Behavioural response of silver eel to effluent plumes: Telemetry experiments

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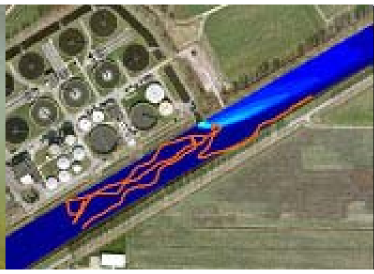
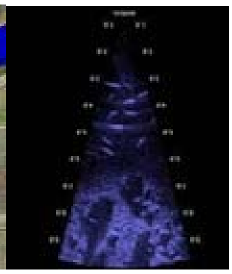

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Summary

Fish migration may be hampered by a range of physical barriers. That non-physical barriers such as sudden changes in water quality may also serve as barriers is often stated, but only very few studies address this issue.

This study focusses on linking the behavioural response of silver eel and river lamprey when encountering a waste water plume (effluent) in field situations. Individual fish movements were tracked by means of acoustic telemetry in 2D (in 2009) and in 3D (in 2010) at a location surrounding a waste water outlet in the Eems-canal near Groningen. Plume dynamics were modelled and calibrated by Deltares and used to directly link to individual movement patterns of fish. In both years, 20 silver eels (downstream migration) were tagged and in 2009 also 13 rvier lamprey (upstram migration) were tagged.

In total, 37 out of 40 silver eels entered the 2D – 3D study site. Of these, 57 % showed avoidance behaviour when encountering the plume, 43 % were indifferent to the plume and no attraction to the plume was observed. Avoidance behaviour varied from moving away from the plume but continuing the migration, to returning and not be detected again, thereby possibly ceasing their migration (3 out of 37). This indicates that waste water plumes may serve as non-physical barriers to migrating silver eel. Given the very dynamic nature of the plume in Groningen, even if waste water plumes serve as non-physical barriers for some of the migrating eels, numerous migratory windows are available in time and in water depths, when the plume is minimal or limited to one shore. Therefore it is estimated that the barrier effect of waste water plumes might be small, although delays in migration are likely to occur.

Our findings may be used for management purposes. The occurrence of a behavioural avoidance response of approximately half of the eels opens up the possibility to manipulate plumes in order to ‘steer’ silver eels to a preferred direction, e.g. away from potential hazardous locations.

Contents

1 Introduction

Fish migration in rivers and waterways has been hampered by many physical structures like dams, weirs, sluices, levees, culverts and hydropower stations. To mitigate these, huge investments have been and will be made, e.g. to construct fishways along barriers. That non-physical barriers such as sharp gradients in water quality may also play a role in hampering fish migration is often mentioned, yet only very few studies have addressed this issue (Barrett 2004, Thorstad et al. 2007, James & Joy, 2008). Most studies focus on hypoxic zones in catchment areas (e.g. Maes et al. 2008 for the River Scheldt) or plumes from hydropower stations with supersaturation of oxygen (e.g. Johnson et al. 2007). In many laboratory studies it has been shown that fish can sense many chemical and physical compounds and show behavioural responses in reaction to some of these (Gray 1983, Atchison 1987, Atland 1998). Yet avoidance behaviour of migratory fish in response to sudden changes in water quality or particular chemical components have been rarely studied in field situations (Thorstad et al. 2007, Thorstad et al. 2005). To what degree migratory fish is hampered by plumes with a very different water quality, such as discharges of waste water, is still not very well known. If plumes evoke behavioural responses, such as avoidance, this may lead to delays or even obstruction in migrations.

In this study we examine whether migratory fish, especially eel *Anguilla anguilla* but also river lamprey *Lampetra fluviatilis*, show behavioural responses when confronted with a waste water plume during their migration. We used 3D telemetry to follow individual behaviour of migrating fish and matched their behaviours to the dynamics and spatial properties of a waste water plume, based on measurements and modelling of the plume (Kleissen et al. 2011). This allowed us to match behaviour of freely migrating fish to the conditions of the waste water plume they encountered. We hypothesize that downstream migrating fish such as silver eel are more likely to show behavioural responses when meeting a waste water plume than upstream migrating fish such as river lamprey, because downstream migrating fish encounter a much steeper gradient when meeting the plume front, whereas upstream migrating fish encounter a very gradual gradient when swimming up the diluted tail end of the plume.

2 Materials and Methods

2.1 VEMCO VPS

For this study, the VEMCO VR2W Positioning System (VPS) setup was deployed, using VEMCO acoustic transmitters and VR2W receivers.

A VR2W receiver (Figure 1) records the identification number and time stamp from acoustic transmitters with a frequency of 69 kHz as a tagged animal travels within receiver range. The VR2W consists of a hydrophone, receiver, ID detector, data logging memory, and battery all housed in a submersible case. The VR2W has a battery life of approximately 15 months and can store 1-million detections. To deploy a VR2W, the receiver is moored along a line, which is connected to a weight at the bottom and a pop-up float (Figure 2, left). Data from the receivers can be exported to a computer through a Blue Tooth connection using the VEMCO VUE software package (Figure 2, right).

Figure 1 VEMCO VR2W receiver (left) and a receiver under water with a silver eel passing (right).

Figure 2 Mooring method (left) and exporting data from a VEMCO VR2W receiver in the field (right).

VEMCO coded transmitters operate at 69 kHz and are available in different sizes. Each tag sends an acoustic pulse train (8 pulses in approximately 3.2 seconds) at pre-set time intervals. These acoustic pulse trains are random about an average delay time to minimise collisions between different tag pulses. E.g. a transmitter can be set to send a pulse train random between 30 to 45 seconds. Each pulse train includes a specific ID number for each tag to track the individual fish.

The different tag sizes range in output level and battery life. For this study, fish were tagged with V7-4L, V9-6L and V9P-6L tags (Table 1; Figure 3, left). The V9P-6L is an acoustic transmitter that can also measure the water pressure with a resolution of 0.22 m, from which the swimming depth of the tagged animal can be calculated. The choice for delay time for a tag depends on the preferred working time of a tag and therefore battery life, and tag size and type. For each study 20 tags were deployed.

Table 1 Specifications of the V7-4L, V9-6L, V9P-6L and V13-1L acoustic transmitter.

Model	**V7-4L**	**V9-6L**	**V9P-6L**	**V13-1L**
Length (mm)	22.5	20	38	36
Diameter (mm)	7	9	9	13
Power output (dB re 1 uPa @ 1m)	136	146	143	147
Weight in air (g)	1.8	2.9	4.6	11
Weight in water (g)	1.0	1.6	2.2	6

Eels were caught with fykenets by a professional fisherman in the Eems canal at Delfzijl (used for location Groningen) and upstream of pumping station Halfweg (for location Amsterdam) and stored in aerated basins for up to several days. River lampreys were caught at Delfzijl only (location Groningen). Only eels with a completely silvery white ventral side were used, rejecting individuals with yellow or partly yellow ventral sides. For each location and year 2 batches of 10 eels, n=20 for Groningen in 2009, n=20 for Groningen in 2010 and n=20 for Amsterdam in 2010, and n=13 river lampreys for Groningen in 2009. The eels ranged from 57 to 108 cm in total length. Males do not grow that large before migrating (Dekker 2000), thus all fish were females. The eels and lampreys were anaesthetised with 2-phenoxy-ethanol (0.9 mlÆl)1), weighed (g), and measured (mm total length). The surgical procedure applied was the best among five different procedures for European eel as tested by Baras & Jeandrain (1998). The VEMCO transmitters were surgically implanted in the body cavity by making a mid ventral 1–2 cm incision in the posterior quarter of the body cavity. The incision was closed using commercial-grade cyanoacrylate adhesive (LoctiteTM, Loctite Nederland BV, Helmond, The Netherlands) for eels and resorbable sutures for river lampreys. Surgery lasted 3–5 min. Eels and lampreys were observed in a recovery tank until swimming behaviour was normal and eels were then released 1 km (location Amsterdam) or 2 km (location Groningen) upstream from the waste water plume site, and lampreys near the catch site allowing them to move downstream to the study site.

Figure 3 *VEMCO transmitters V13 sync-tag, V9 and V7 (left), and a transmitter implanted in an eel (right).*

The VR2W Positioning System (VPS) is a non-real-time underwater acoustic fine-scale positioning system. The system consists of underwater acoustic transmitters (sync-tags) and VR2W's receivers. The VR2W's are deployed in a grid of triangles or squares. Acoustic transmitters are deployed within this set-up, also moored to a line connected to a weight and a float. These transmitters, sync-tags, are tags that have a long delay time and are deployed to correct for clock drift between submerged receivers. For the studies, four V13 and five V9T were used with a delay between 500 and 700 seconds. The V9T sync-tags measure water temperature between 0 and 40 °C, with an accuracy of 0.5 °C. After testing and deploying the receiver and sync-tag positions, the equipment was left in the water during the study. After the study, the receivers and sync-tags were retrieved from the water and the data from the receivers were sent to the processing service provided by VEMCO to obtain calculated positions of the eels.

Data obtained from the VPS study give a calculated position of the fish at a certain time with a standard error circle, which was 5 meter for most of the calculated positions within the area covered by the triangles of VR2W receivers. In the area covered within the receiver triangles, precision is highest, while precision decreases outside the area covered within the receiver triangles (Figure 4). The calculation of the position of a fish depends on the speed of sound through water, which is temperature dependent. Therefore information on temperature differences within the system are important, because large differences between the waste water and receiving water could decrease the precision when not accounted for (Figure 4).

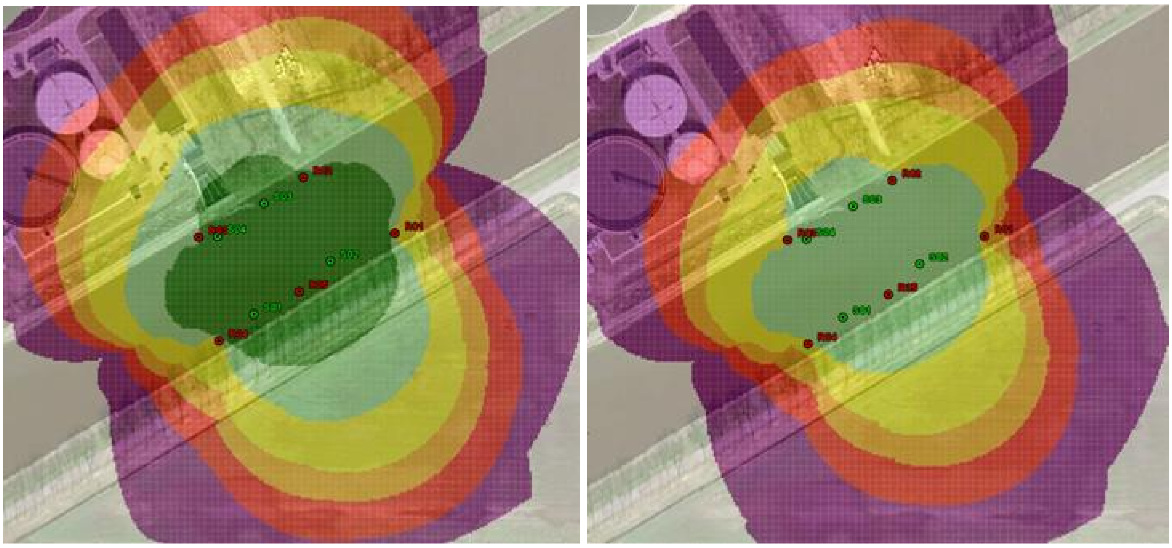

Figure 4 *Overlay of precision of the estimates, with green as high precision and decreasing precision outwards to red and purple. On the right, the precision is lower due to higher fluctuations in water temperature between the waste water and receiving water.*

2.2 Location

2.2.1 Locations 2009

In september 2009 a positioning study was planned at Amsterdam Westpoort with a system that uses cables between the hydrophones and a computer that loggs the data. To deploy this system, a computer must log data during the entire period of the study, to store the data that are not stored in the hydrophone. To assure that the system could run over a period of time, a petrol aggregate was installed near the site, with the equipment in a nearby placed van. However due to safety reasons and high changes of theft, this setup was not allowed in the Amsterdam harbour area and had to be removed from the site.

The VPS system uses VR2W receivers and can be installed without any other equipment placed along the site. The VPS set-up was tested and used between 4 December 2009 and 6 June 2010 in Groningen at the Eemscanal near the Garmerwolde water treatment plant outlet (Figure 5), using five receivers (Table 2) and four V13-1L sync-tags. Of the 20 eels, 10 were tagged with a V7-4L tag and 10 with a V9-6L tag with shorter delay (Table 3), to test which type of tag and delay time was most suitable for this and future studies.

Table 2 *Receiver VPS study number and VR2W number with position used in 2009 in Groningen.*

VPS number	Receiver number	Latitude	Longitude
R01	102053	53.247720	6.676200
R02	103669	53.247940	6.675470
R03	102055	53.247700	6.674640
R04	103672	53.247220	6.674850
R05	102059	53.247420	6.675480

Table 3 *Overview of the tags used for the study.*

Tag	Number	Delay (seconds)	Estimated tag life
V7-4L	10	20-40	77 days
V9-6L	10	12-23	26 days

Figure 5 VPS set-up at Groningen in 2009 with 5 VR2W's. Receivers are indicated as red dots, sync-tags as green dots.

2.2.2 Locations 2010

In 2010 the VPS system was used at the Amsterdam Westpoort site (Figure 6) between 27 September and 26 October 2010. A total of five receivers (Table 4) and five sync-tags were placed near the outlet, while another series of five receivers and four sync-tags were placed at a reference site more upstream (Figure 7). Also two CTD's were placed at the site, to obtain information on water temperature and water velocity and thereby information on the waste water. One CTD was placed in front of the outlet, and one CTD near the pumping station on the South side of the reference site. Along with temperature data from the V9T-6L sync-tag and temperature and velocity data from the two CTD's, data on the amount and condition of the waste water and the receiving water were obtained from the waste water treatment plant and from the water agency that stores information on the water flow through the pumping station. Eels were tagged with V7-4L tags (Table 5).

Figure 6 Waste water outlet at the site Amsterdam Westpoort (left) and the difference in water conditions i.e. 'plume front' between the plume on the right and the receiving water on the left (right photo).

Table 4 Receiver VPS study number and VR2W number with position used in 2010 in Amsterdam.

VPS number	Receiver number	Site	Latitude	Longitude
R01	102052	Waste water	52.399110	4.774750
R02	102054	Waste water	52.398570	4.774490
R03	102056	Waste water	52.399090	4.775310
R04	102055	Waste water	52.398750	4.775200
R05	102053	Waste water	52.398220	4.775010
R06	102058	Reference	52.395600	4.773060
R07	102059	Reference	52.395100	4.772920
R08	102057	Reference	52.395210	4.773550
R09	102061	Reference	52.394810	4.773240
R10	102060	Reference	52.394550	4.772490

Table 5 Overview of the tags used for the study in 2010 in Amsterdam.

Tag	Number	Delay (seconds)	Estimated tag life
V7-4L	20	20-35	70 days

Table 6 Receiver VPS study number and VR2W number with position used in 2010 in Groningen.

VPS number	Receiver number	Latitude	Longitude
R01	102056	53.247090	6.673060
R02	102057	53.247450	6.674010
R03	102054	53.247700	6.674700
R04	102055	53.247910	6.675370
R05	102061	53.248190	6.676070
R06	102052	53.246550	6.673010
R07	102063	53.246900	6.674030
R08	102053	53.247220	6.674890
R09	102060	53.247430	6.675540
R10	102059	53.247700	6.676280
R11	102058	53.248070	6.677260

Table 7 Overview of the tags used for the study at Groningen in 2010.

Tag	Number	Delay (seconds)	Estimated tag life
V9P-6L	20	20-35	39 days

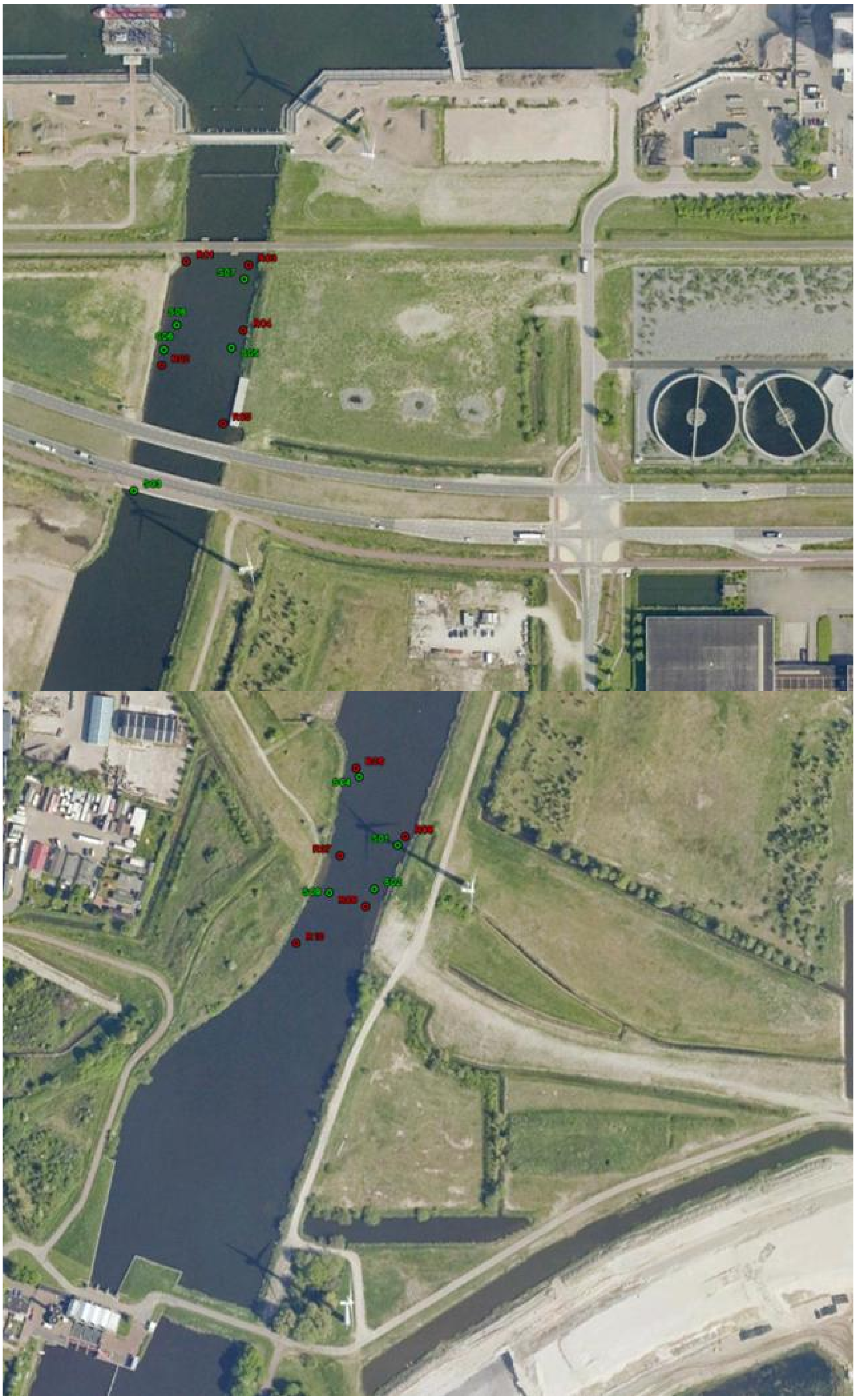

Figure 7 VPS set-up at Amsterdam in 2010 with 5 VR2W's near the outlet (above) and with 5 VR2W's at the control site more upstream from the outlet (below). Receivers are indicated as red dots, sync-tags as green dots.

In 2010 the VPS system was also used at the Groningen site (Figure 8) between 27 October and 23 November 2010. A total of 11 receivers (Table 6) and nine sync-tags were placed near the outlet and the area upstream of the outlet. One CTD was placed in front of the waste water outlet and another one was placed upstream in the Eems-canal. Along with temperature data from the V9T-6L sync-tag and temperature and velocity data from the two CTD's, data on the amount and condition of the waste water and the receiving water in the Eems-canal were obtained from the waste water treatment plant and from the water agency that stores information on the water flow through the pumping station. Eels were tagged with V9P-6L tags, which record pressure (Table 7). In Amsterdam these pressure tags were not used, because the site at Amsterdam is much shallower than that in Groningen.

