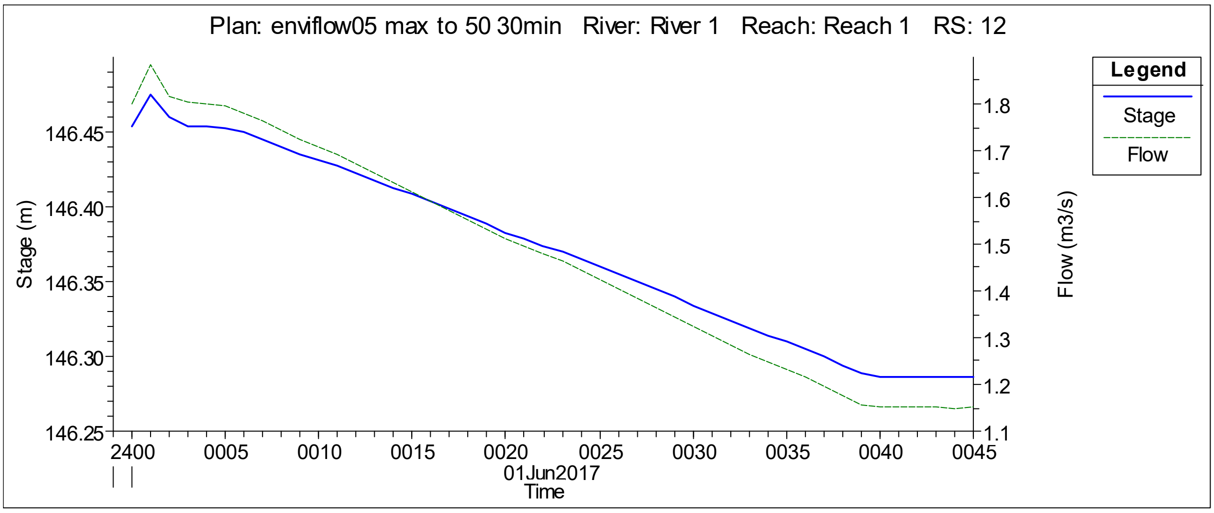

Plan: enviflow05 max to 25 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.45
146.40
146.35
146.30
146.25
146.20
146.15
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

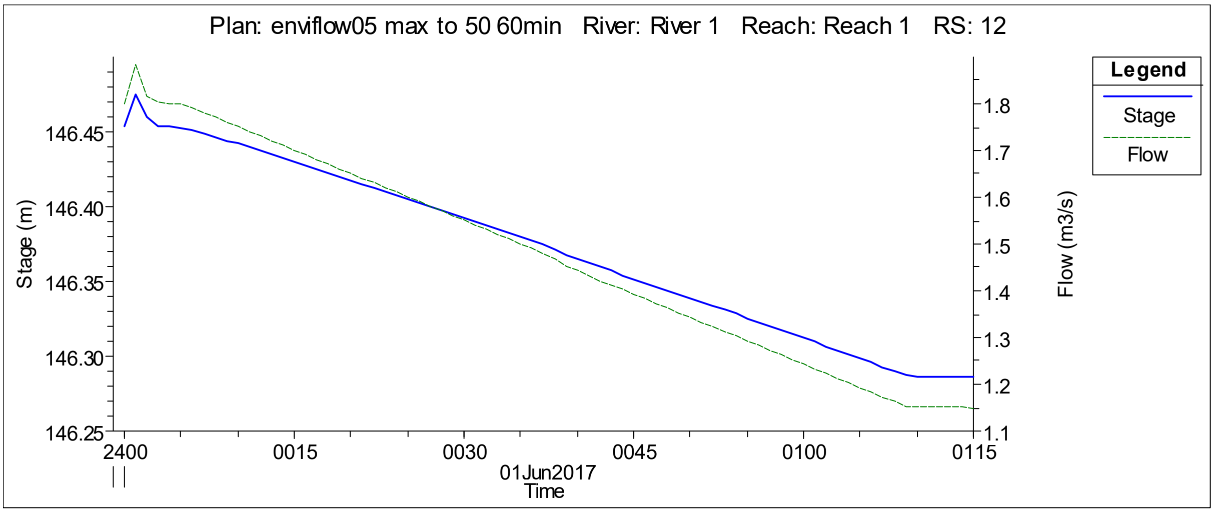

Plan: enviflow05 max to 25 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.45
146.40
146.35
146.30
146.25
146.20
146.15
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow