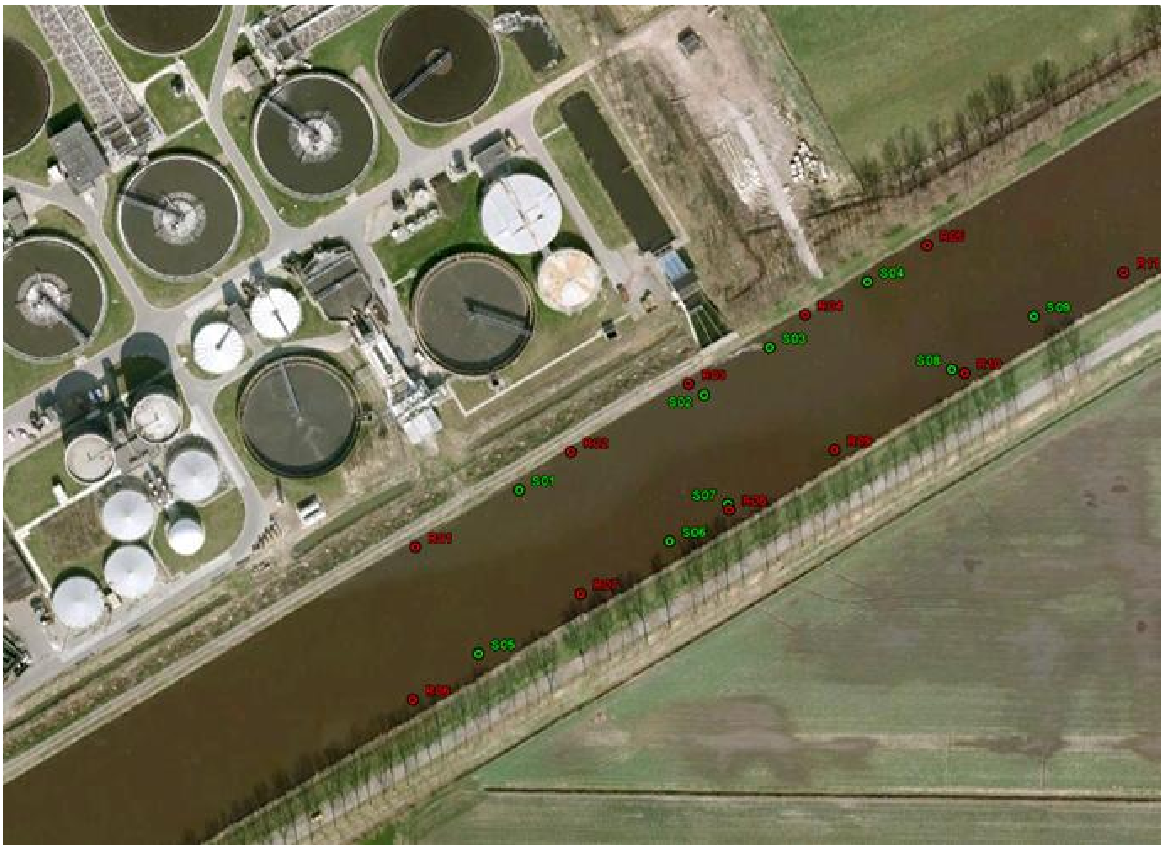

Figure 8 VPS set-up at Groningen in 2010 with 11 receivers. Receivers are indicated as red dots, sync-tags as green dots.

2.3 Data analysis

Individual 2D tracks were plotted for location Groningen for each eel and lamprey in 2009. For this year the parameter input for the modelling of the plume at location Groningen was too coarse to allow detailed modelling of the waste water plume dynamics (Kleissen et al. 2011). Therefore, eel and lamprey movements for location Groningen in 2009 could only be matched with the approximate location of the upstream front of the plume.

For location Amsterdam, eel movement patterns could be matched with plume dynamics in 2D in two sections of the discharge canal, due to the location of the bridge directly upstream from the waste water outlet splitting up the study area in two.

For location Groningen in 2010, all 20 eels were tagged with transmitters with depth sensors. This allowed to match behavioural patterns of moving silver eel to plume dynamics in 3D (Kleissen et al. 2011). Moreover, the area in which 3D movements could be tracked was almost doubled when compared to the 2D tracking area for Groningen in 2009. For each eel, based on the VPS position datasets, positions were calculated with 15 s intervals to make track lines for each individual silver eel. Each of these positions was matched with the plume strength of the grid cell of the plume model the silver eel was in at that time. Plume dynamics were well captured within this time interval and no higher resolution to describe the features of the plume in time and space was needed. Eel movement appeared at a much smaller time scale and the telemetry data allowed to make track lines with a time resolution varying from 20-35 s intervals between measured positions. To link the track lines to the plume model, interpolation from the data points to 15 s interval 3D positions of the eels were calculated. This interval was chosen to be only slightly less than the measuring interval of 20-35 s in order to avoid unsubstantiated precision in the track lines. These results were plotted in 2D and in depth in combination with experienced plume strength by the model, and compared with the plume dimensions during the time that the eel was confronted with the plume.

Movement patterns of downstream migrating eels were categorized into different types of behaviour. Based on the variety in behaviour that was observed, three main types could occur when an eel is confronted with a waste water plume:
1) No response to the plume, 2) Avoidance response to the plume, 3) Attraction response to the plume.

For each of these three categories the following subdivision in behaviour was made:

1) No response to plume
    a. Passing though the area with the plume with no divertion from the plume
    b. Random returning, with no relation between turns and plume front or area, and eventually passing through
    c. Extensive random movements with no apparent relation to the plume front or area

2) Avoidance behaviour to plume
    a. Return behaviour when confronted with plume, no passage of the study site
    b. Passing through but when meeting the plume diverted away from the plume and eventually passing the study area
    c. Multiple turnings in swimming direction associated with meeting the plume, but eventually passing through the study area
    d. Extensive movements and turning swimming direction, but movement activity predominantly outside the plume area

3) Attraction behaviour to plume
    a. Passing through, but when meeting the plume, movement activity is centered in the area with the highest plume strength, before eventually followed by passing through, or by staying in the plume area for the remaining part of the study period.

These subcategories are also schematically pictured in Figure 9.

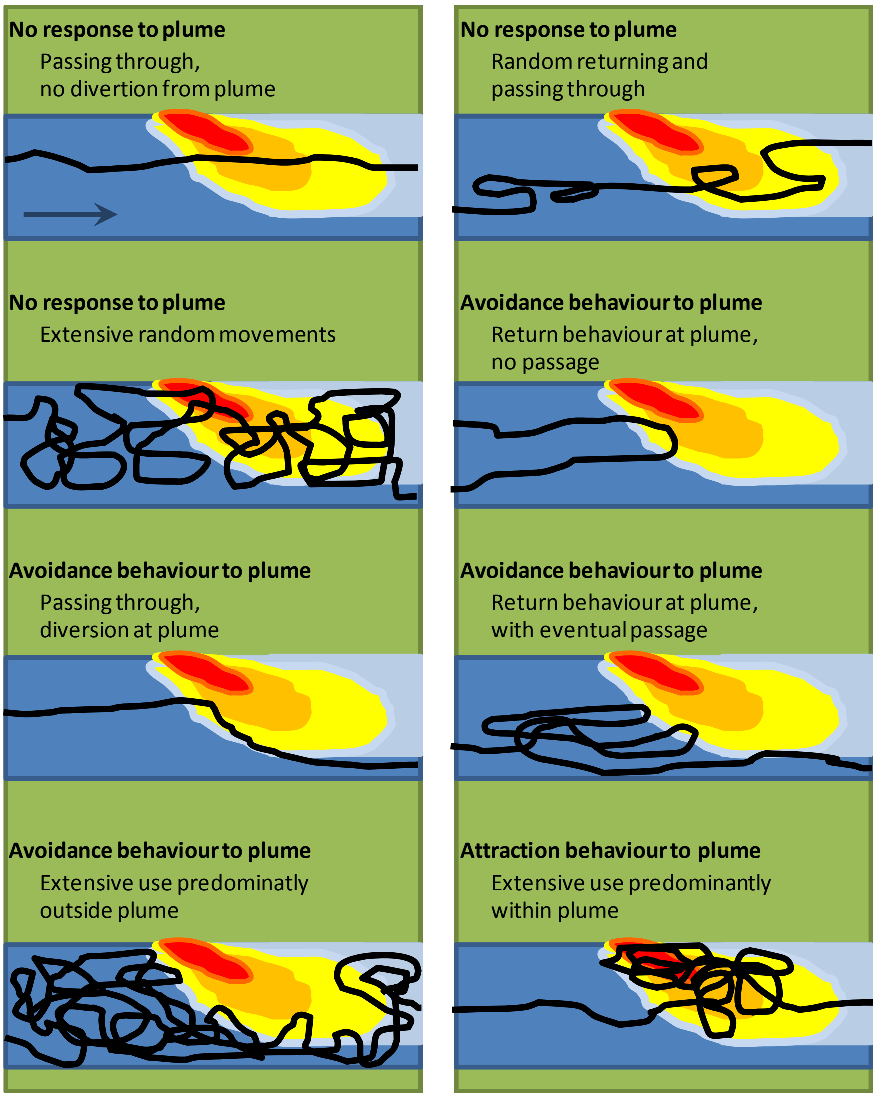

Figure 9 *Classification for eel behaviour in response to meeting a plume, where the black line represents the movement pattern of an eel entering the site from the left along with the flow direction (blue arrow) , the colours represent the strength of the plume, ranging from dark blue with no plume influence to red with high plume strength near the outlet of the waste water discharge (see text for details).*

3 Results

During the experiment in Groningen in 2009, 18 out of 20 silver eels with transmitters entered the study site at the waste water outlet, and only 3 out of 13 river lampreys entered the site. For the 2010 experiment at location Amsterdam, 20 out of 20 silver eels entered the study site. For the 2010 Groningen experiment, 19 out of 20 silver eels entered the study site.

Individual patterns of the 18 silver eels that entered the study site Groningen in 2009 are given in Appendix 1. For the 19 silver eels that entered the study site Groningen in 2010, individual track lines with experienced plume strength, depth profiles and modelled plume strength area during the time that a silver eel was confronted with the plume, are given in Appendix 2. Individual variation in patterns was large, varying from fast directed movements to extensive swimming around movements.
For the 2010 experiment at location Amsterdam the plume dynamics proved to be very large and when the pumping station at Halfweg was not discharging, the plume could fill up the entire discharge canal (Kleissen et al. 2011). As already mentioned, a bridge hampered a continuous coverage of eel movement patterns. The eels showed frequent recurrence behaviour moving out of the discharge canal into the neighbouring harbour and back into the discharge canal, possibly due to disturbance in this busy industrial harbour. It was therefore not possible to directly link individual behaviour of migrating silver eels to plume dynamics, and it could not be concluded whether there were behavioural responses to meeting the plume.

The individual patterns at location Groningen were scored according to the categorization of behaviour as stated above in 2.3 (Table 8, and Figure 10).

Table 8 Categorization of eel behaviour at location Groningen in 2009 and 2010.

Location Groningen Eems-canal site			2009	2010
No downstream movement:				
		No appareance within detection area	2	1
Downstream movement,				
	No apparent response to plume:			
		Passing through, no divertion from plume	3	2
		Random returning and passing through	5	3
		Extensive random movements	0	3
	Plume avoidance behaviour			
		Return behaviour at plume, no passage	2	1
		Passing through, diversion at plume	2	1
		Return behaviour at plume, with eventual pa	6	5
		Extensive use predominatly outside plume	0	4
	Plume attraction behaviour			
		Extensive use predominantly within plume	0	0
Total			20	20

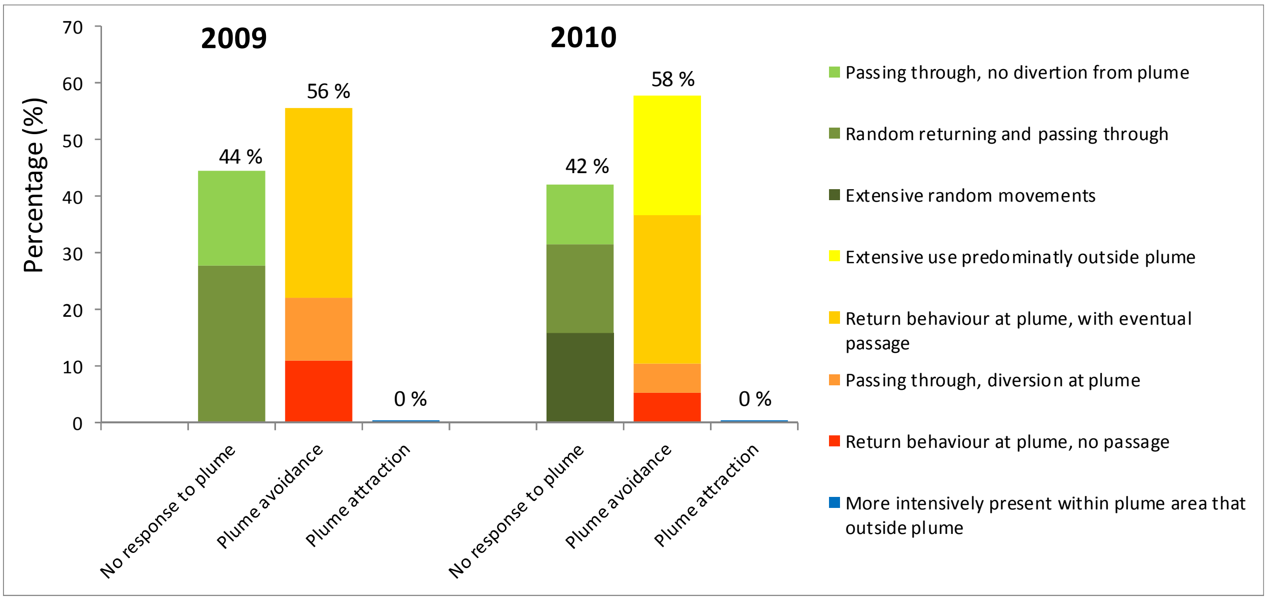

Figure 10 Distribution of behavioural responses of silver eel when confronted to a waste water plume, at location Groningen in 2009 and 2010 (see Appendix 1 and 2 for individual patterns). In both years, the majority of silver eels showed plume avoidance behaviour when being confronted with a waste water plume (56 % in 2009 and 58 % in 2010). A minority showed no clear response to the plume (44 % in 2009 and 42 % in 2010) and appeared to be indifferent to the plume. No attraction to the plume was observed. There were some differences in subcategories between years within each type of response, but the results in both years were very similar.

Of all the eel that showed an avoidance response (21 out of 37, Table 8), 18 eventually passed the study site. However, 3 eels returned when confronted with the plume front and were not observed to pass the study area within the study period.

The categorization of eel behaviours in 2009 and 2010 was made in 2D. For 2010, depth profiles were also available (see Appendix 2). However, for those eels that showed a response to the plume, the response appeared to be more prominent in the 2D dimension, and a more direct link between plume strength and water depth appeared present. Eels were swimming at varying depth, frequently changing from surface layer to bottom water layer when swimming, and dwelling on the bottom during more stationary periods, but with no obvious link to encountered plume strength that generally decreased with water depth (Kleissen et al. 2011).

All three river lampreys showed no response to the plume area or plume front when passing relatively straightforward through the study area in an upstream direction (see Appendix 1). One river lamprey later returned swimming downstream through the study area without showing a response to the plume.

4 Discussion and conclusions

The results from the 2009 and 2010 experiments at location Groningen indicate that a majority of 57 % of downstream migrating silver eels shows a behavioural response when being confronted with a waste water plume. A minority of 43 % showed no response and appeared to be indifferent to the plume when encountering it. Attraction to the plume was not observed. The behavioural response appeared more clearly in the 2D dimension than in the water depth dimension. There were no clear responses of diving deeper when being confronted with the plume. Moving sideways away from the outlet of waste water, or reverse their swimming direction was the most common response to the plume.

These results are based on the results of individual datasets of 18 and 19 eels in 2009 and 2010 respectively, on one study location only (Groningen). Location Amsterdam unfortunately proved to be too complex in plume dynamics and other disturbing factors such as the location of a bridge and the neighbouring industrial harbour to directly link individual behaviour of eels to plume area or front. The fact that the results were very similar in both years, however, gives more confidence in the conclusions drawn from these experiments. The location in the Eems-canal near Groningen proved to be very suitable to study the response. The canal is very monotonous in habitat quality and changes in behaviour occurring at the exact location where the plume front or area are present can therefore reliably be linked.

Our results indicate that waste water plumes may serve as non-physical barriers to migrating silver eel. Three eels even appeared to cease their migration after returning when encountering the plume front. Whether they did not resume their migration after the experiment was ended, or whether they were not motivated to migrate this year as observed for 19-30% of the silver eels in the River Meuse (Winter et al. 2006, Winter et al. 2007), can not be determined from our data. Given the very dynamic nature of the plume in both Groningen and Amsterdam, even if waste water plumes serve as non-physical barriers for some of the migrating eels, in time and water depth numerous migratory windows are available when the plume is minimal or limited to one shore. Therefore it is estimated that the barrier effect of waste water plumes might be small, although delays in migration are likely to occur. The precise factors that trigger this behavioural response are still unclear. Even though temperature was used as a tracer for plume strength, given that there was always a subtle difference in temperature of the discharged effluent and the receiving surface water, the differences are probably too small to trigger a behavioural response. Another potential cue might be the water current. Eels that move sideward might just be following the extra side component in flow, but returning in response to a slightly increased side flow is more unlikely to occur. Silver eel encounter many ‘side flows’ during their migrations through natural river systems and therefore a relatively strong response as turning is not expected to result from flow. A waste water plume contains a very diverse cocktail of chemical components, and eels are known for their good smell, so the list of candidate cues that may have triggered the behavioural responses is very long.

Next to the study on avoidance behaviour of Atlantic salmon to a spill of waste water discharge from a wood pulp factory (Thorstad et al. 2005), our study is, to our knowledge, the only other study that establishes a behavioural response to plumes that are not related to oxygen, i.e. hypoxic conditions or super saturation.

Our results may be used for management purposes. The occurrence of a behavioural avoidance response of approximately half of the eels opens up the possibility to manipulate plumes in order to ‘steer’ silver eels to a preferred direction, e.g. away from potential hazardous locations.

5 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Report C081/11
Project Number: 430.51036.01

The scientific quality of this report has been peer reviewed by a colleague scientist and the head of the department of IMARES.

Approved: Dr. H.J.L. Heessen
Research Scientist

Signature:

Date: 29 September 2011

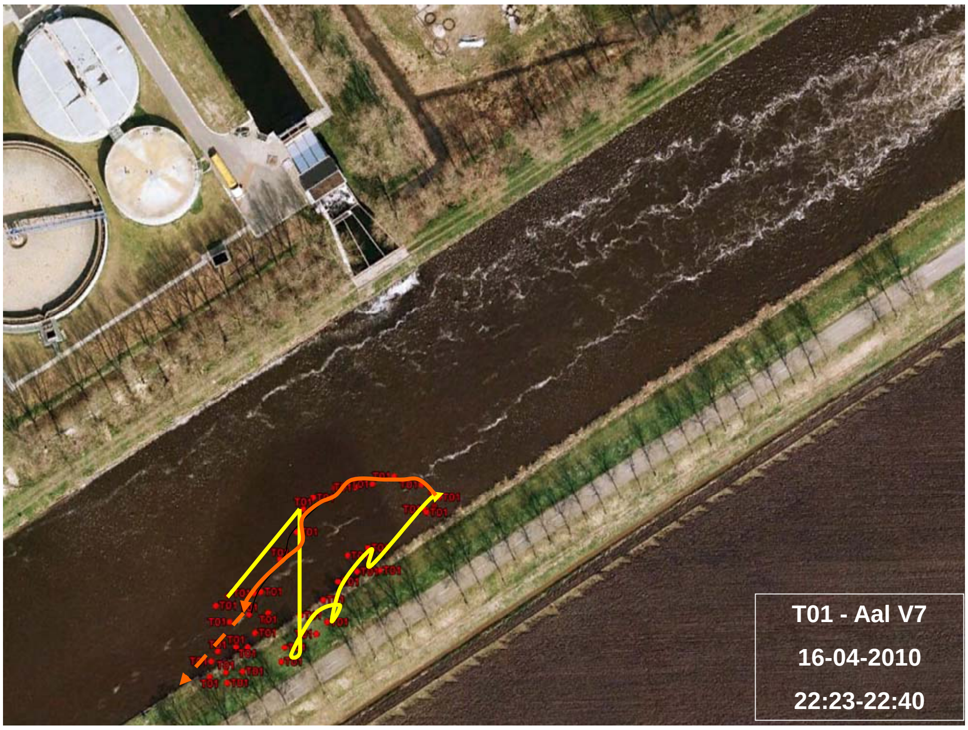
Approved: J.H.M. Schobben, MSc.
Head of Department

Signature:

Date: 29 September 2011

Appendix 1. Individual movement patterns of silver eel and river lamprey at the study site Groningen during the 2009 experiment.

Each panel represents a top view of the study site with the outlet of the waste water located on the North side of the canal in which the movement pattern of an individual eel or river lamprey is plotted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16-04-2010
22:23-22:40


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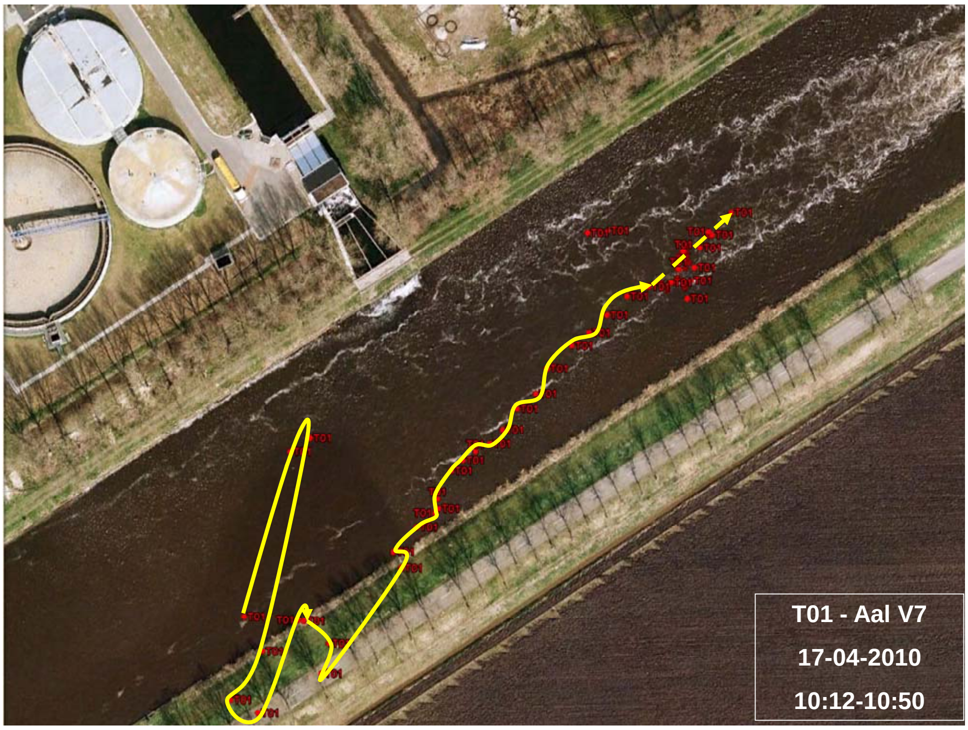
17-04-2010
03:52-04:08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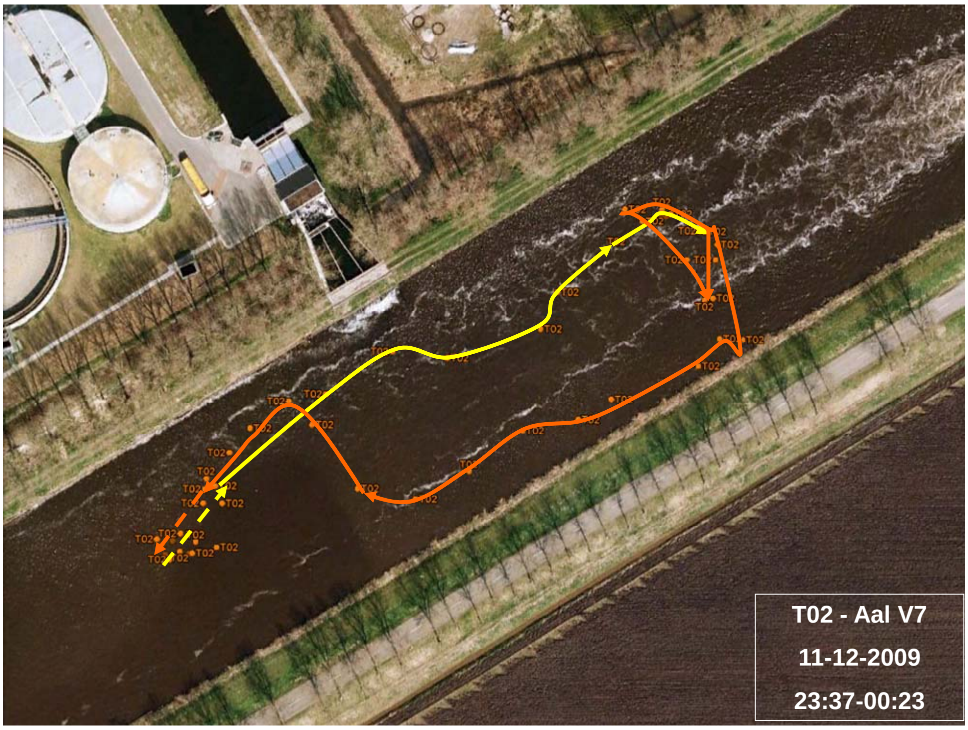
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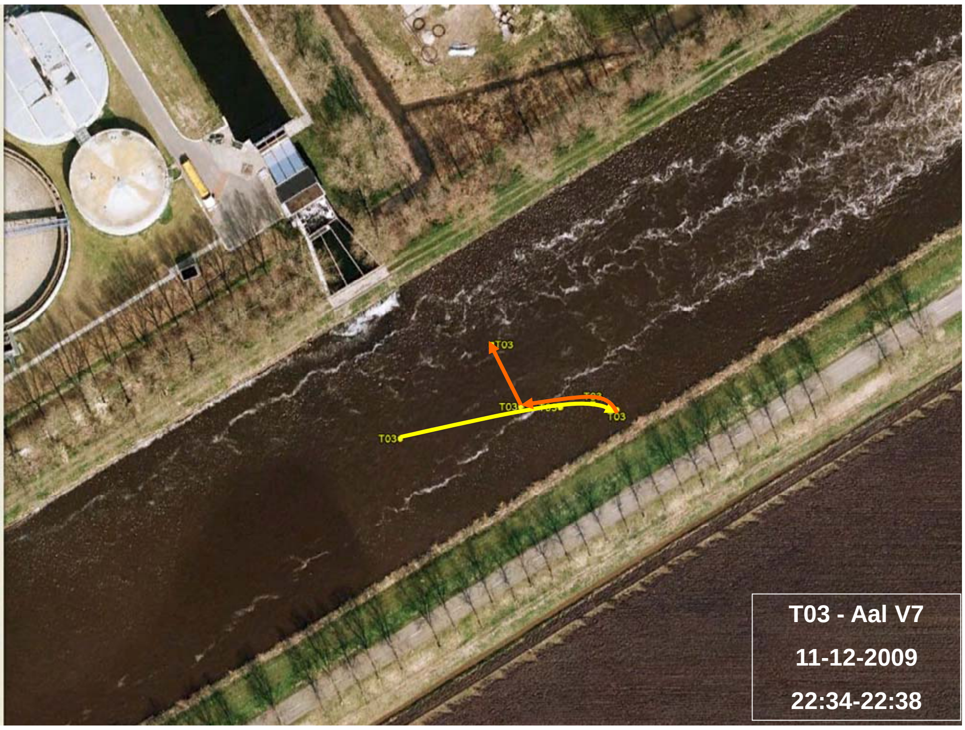
11-12-2009
23:37-00:23


T02 - Aal V7
12-12-2009
03:34-04:09


T02 - Aal V7
12-12-2009
17:01-17:15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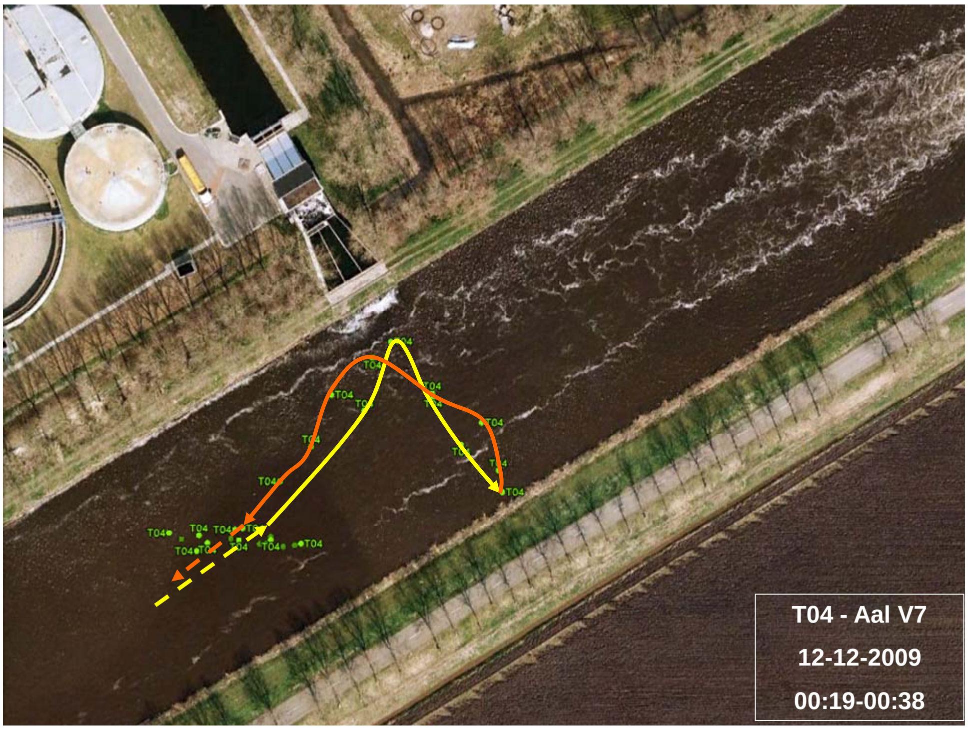
22:34-22:38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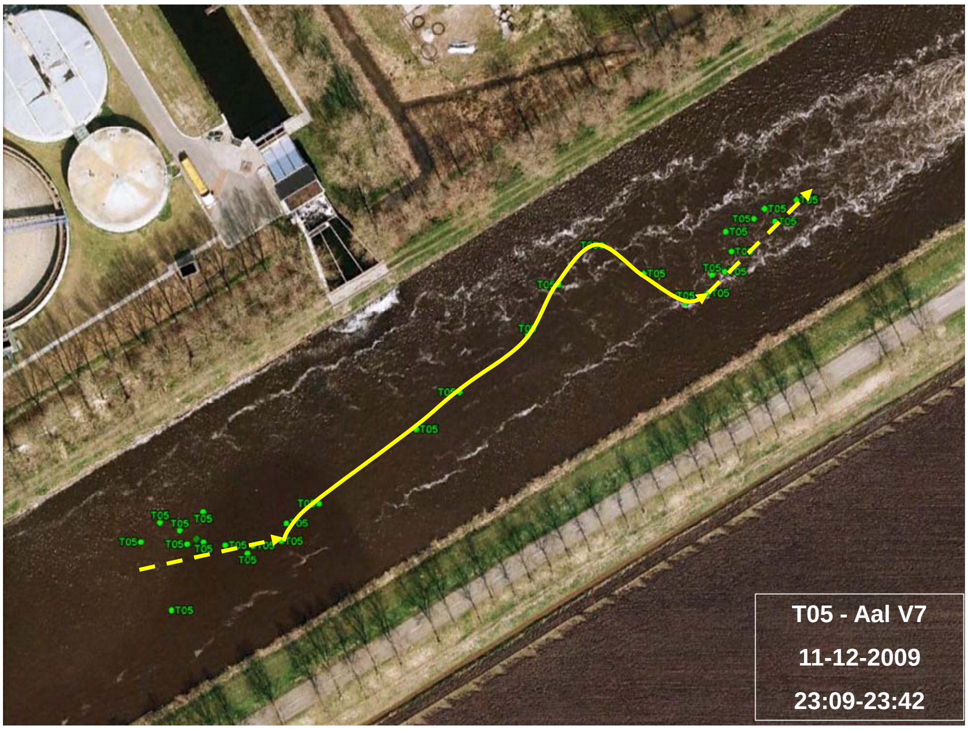
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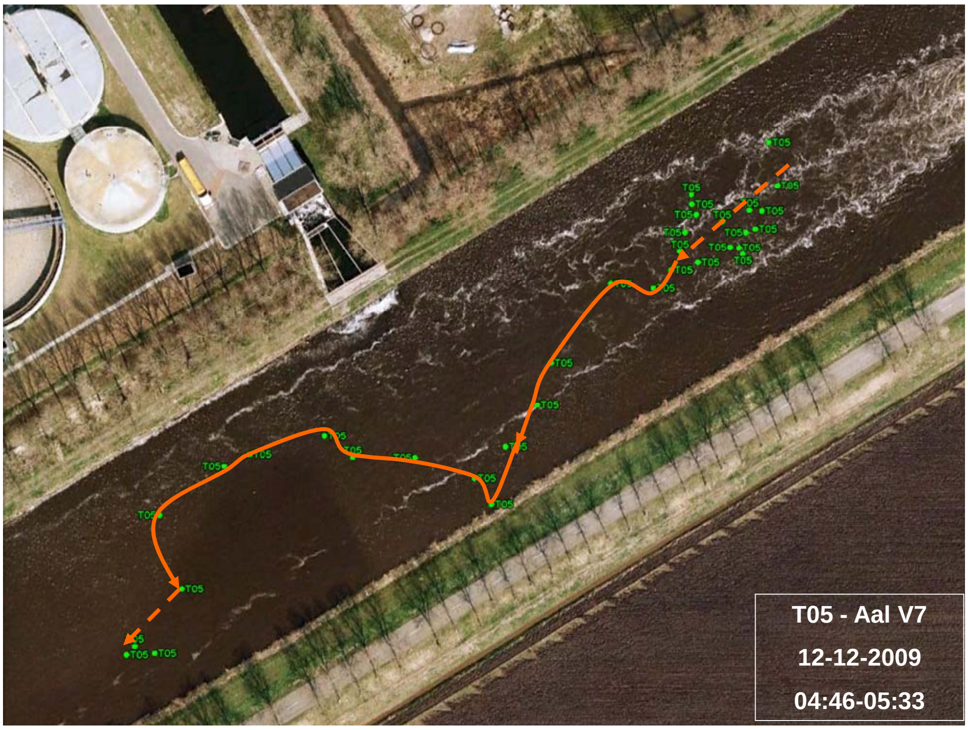
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12-12-2009
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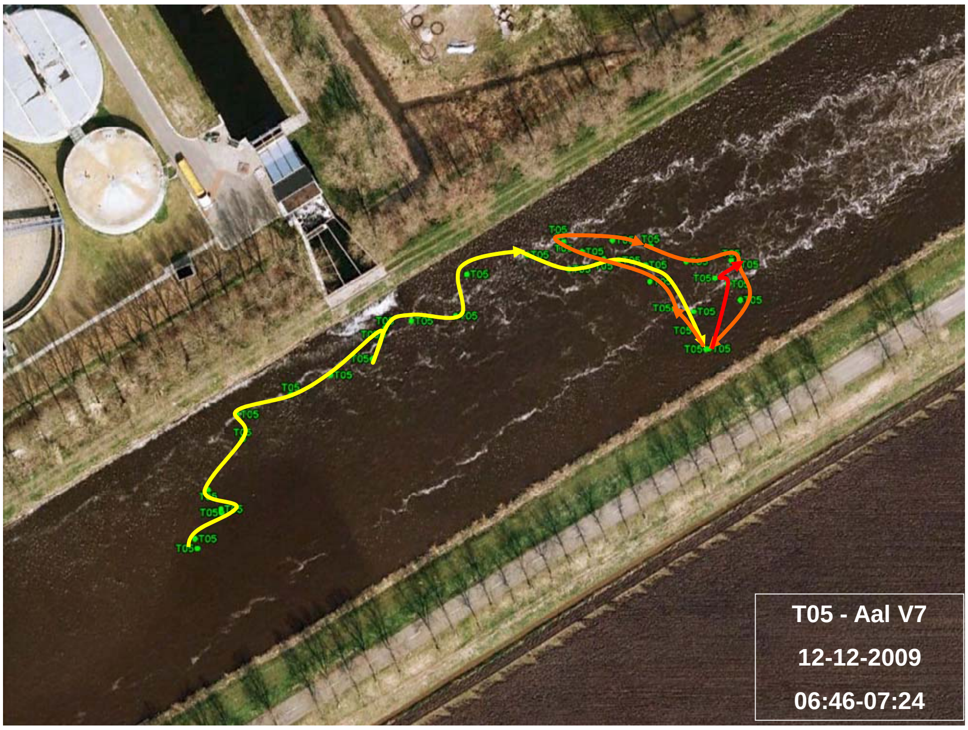
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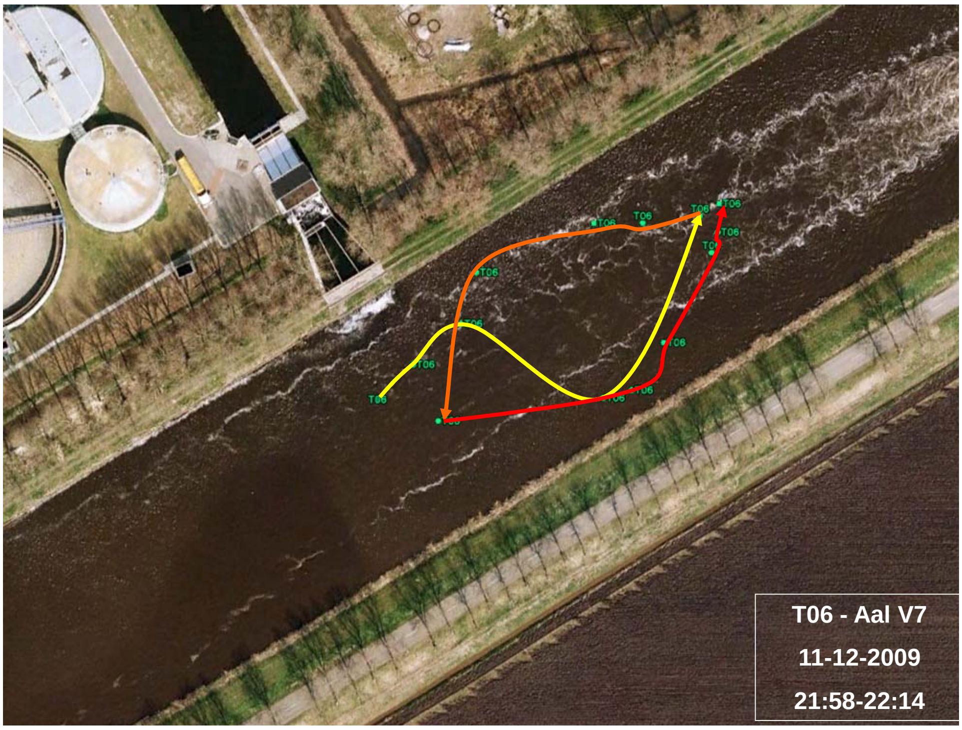
12-12-2009
06:46-07:24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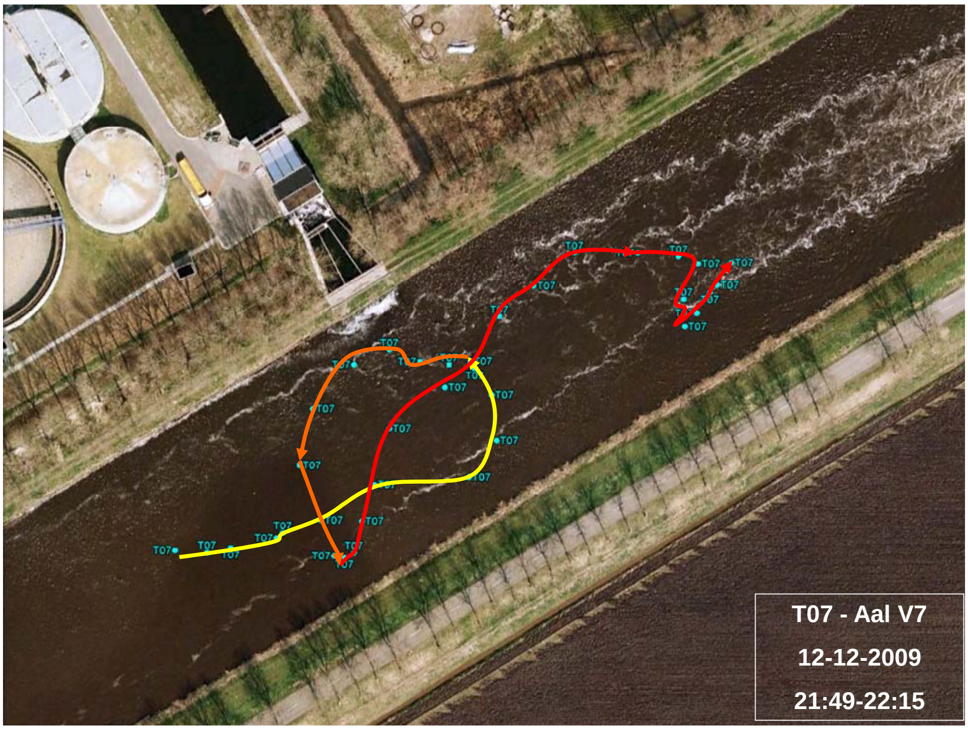
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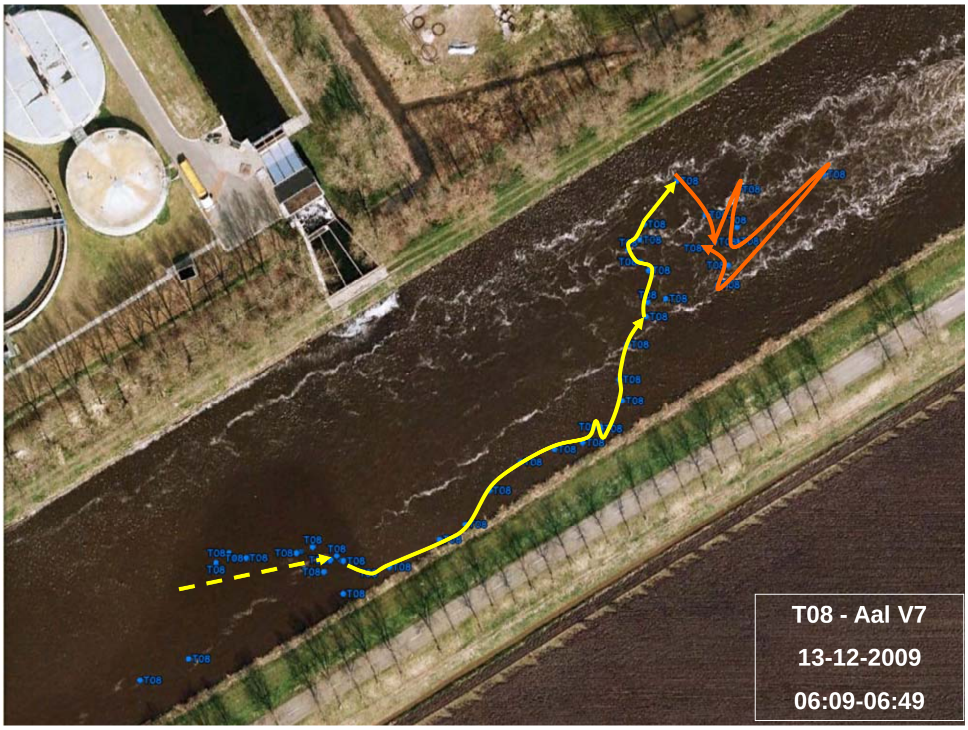
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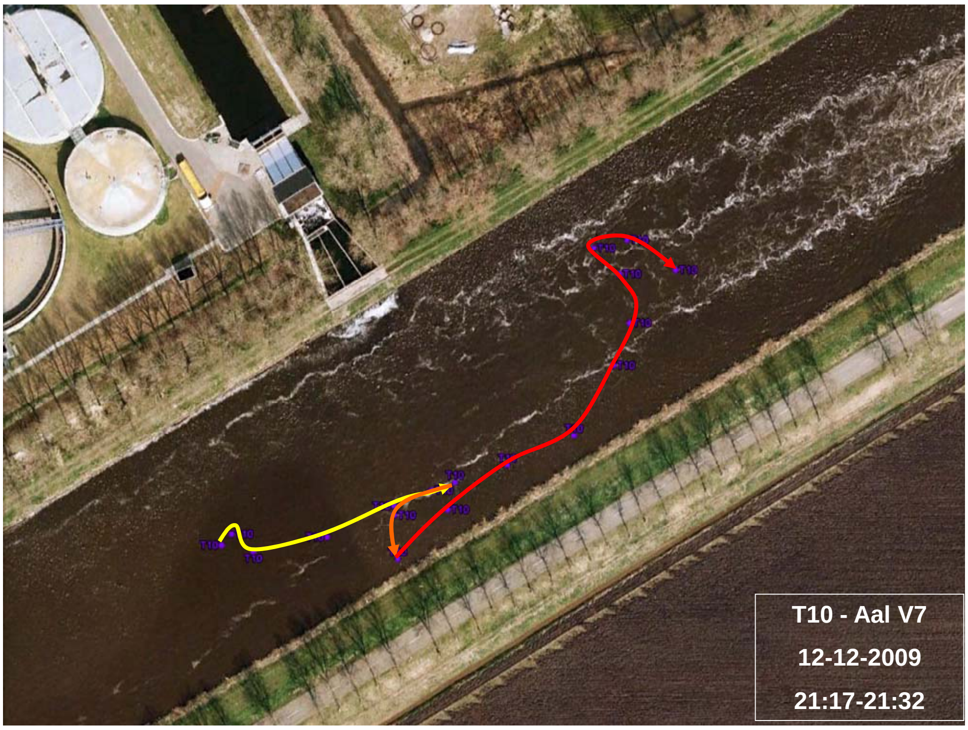
T09 - Aal V7
12-12-2009
19:52-19:56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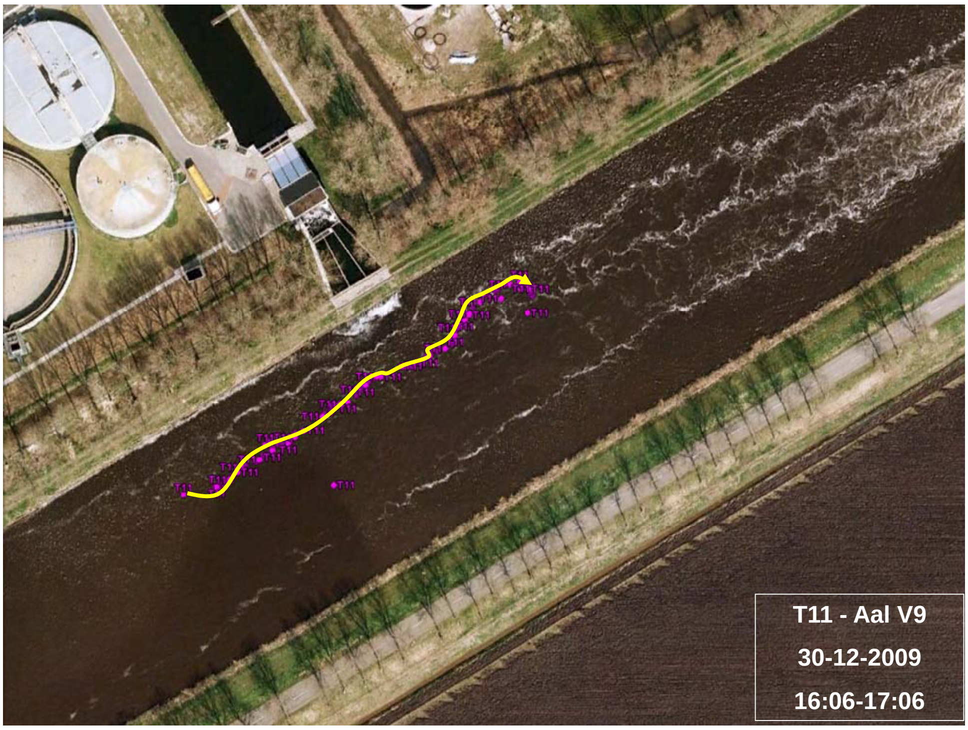
12-12-2009
21:17-21:32