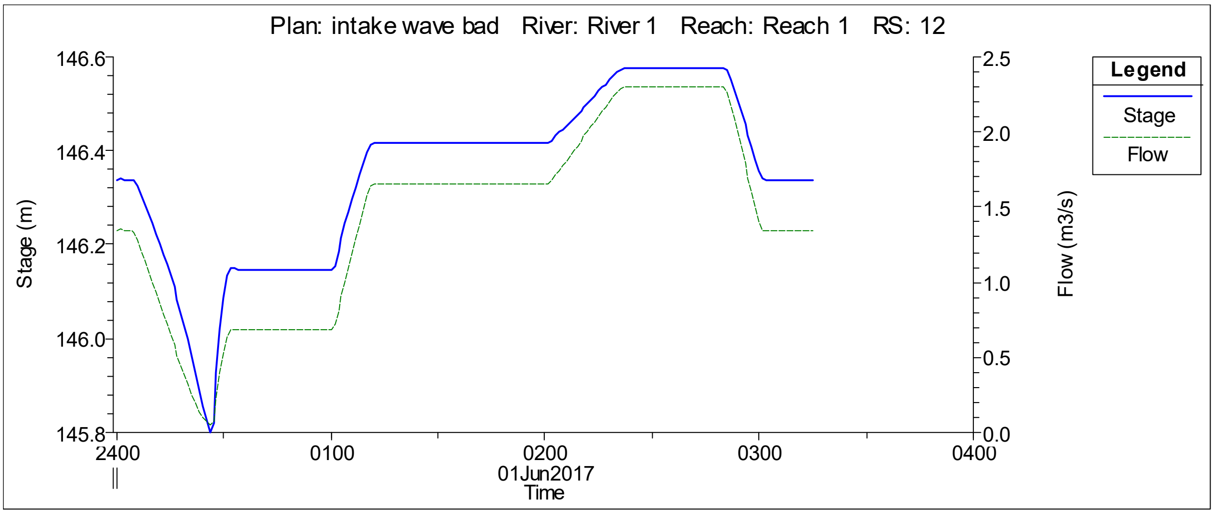

Plan: enviflow05 max to 25 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.45
146.40
146.35
146.30
146.25
146.20
146.15
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow

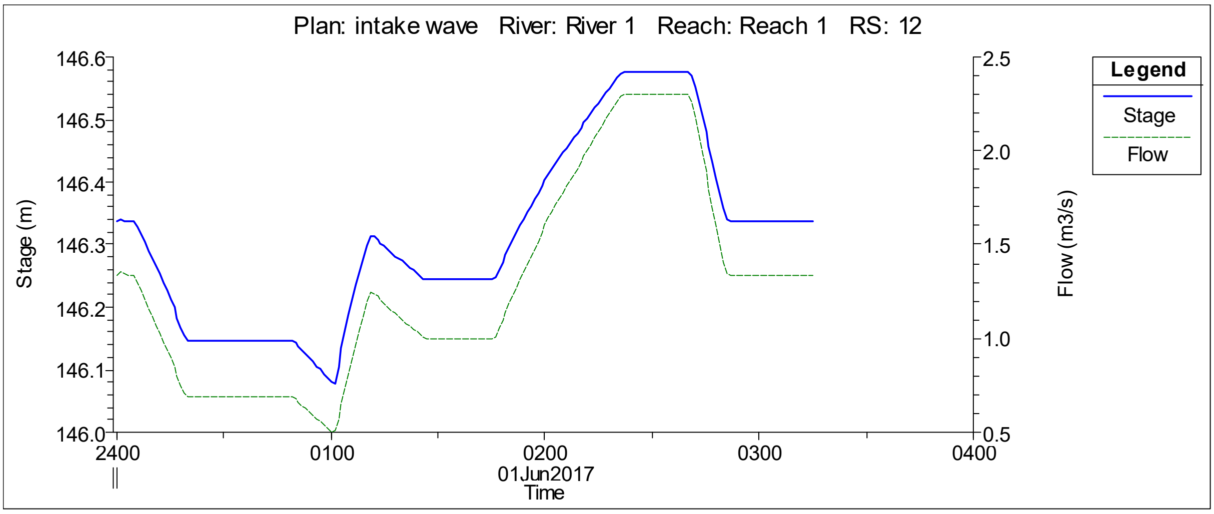

Plan: enviflow05 max to 50 3min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.45
146.40
146.35
146.30
146.25
Flow (m3/s)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
2400
0005
0010
0015
01Jun2017
Time
Legend
Stage
Flow