T11 - Aal V9
30-12-2009
01:45-16:05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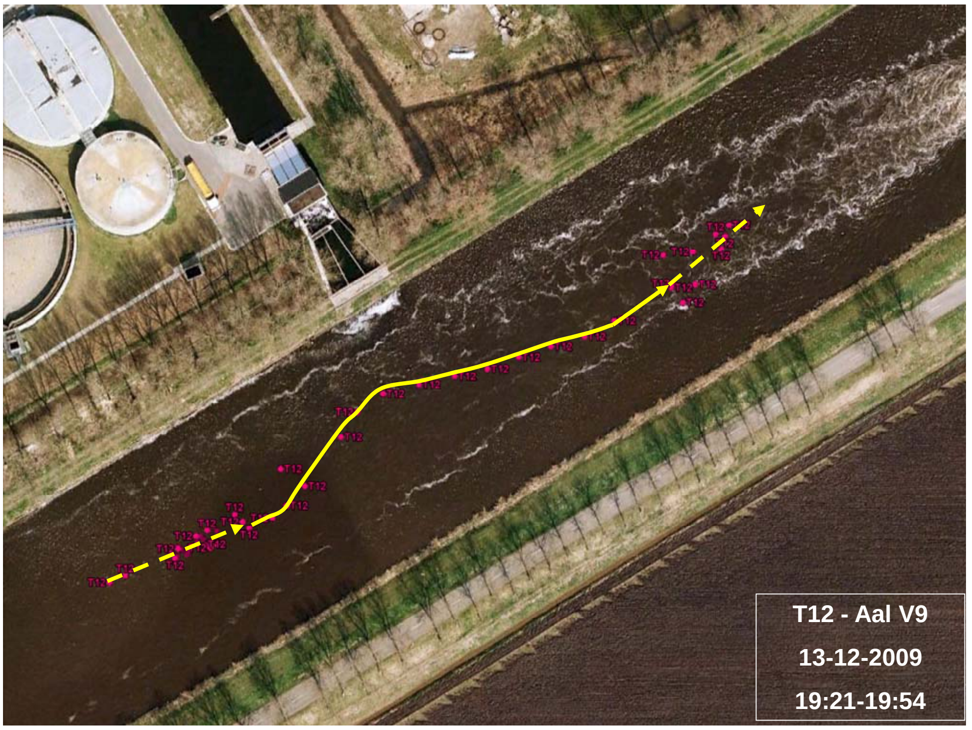
30-12-2009
16:06-17:06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13-12-2009
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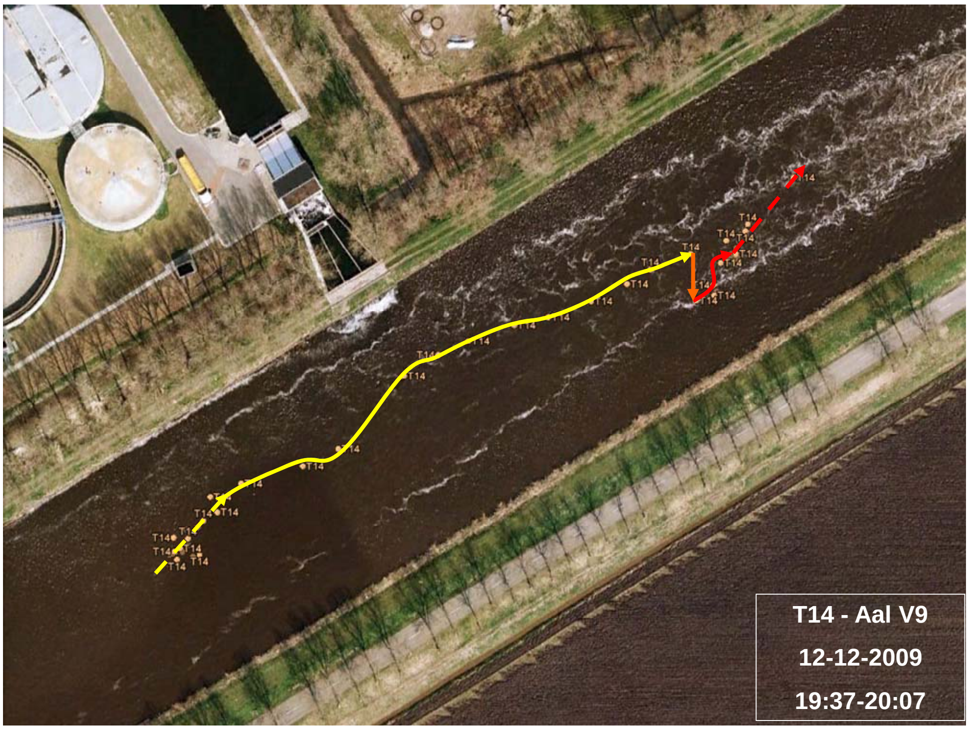
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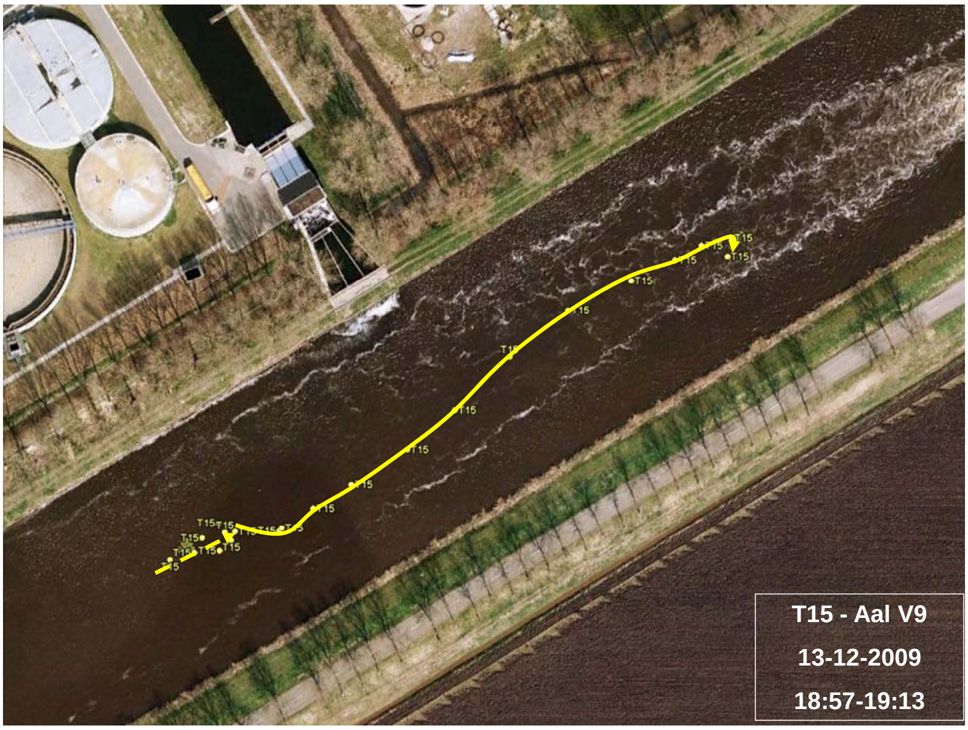
19:37-20:07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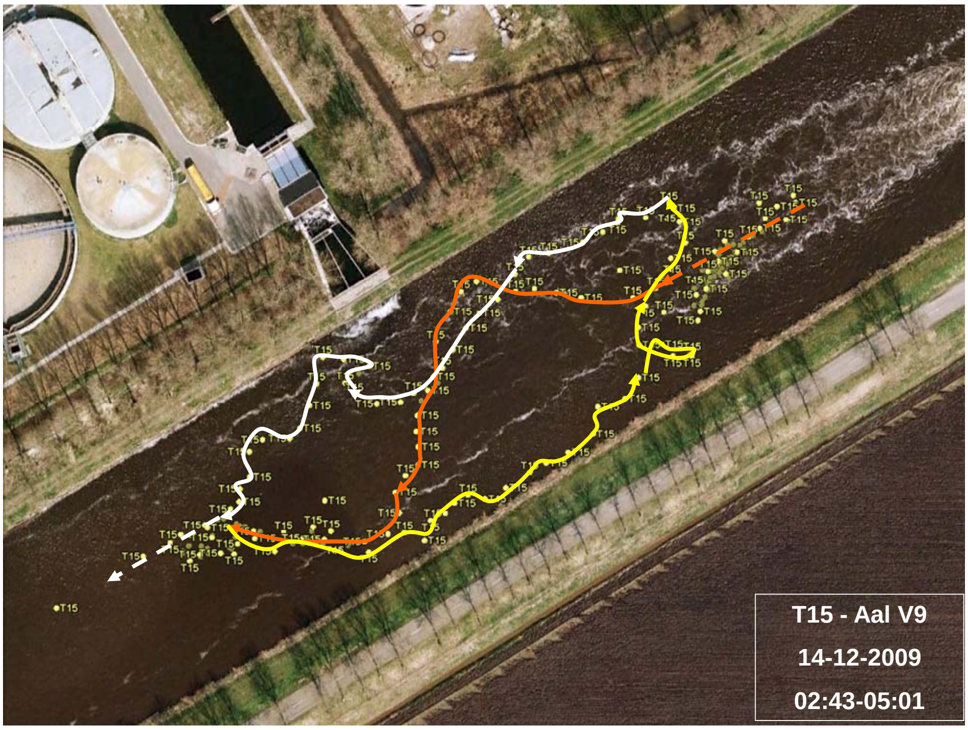
13-12-2009
18:57-19:13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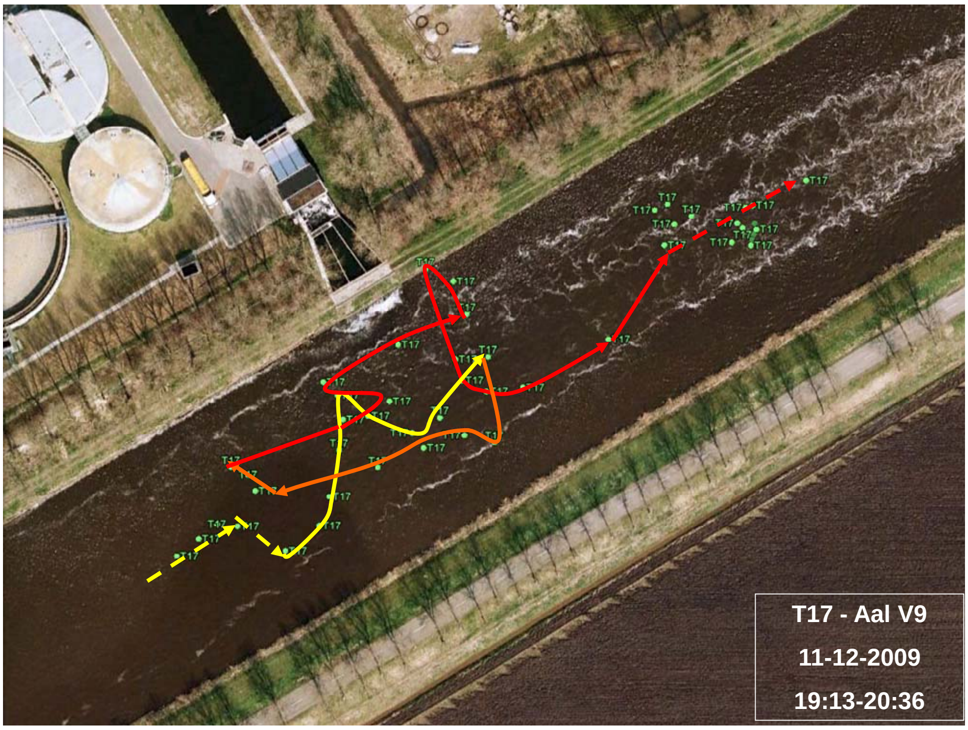
14-12-2009
02:43-05:01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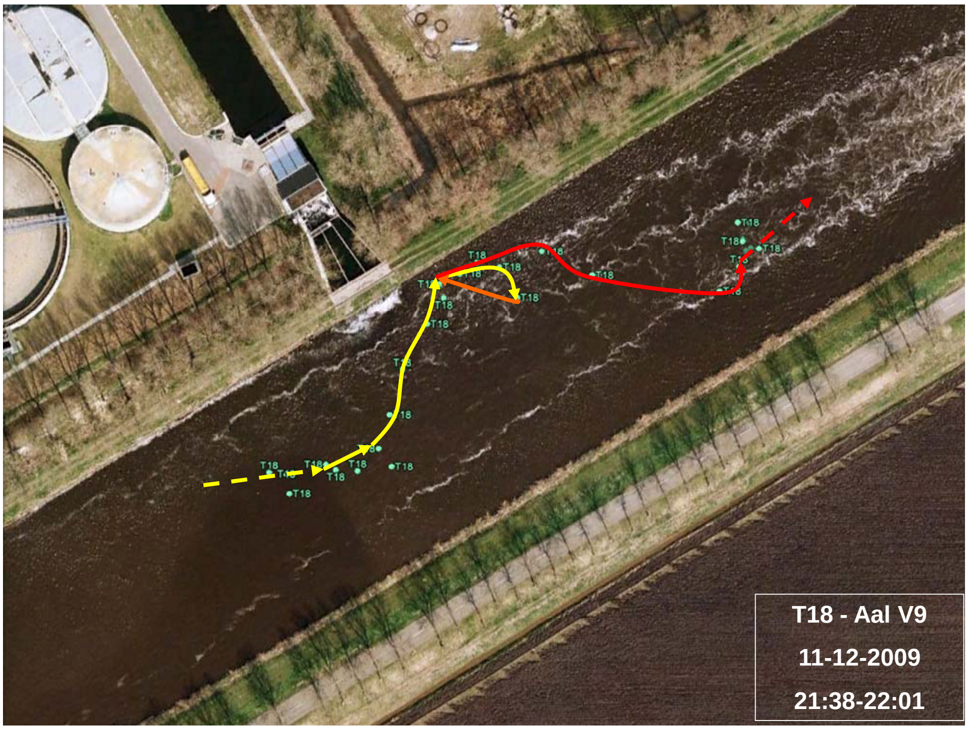
11-12-2009
19:13-20:36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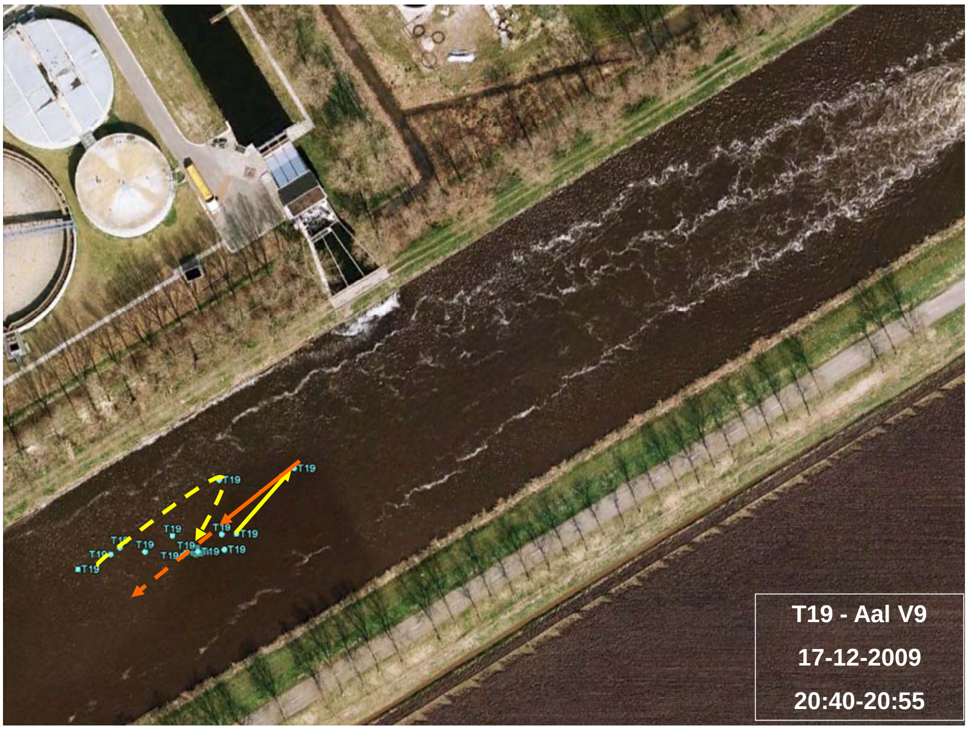
11-12-2009
21:38-22:01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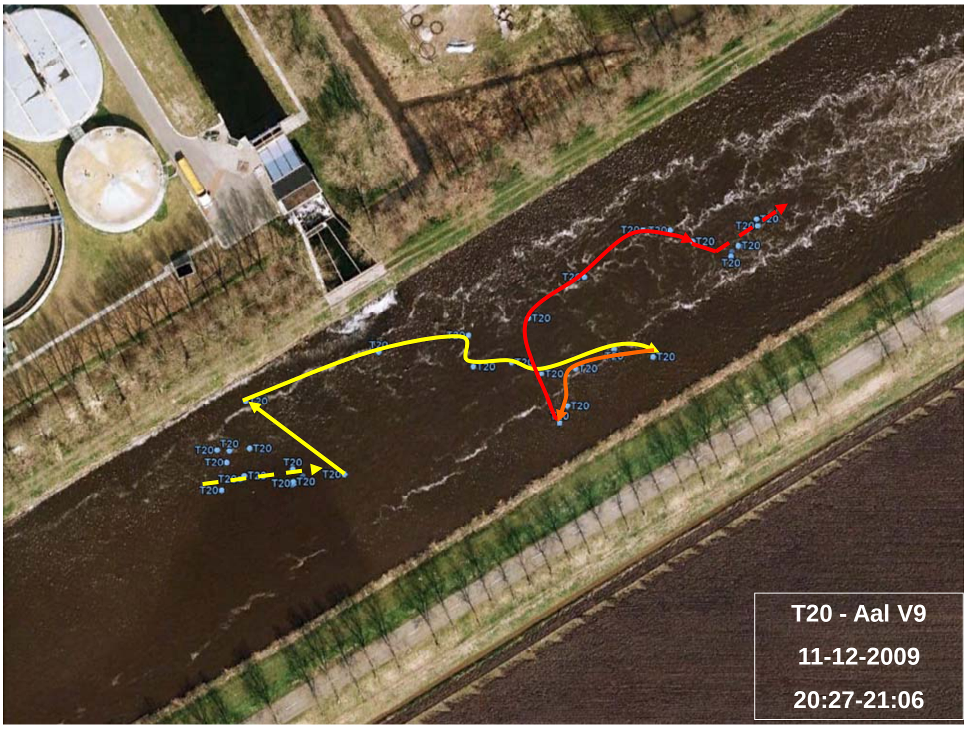
17-12-2009
20:40-20:55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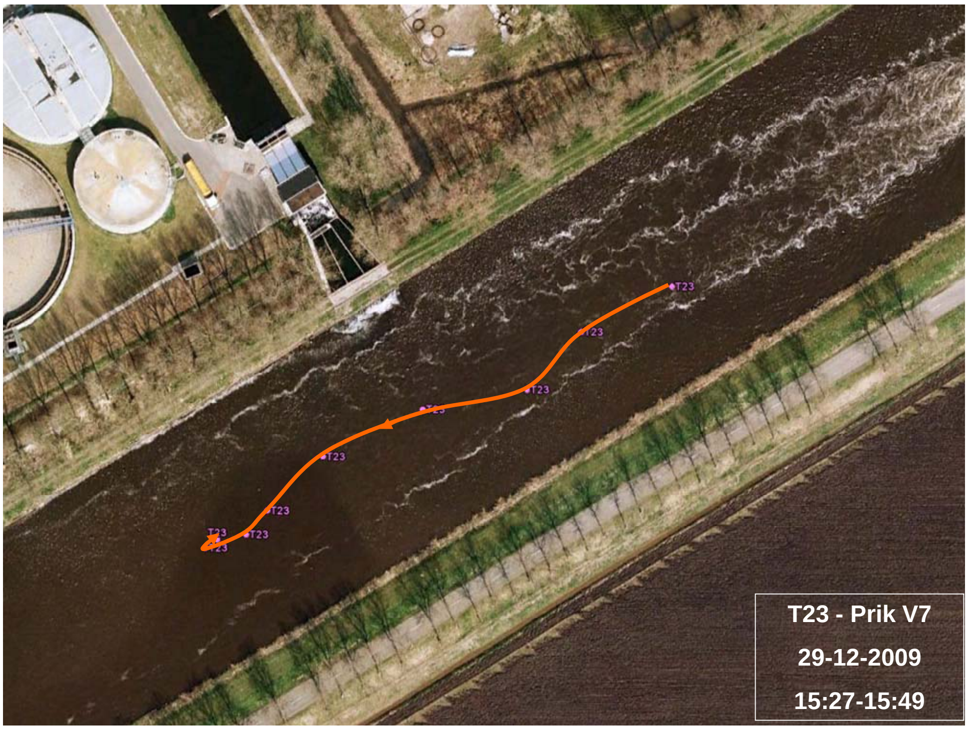
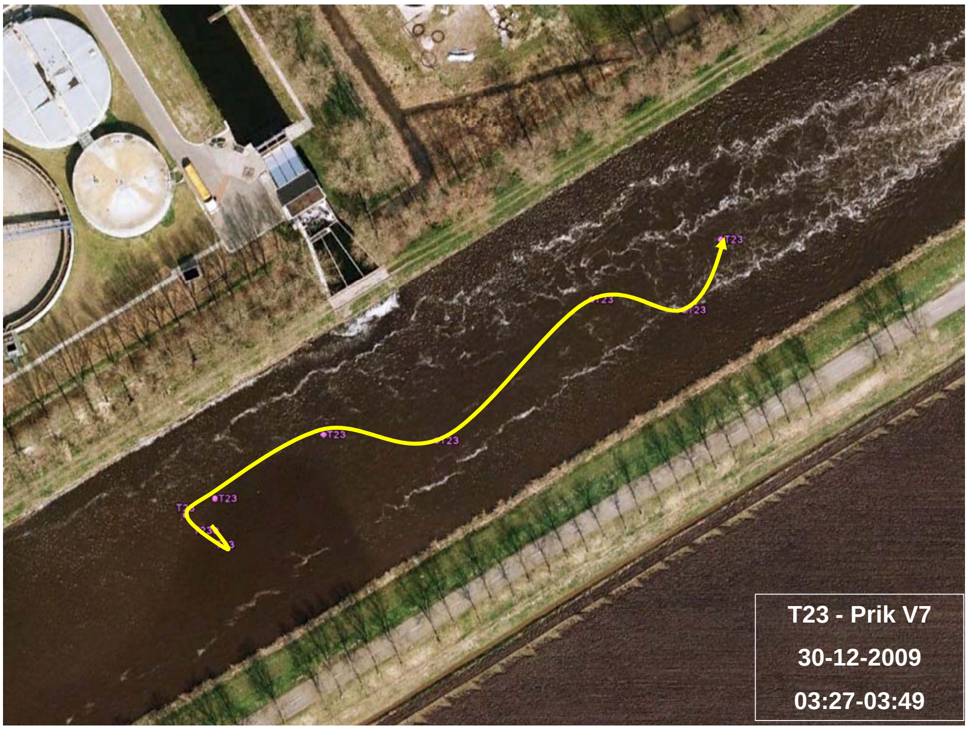


T23 - Prik V7
29-12-2009
15:27-15:49



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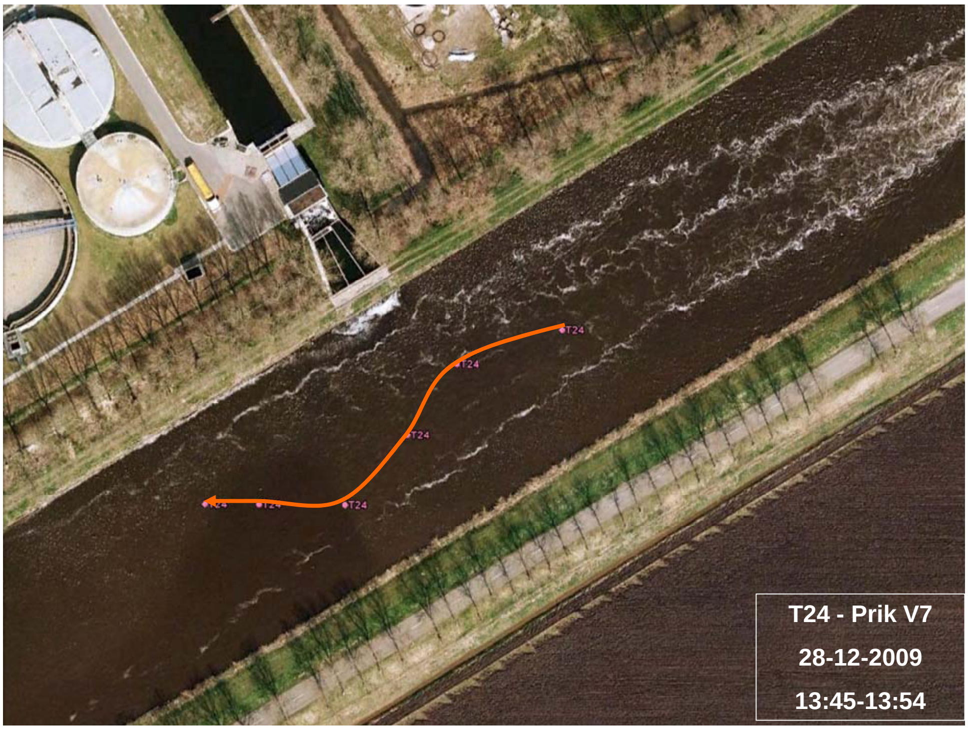
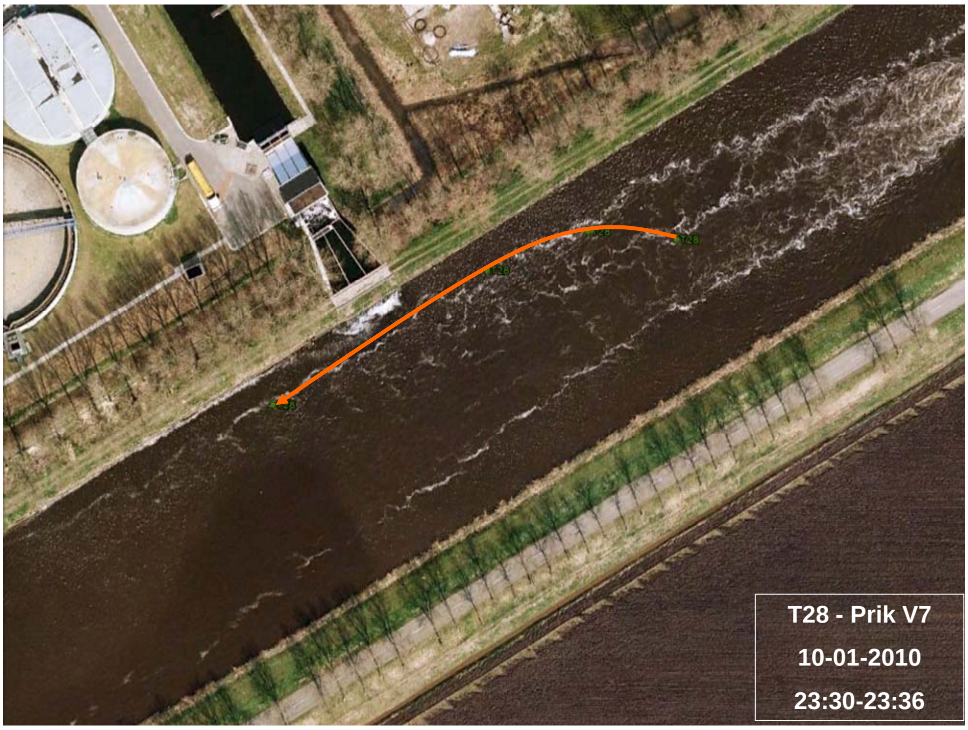
30-12-2009
03:27-03:49


T24 - Prik V7
28-12-2009
13:45-13:54


T28 - Prik V7
10-01-2010
23:30-23:36

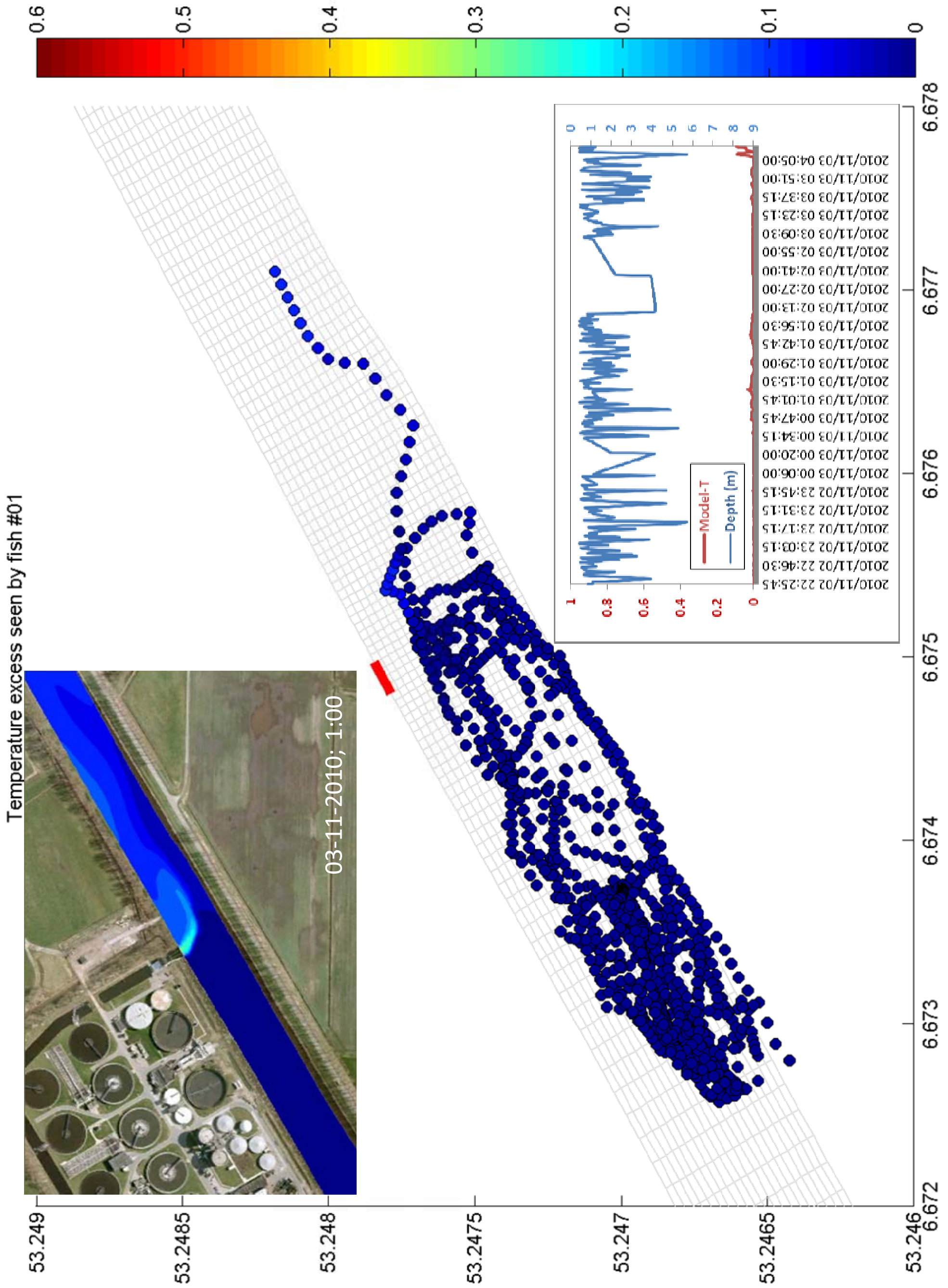
Appendix 2. Individual movement patterns of silver eel at the study site Groningen during the 2010 experiment.

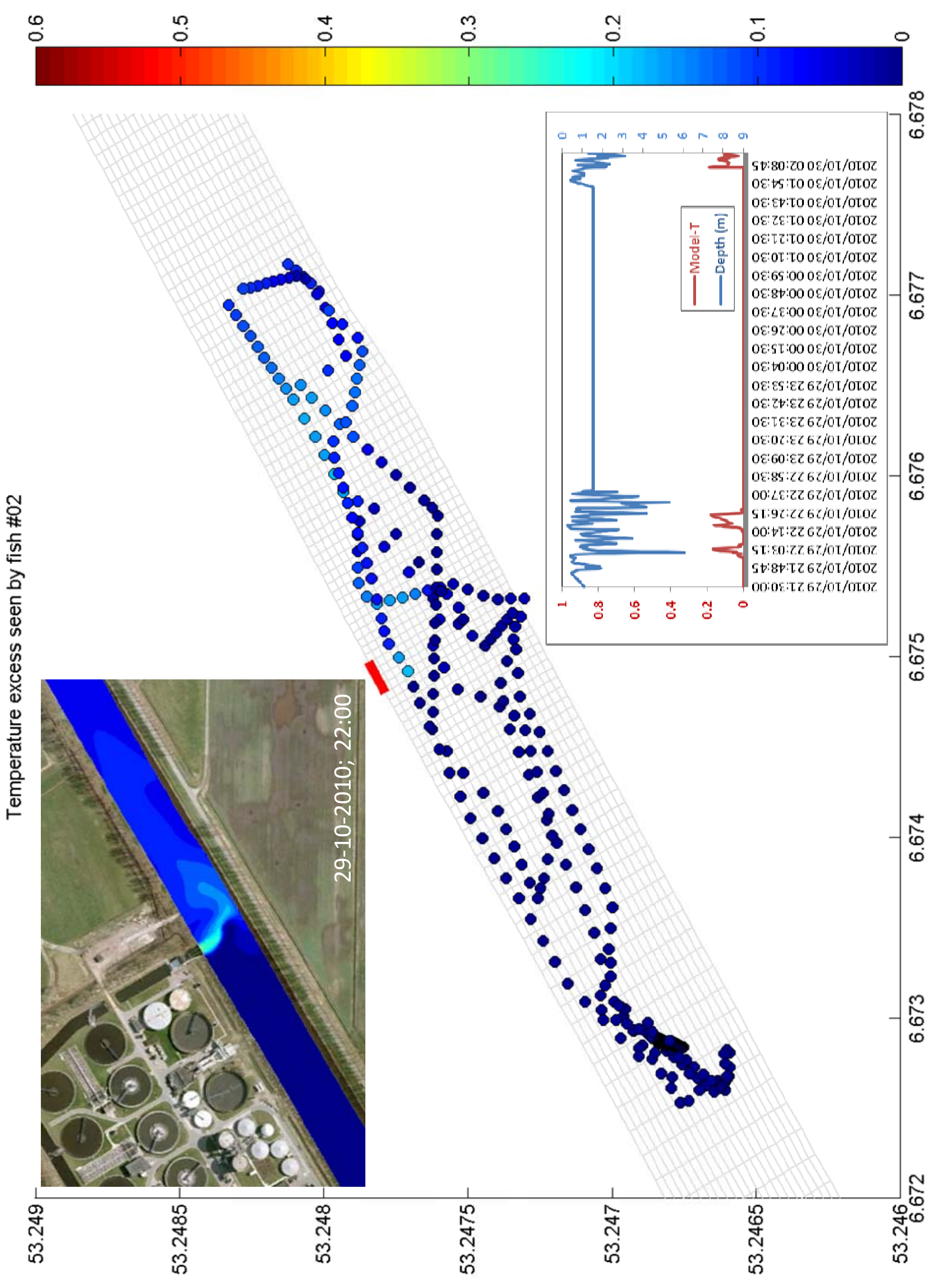
Each page covers the data associated with one eel (numbered from #01 to #20). #17 did not show up in the study area.

Each panel in the left top represents a top view of the study site with the outlet of the waste water located on the North side of the canal and the plume dimensions and strength at the date and time that the silver eel first confronted the plume. The scale of the plume strength is given in the right hand bar, starting from 0 i.e. no plume influence to 0.6 i.e. strong plume influence.