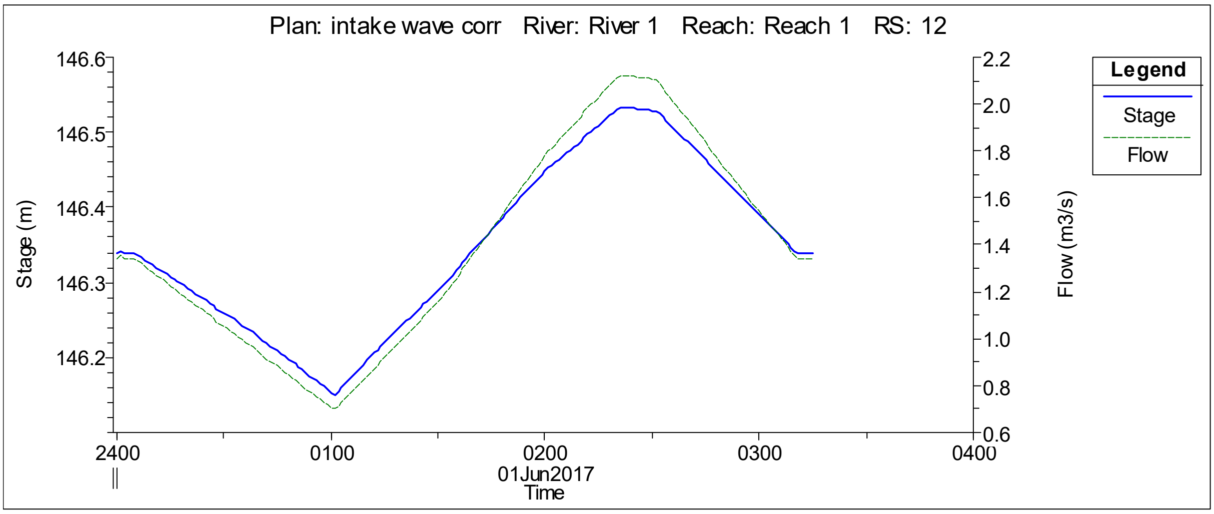

Plan: enviflow05 max to 50 10min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.45
146.40
146.35
146.30
146.25
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
Flow (m3/s)
2400
0005
0010
0015
0020
0025
0030
01Jun2017
Time
Legend
Stage
Flow

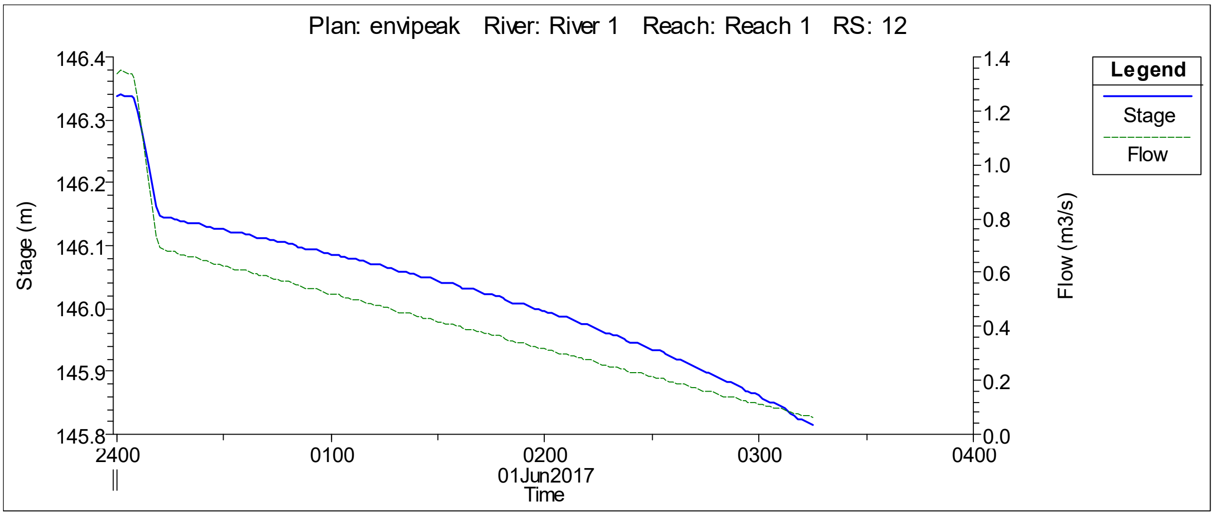

Plan: enviflow05 max to 50 30min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.45
146.40
146.35
146.30
146.25
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
Flow (m3/s)
2400
0005
0010
0015
0020
0025
0030
0035
0040
0045
01Jun2017
Time
Legend
Stage
Flow


Plan: enviflow05 max to 50 60min River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.45
146.40
146.35
146.30
146.25
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
Flow (m3/s)
2400
0015
0030
0045
0100
0115
01Jun2017
Time
Legend
Stage
Flow


Plan: intake wave bad River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.6
146.4
146.2
146.0
145.8
Flow (m3/s)
2.5
2.0
1.5
1.0
0.5
0.0
2400
0100
0200
0300
0400
01Jun2017
Time
Legend
Stage
Flow


Plan: intake wave River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.6
146.5
146.4
146.3
146.2
146.1
146.0
Flow (m3/s)
2.5
2.0
1.5
1.0
0.5
2400
0100
0200
0300
0400
01Jun2017
Time
Legend
Stage
Flow


Plan: intake wave corr River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.6
146.5
146.4
146.3
146.2
Flow (m3/s)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
2400
0100
0200
0300
0400
01Jun2017
Time
Legend
Stage
Flow


Plan: envipeak River: River 1 Reach: Reach 1 RS: 12
Stage (m)
146.4
146.3
146.2
146.1
146.0
145.9
145.8
Flow (m3/s)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2400
0100
0200
0300
0400
01Jun2017
Time
Legend
Stage
Flow

Pictures

Picture on Brandåa middle of the reach, during stop and after restart.

Pictures of The Brandåa outlet channel, before and after stop

Sundli 2km downstream from power plant, during stop and after restart

Sundli 1km downstream from power plant, during stop and after restart