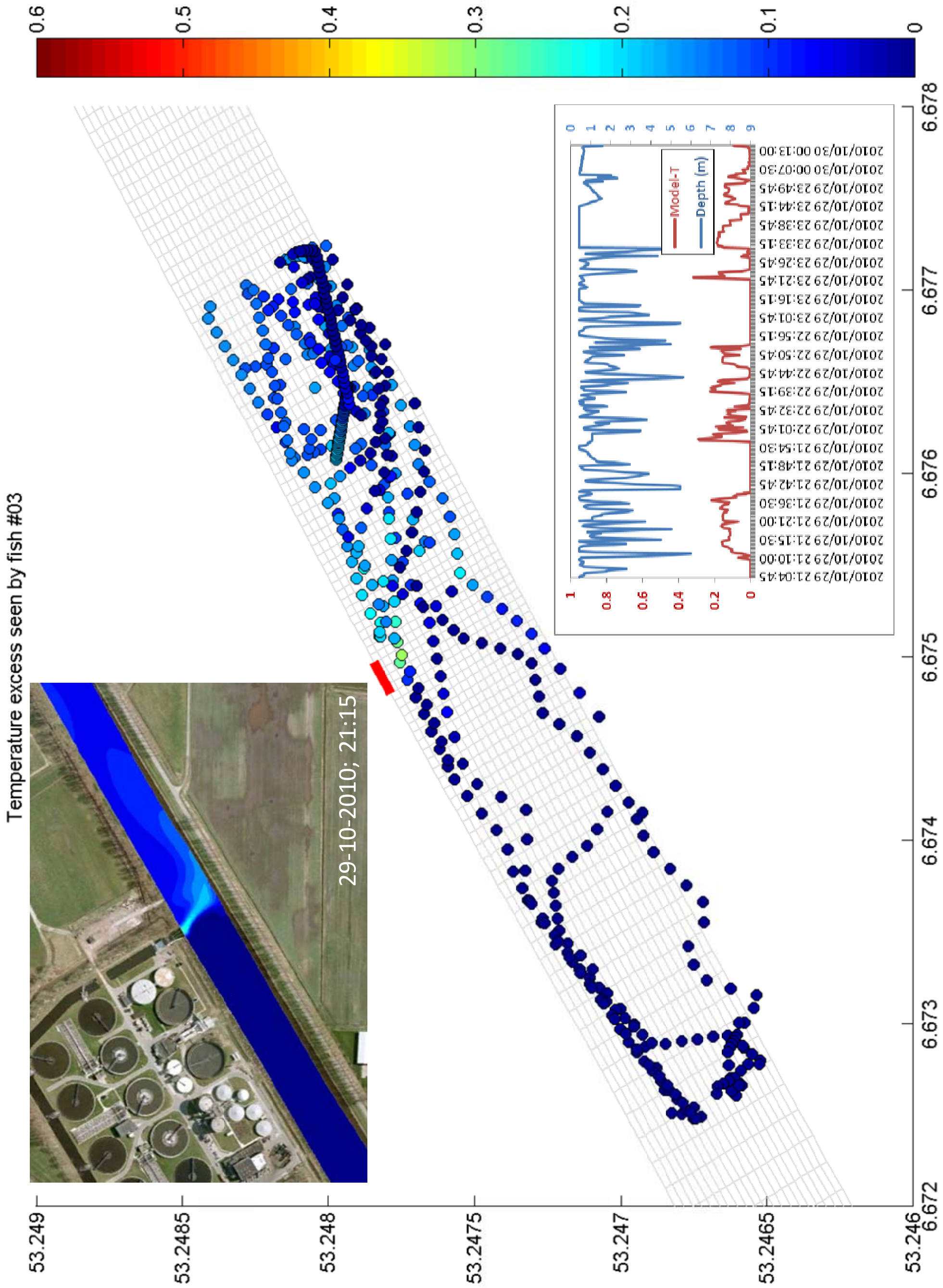
The diagonal panel in the middle represents a top view (in 2D) of the study site in the canal in which each 15 s position point of the particular silver eel. Water flows from left to right. The colour of each data point represents the experienced plume strength by the eel at its 3D position (taking depth into account). The outlet of the waste water discharge is indicated with a red line at the north side of the canal.

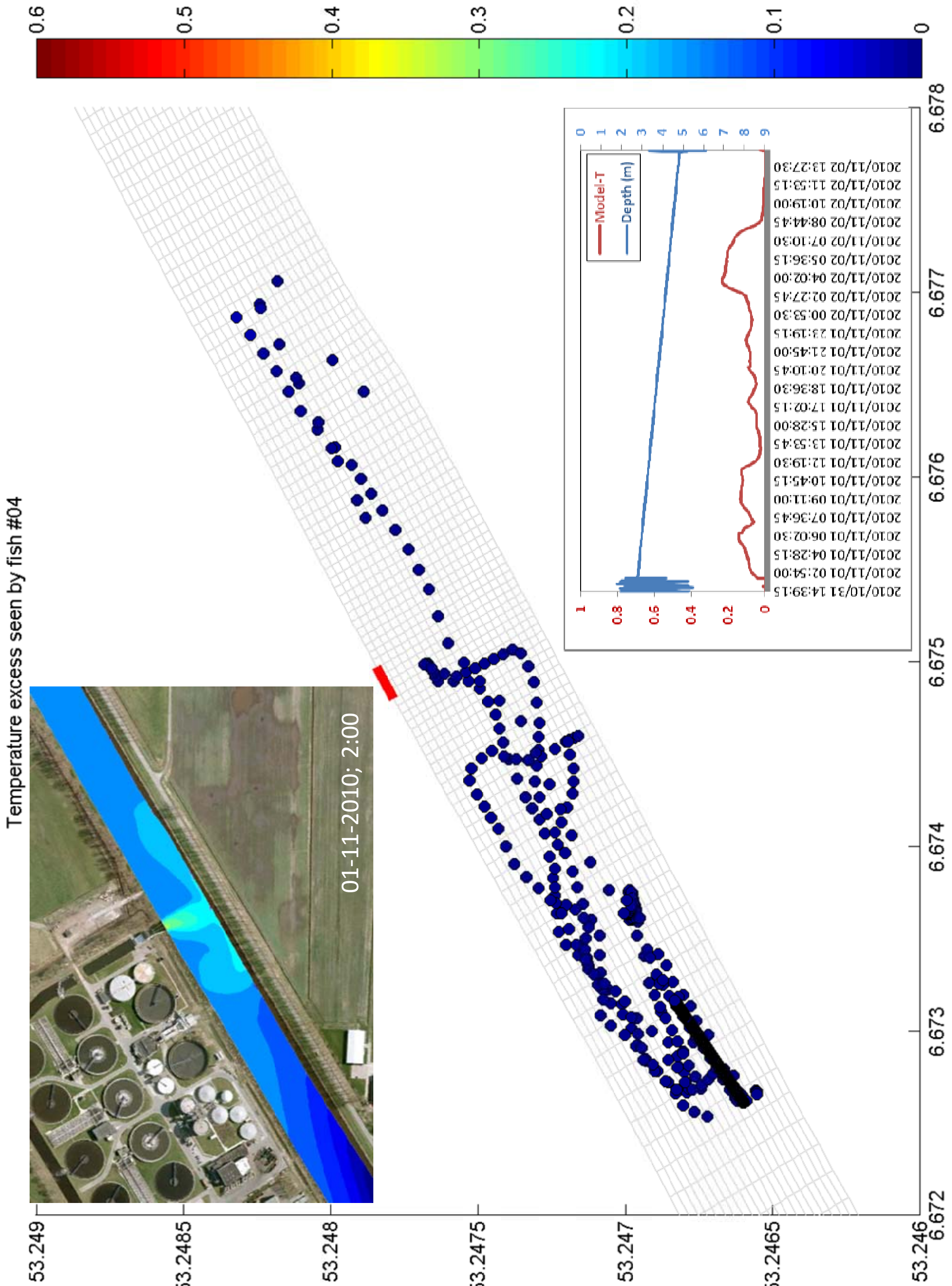
The right hand lower panel represents the modeled plume strength that is experienced by the eel in time (in red) compared with the water depth (in meters below the water surface) that the eel was swimming in time (in blue) during its presence in the study area.


Temperature excess seen by fish #01
03-11-2010; 1:00
Model-T
Depth (m)
0.6
0.5
0.4
0.3
0.2
0.1
0
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
6.673
6.674
6.675
6.676
6.677
6.678



Temperature excess seen by fish #02
29-10-2010; 22:00
Model-T
Depth (m)
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
6.673
6.674
6.675
6.676
6.677
6.678
0
0.1
0.2
0.3
0.4
0.5
0.6


Temperature excess seen by fish #03
29-10-2010; 21:15
Model-T
Depth (m)


Temperature excess seen by fish #04
01-11-2010; 2:00
Model-T
Depth (m)
0.6
0.5
0.4
0.3
0.2
0.1
0
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
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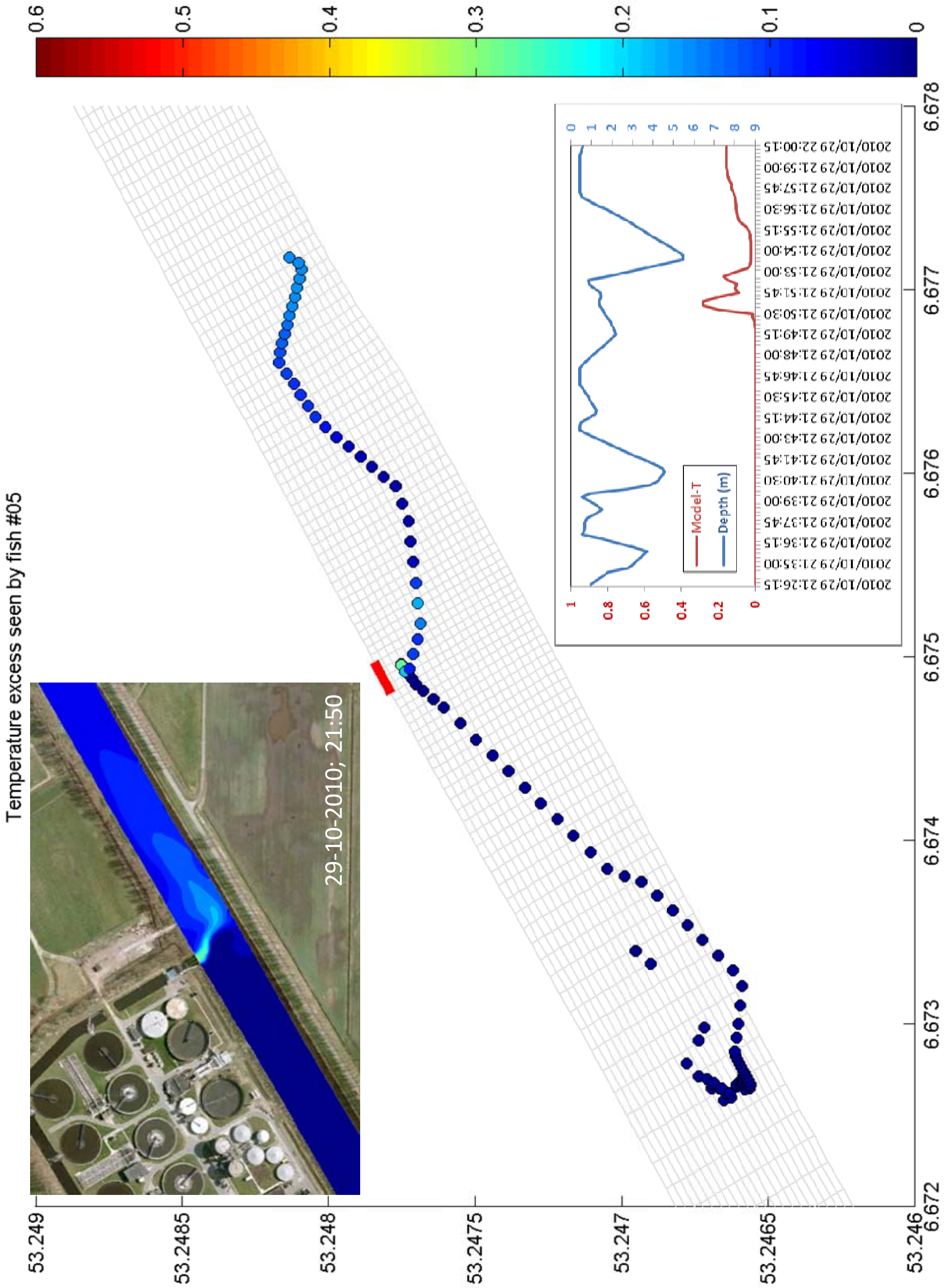
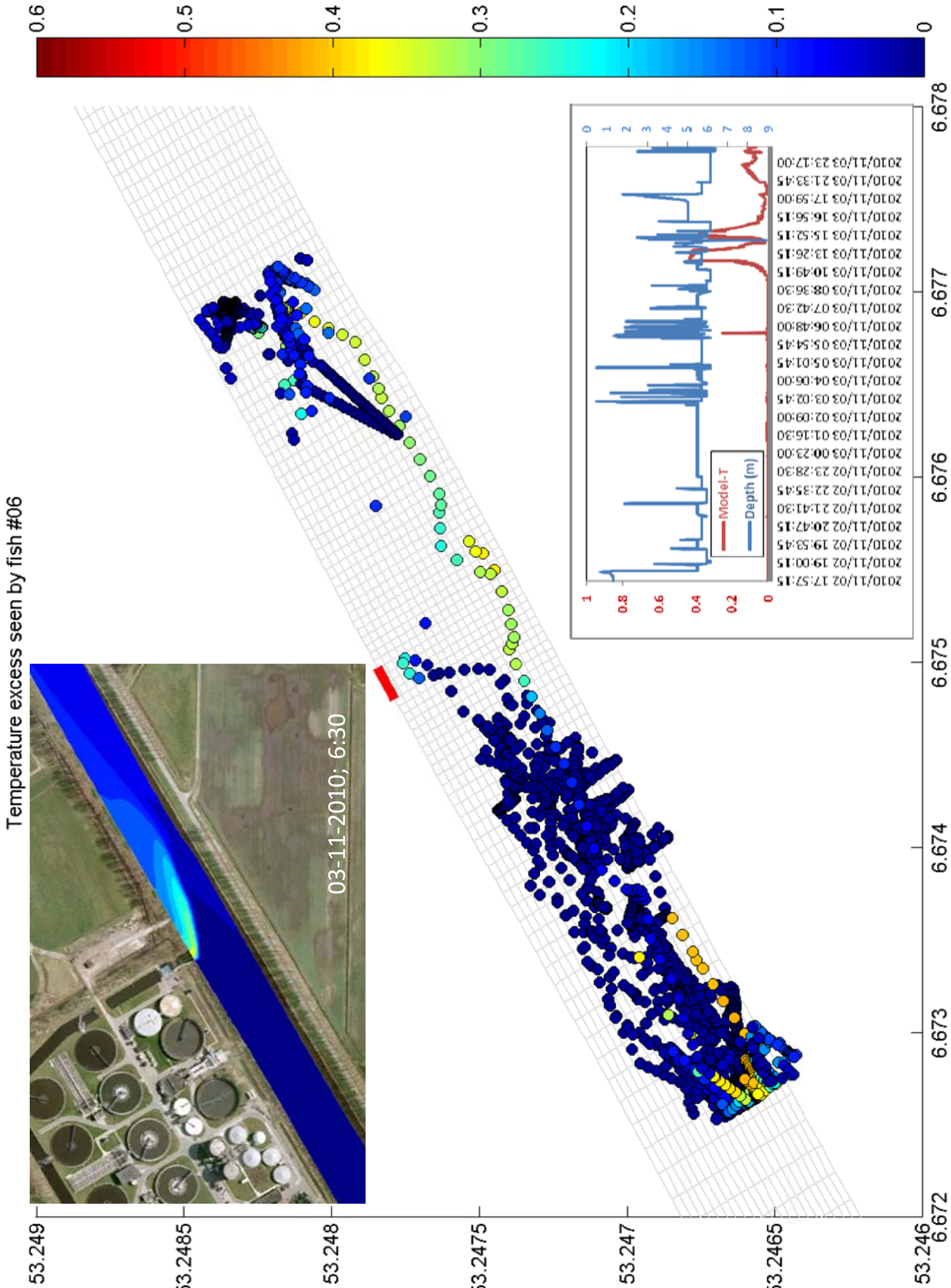
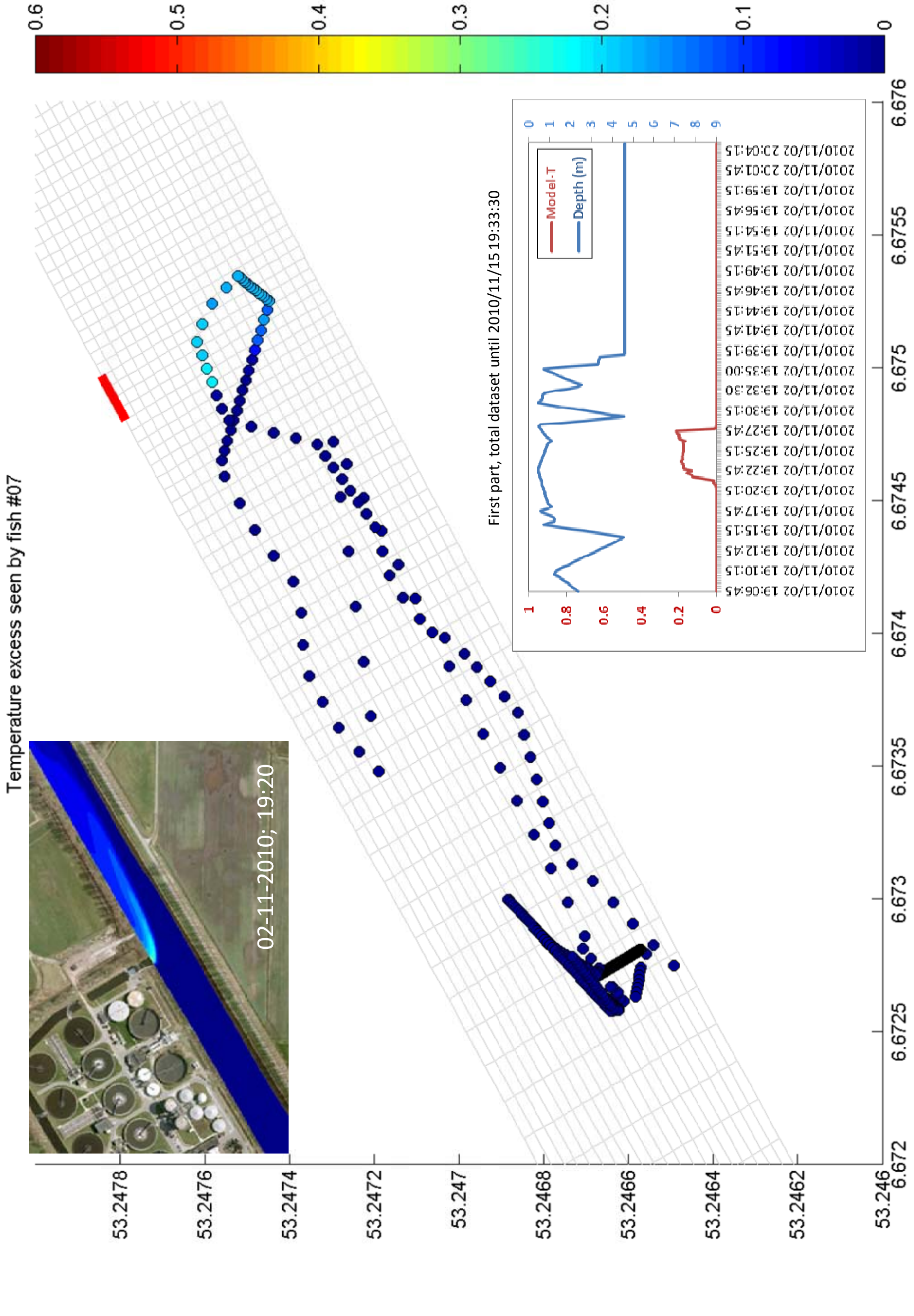
6.676
6.677
6.678



Temperature excess seen by fish #05
29-10-2010; 21:50
Model-T
Depth (m)
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
6.673
6.674
6.675
6.676
6.677
6.678
0
0.1
0.2
0.3
0.4
0.5
0.6



Temperature excess seen by fish #06
03-11-2010; 6:30
Model-T
Depth (m)


Temperature excess seen by fish #07
02-11-2010; 19:20
First part, total dataset until 2010/11/15 19:33:30
Model-T
Depth (m)
0.6
0.5
0.4
0.3
0.2
0.1
0
53.2478
53.2476
53.2474
53.2472
53.247
53.2468
53.2466
53.2464
53.2462
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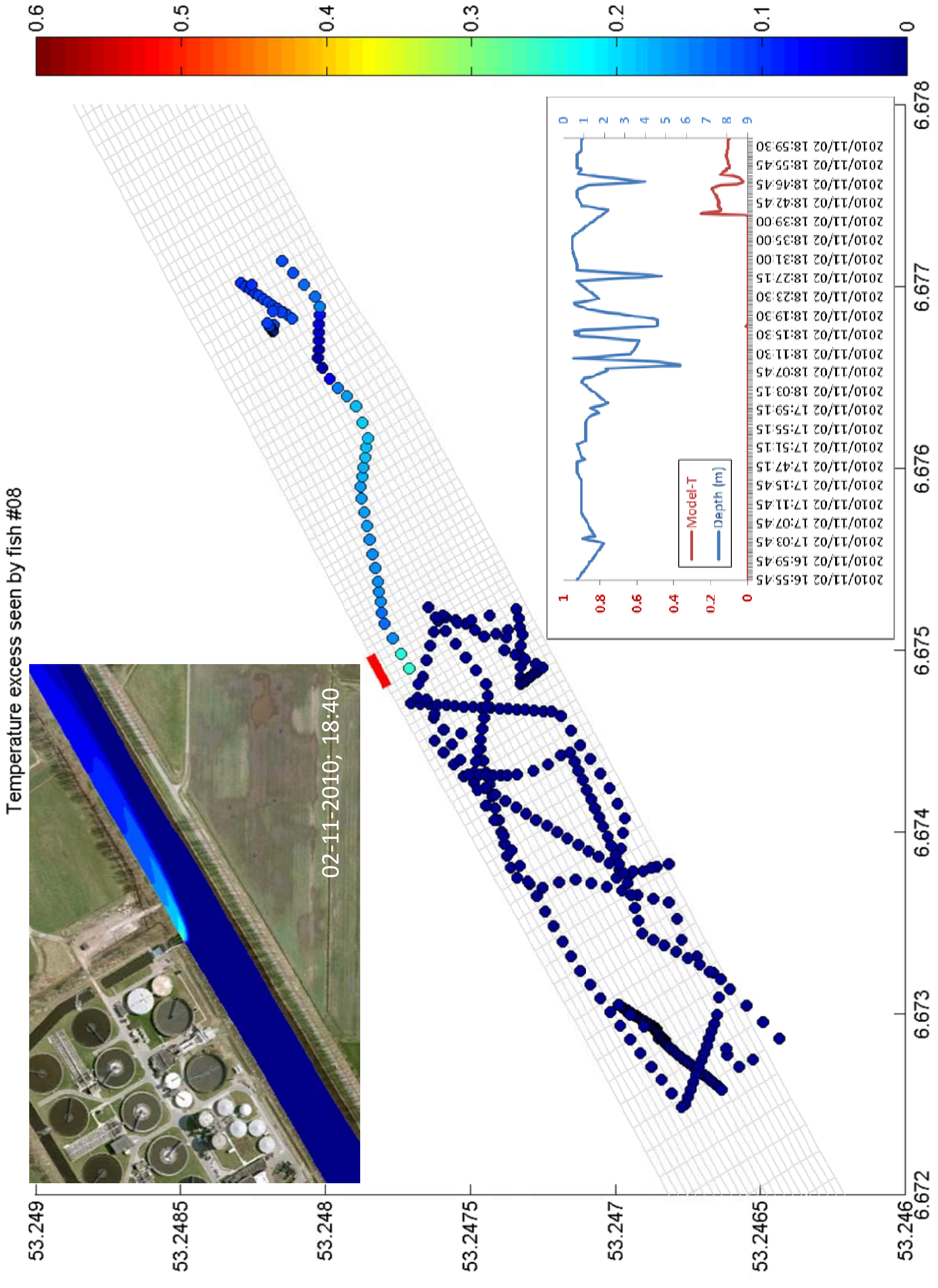
6.675
6.6755
6.676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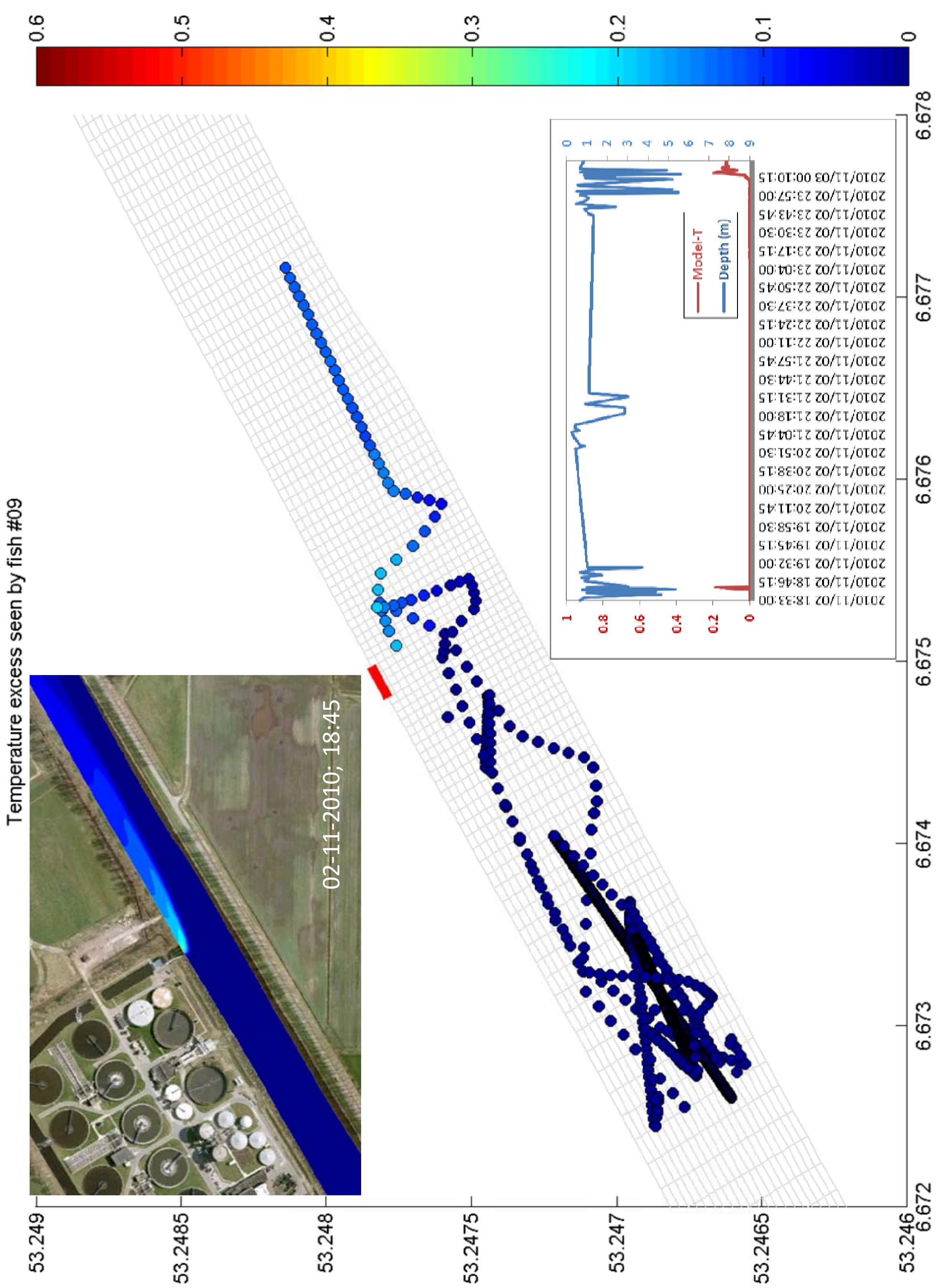
Model-T
Depth (m)



Temperature excess seen by fish #09
02-11-2010; 18:45
Model-T
Depth (m)
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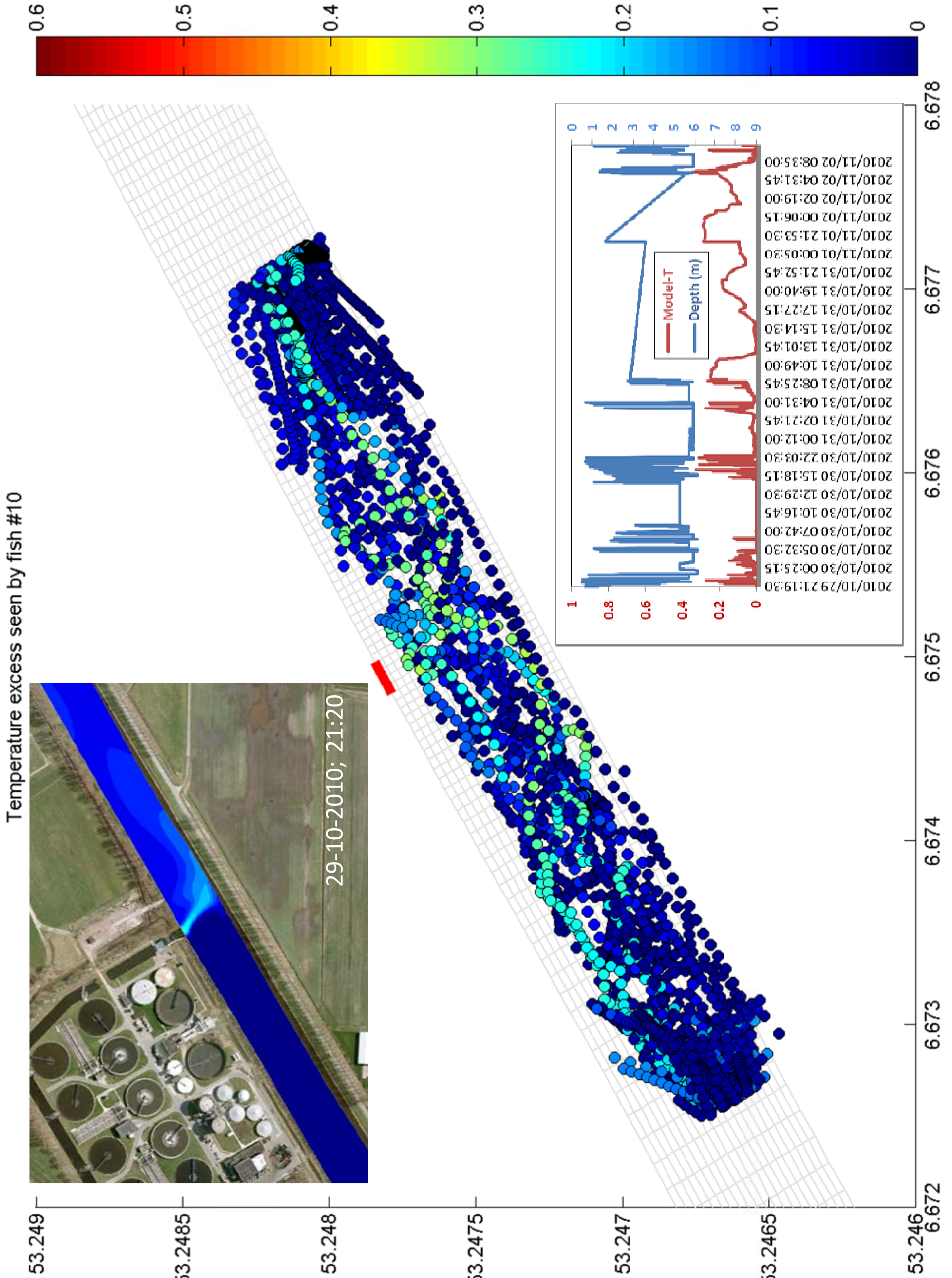
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
6.673
6.674
6.675
6.676
6.677
6.678
0
0.1
0.2
0.3
0.4
0.5
0.6


Temperature excess seen by fish #10
29-10-2010; 21:20
Model-T
Depth (m)
0.6
0.5
0.4
0.3
0.2
0.1
0
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
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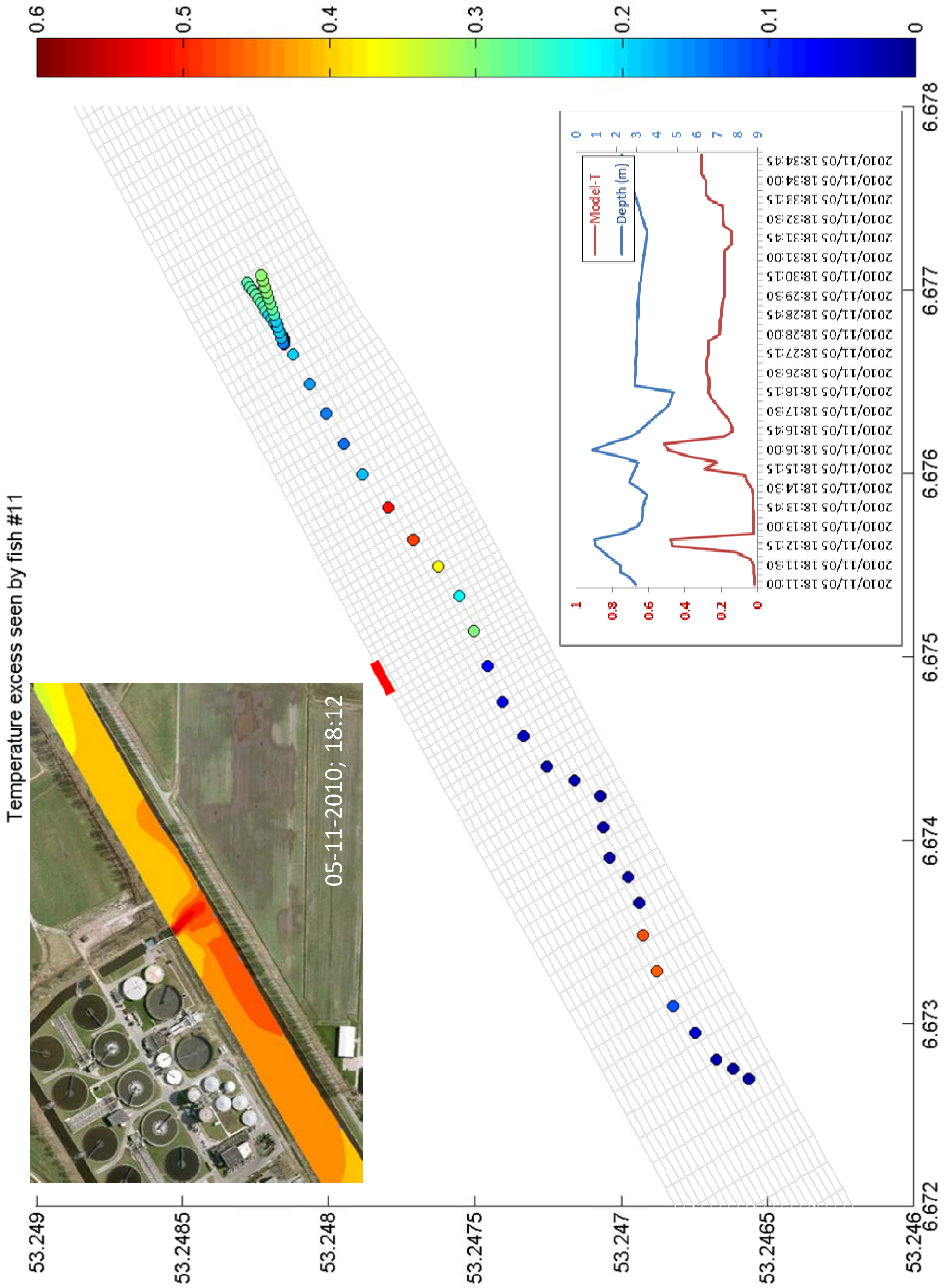
6.676
6.677
6.678


Temperature excess seen by fish #11
05-11-2010; 18:12
Model-T
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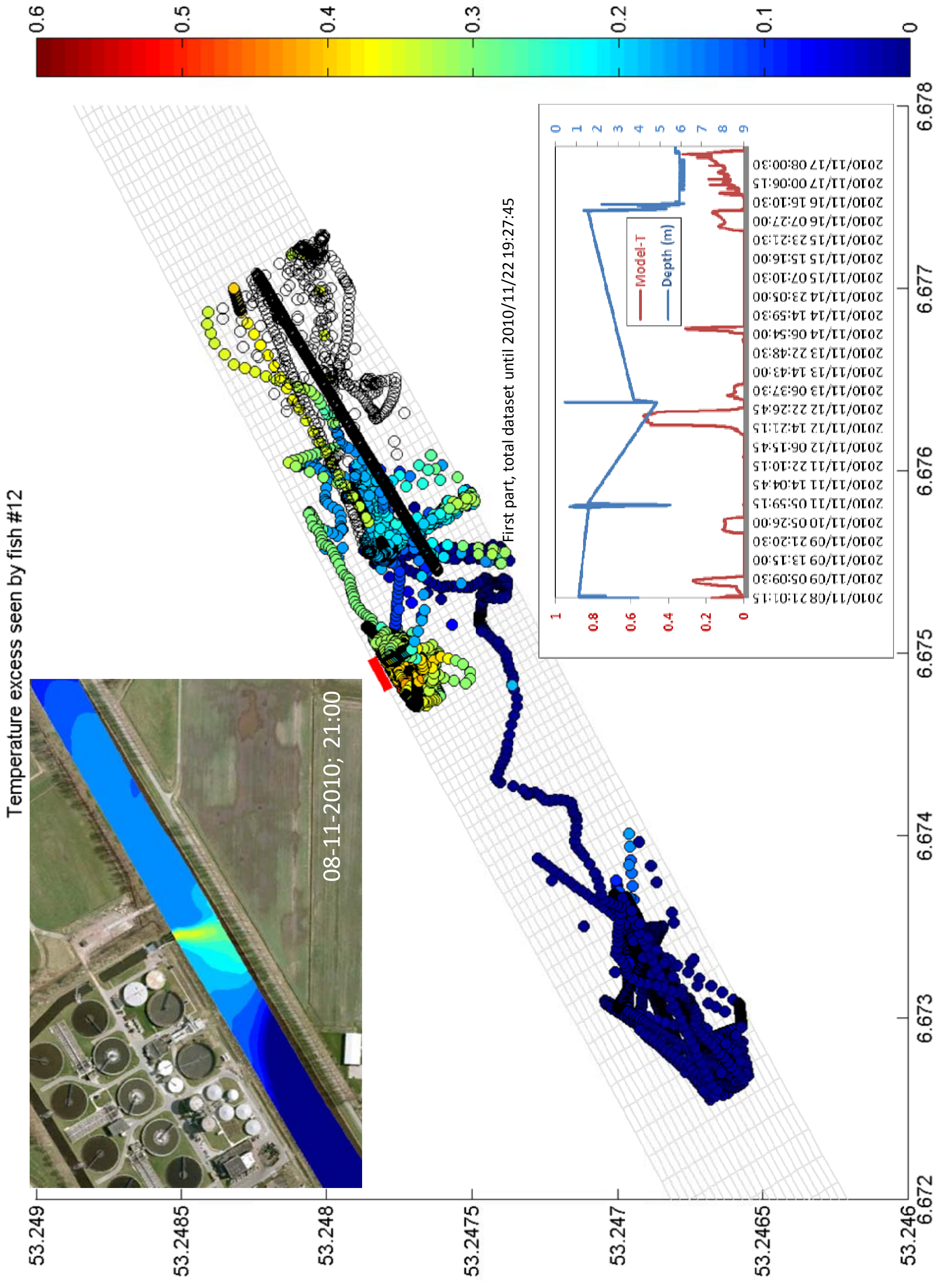
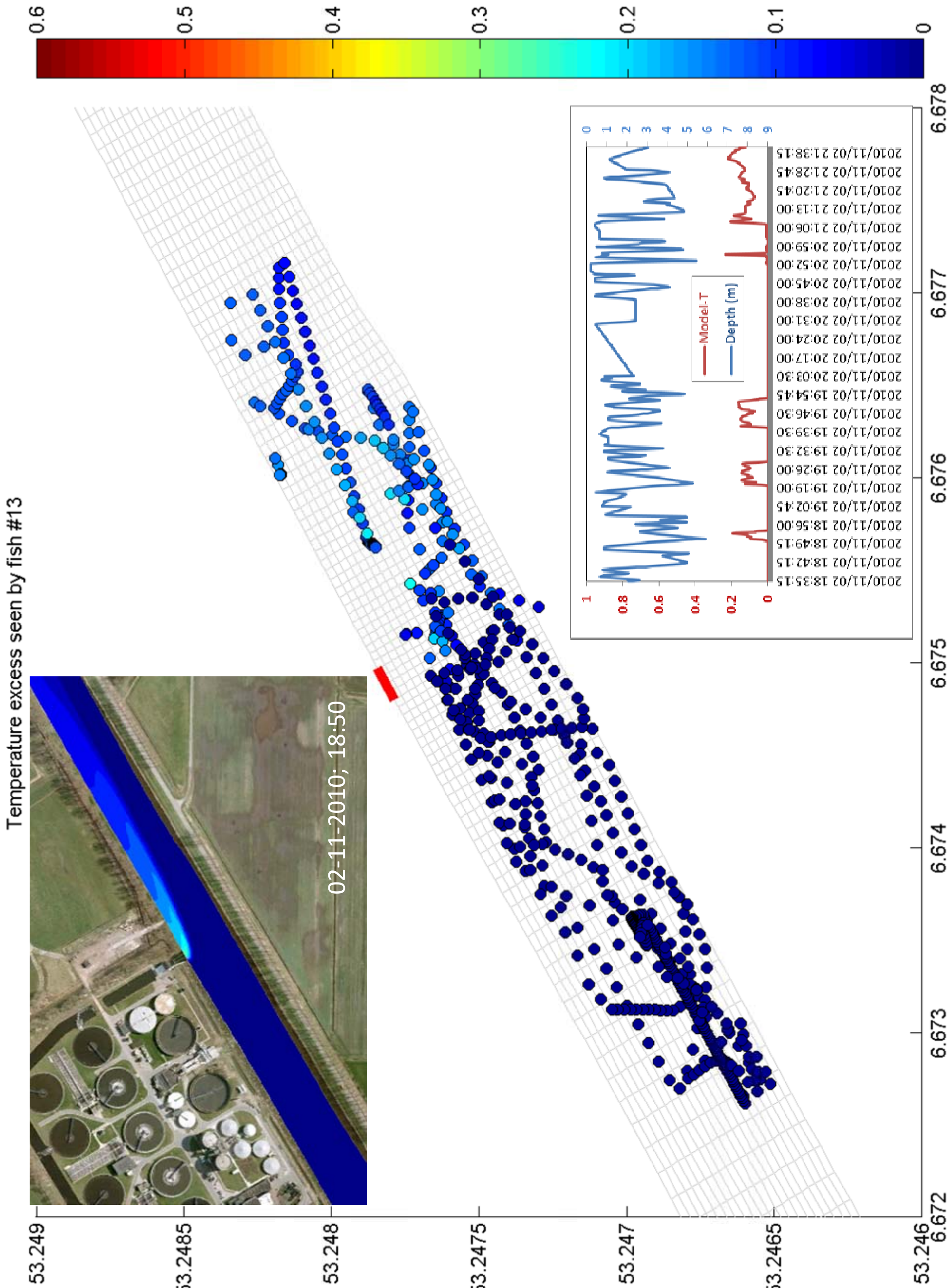
53.248
53.2475
53.247
53.2465
53.246
6.672
6.673
6.674
6.675
6.676
6.677
6.678
0
0.1
0.2
0.3
0.4
0.5
0.6



Temperature excess seen by fish #12
08-11-2010; 21:00
First part, total dataset until 2010/11/22 19:27:45
Model-T
Depth (m)


Temperature excess seen by fish #13
02-11-2010; 18:50
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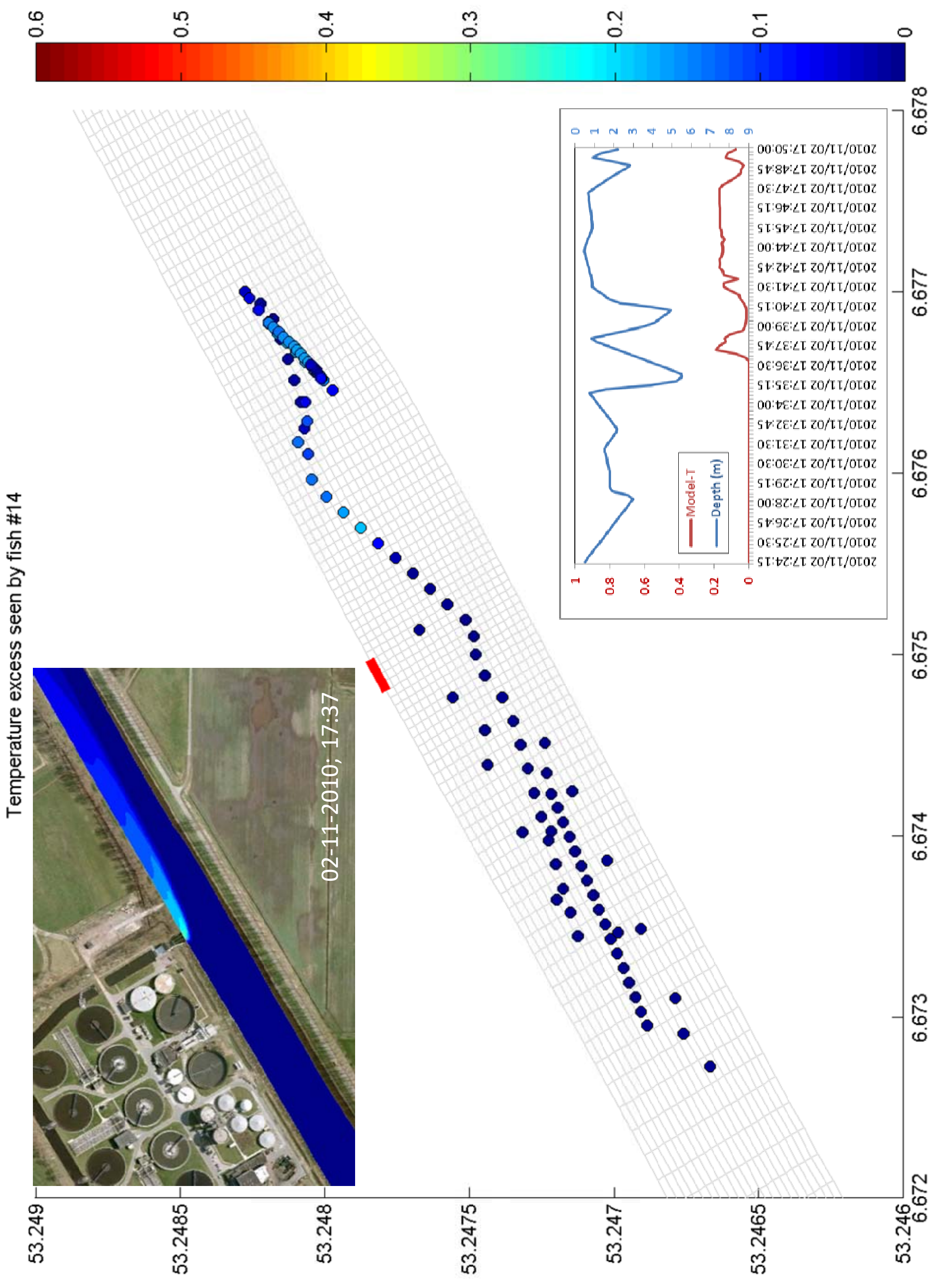
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
6.673
6.674
6.675
6.676
6.677
6.678
0.6
0.5
0.4
0.3
0.2
0.1
0
Model-T
Depth (m)


Temperature excess seen by fish #14
02-11-2010; 17:37
Model-T
Depth (m)
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0.5
0.4
0.3
0.2
0.1
0
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
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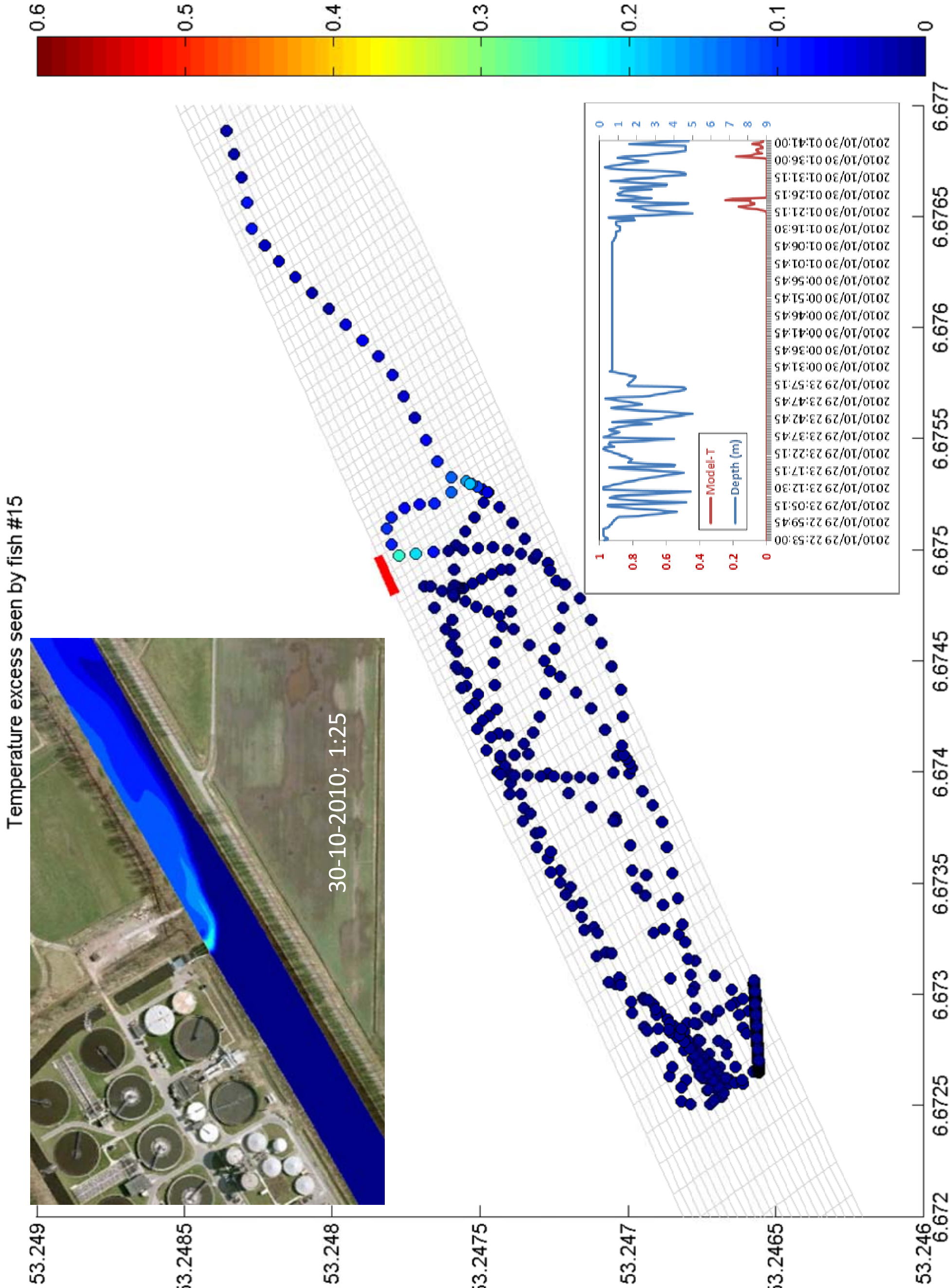
6.676
6.677
6.678


Temperature excess seen by fish #15
30-10-2010; 1:25
Model-T
Depth (m)
0.6
0.5
0.4
0.3
0.2
0.1
0
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
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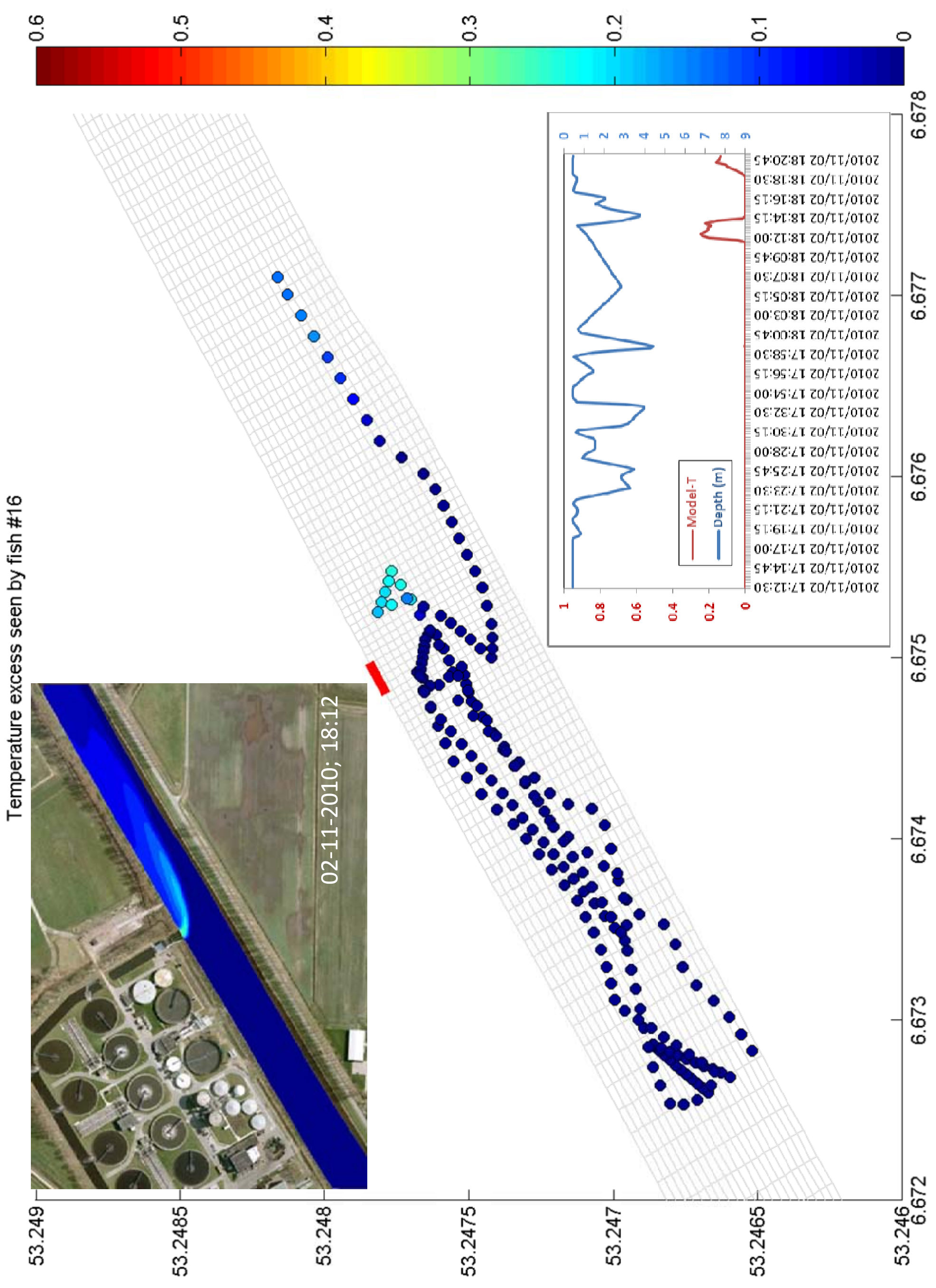
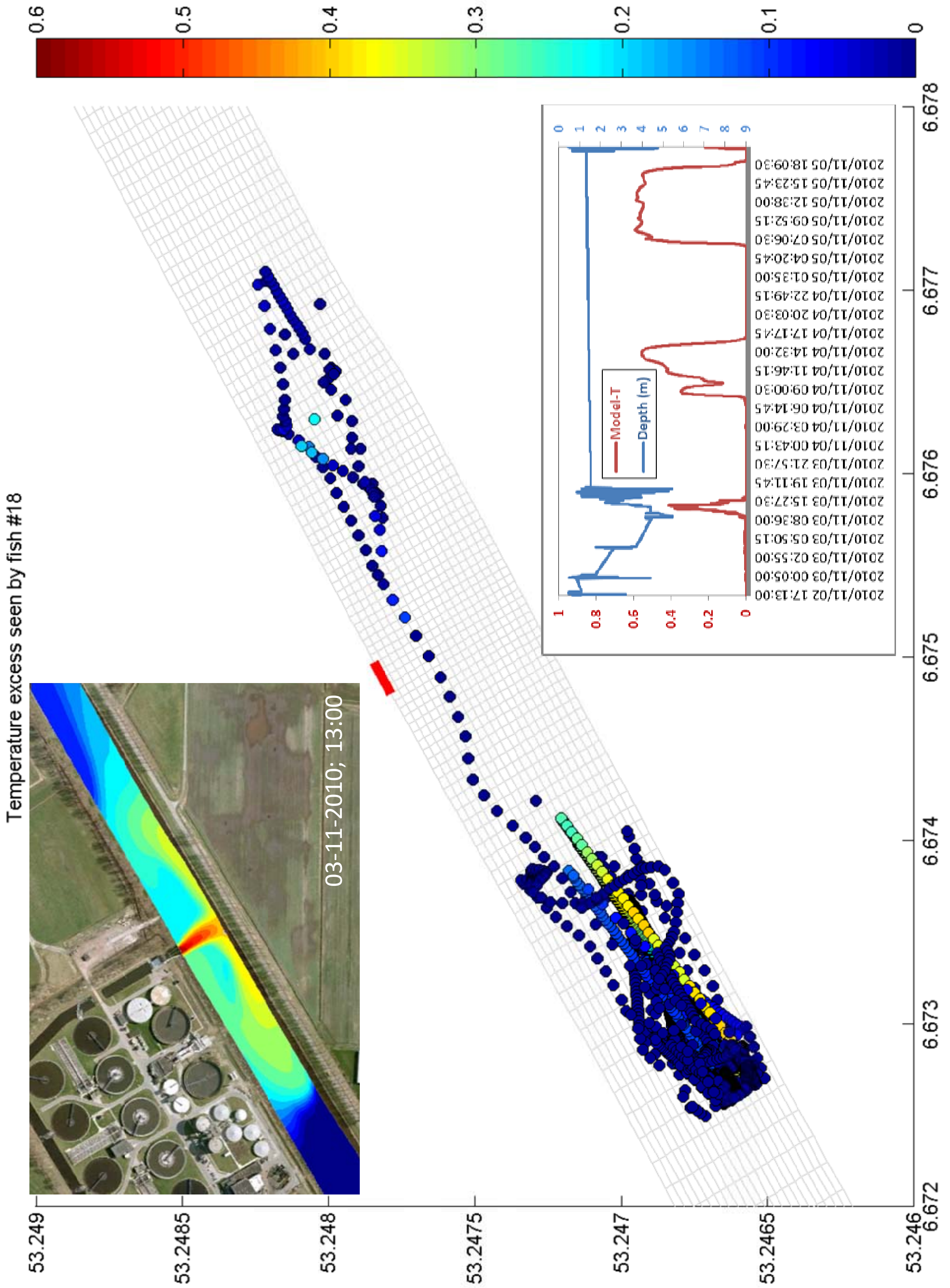
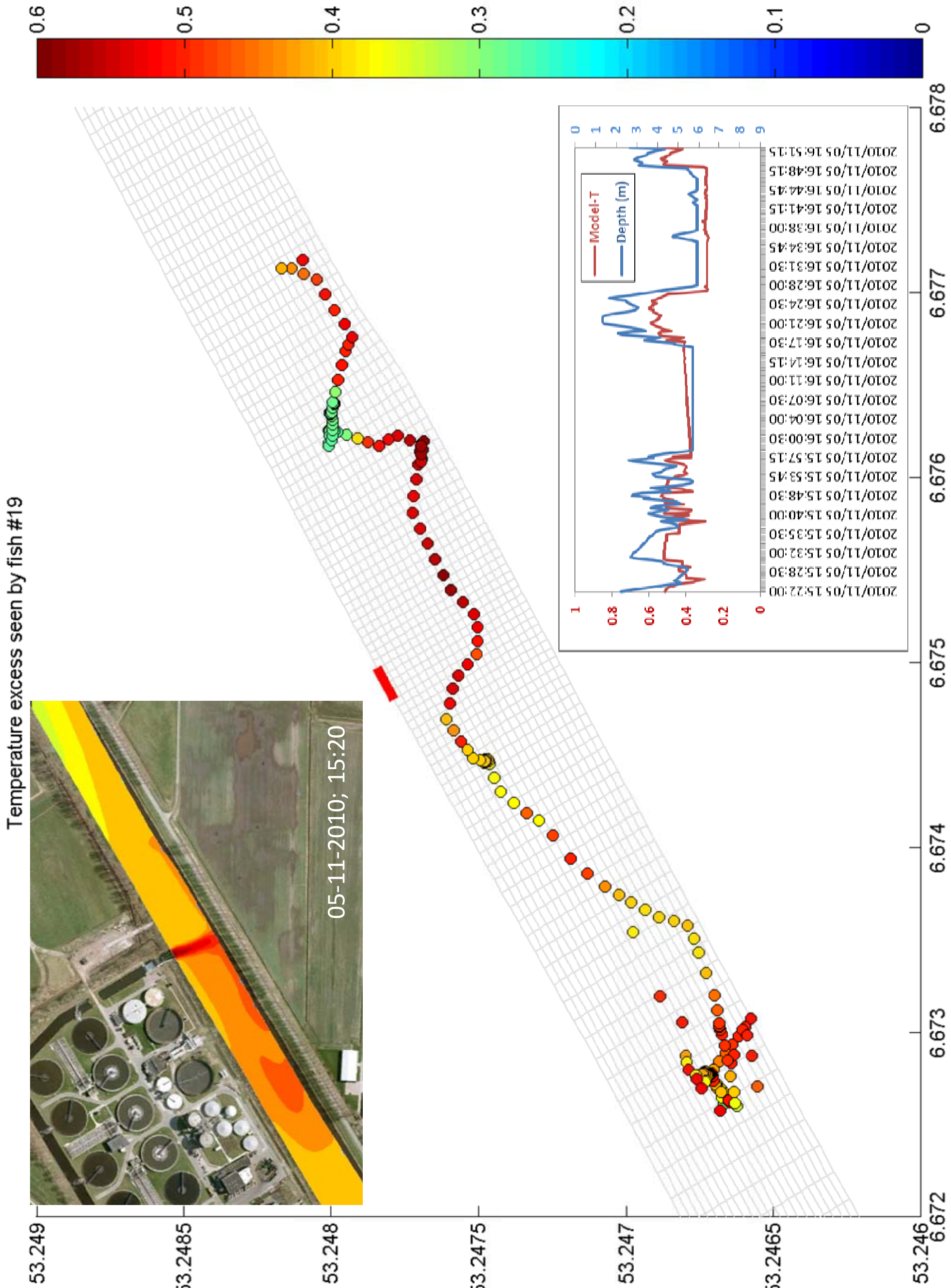
6.676
6.6765
6.677

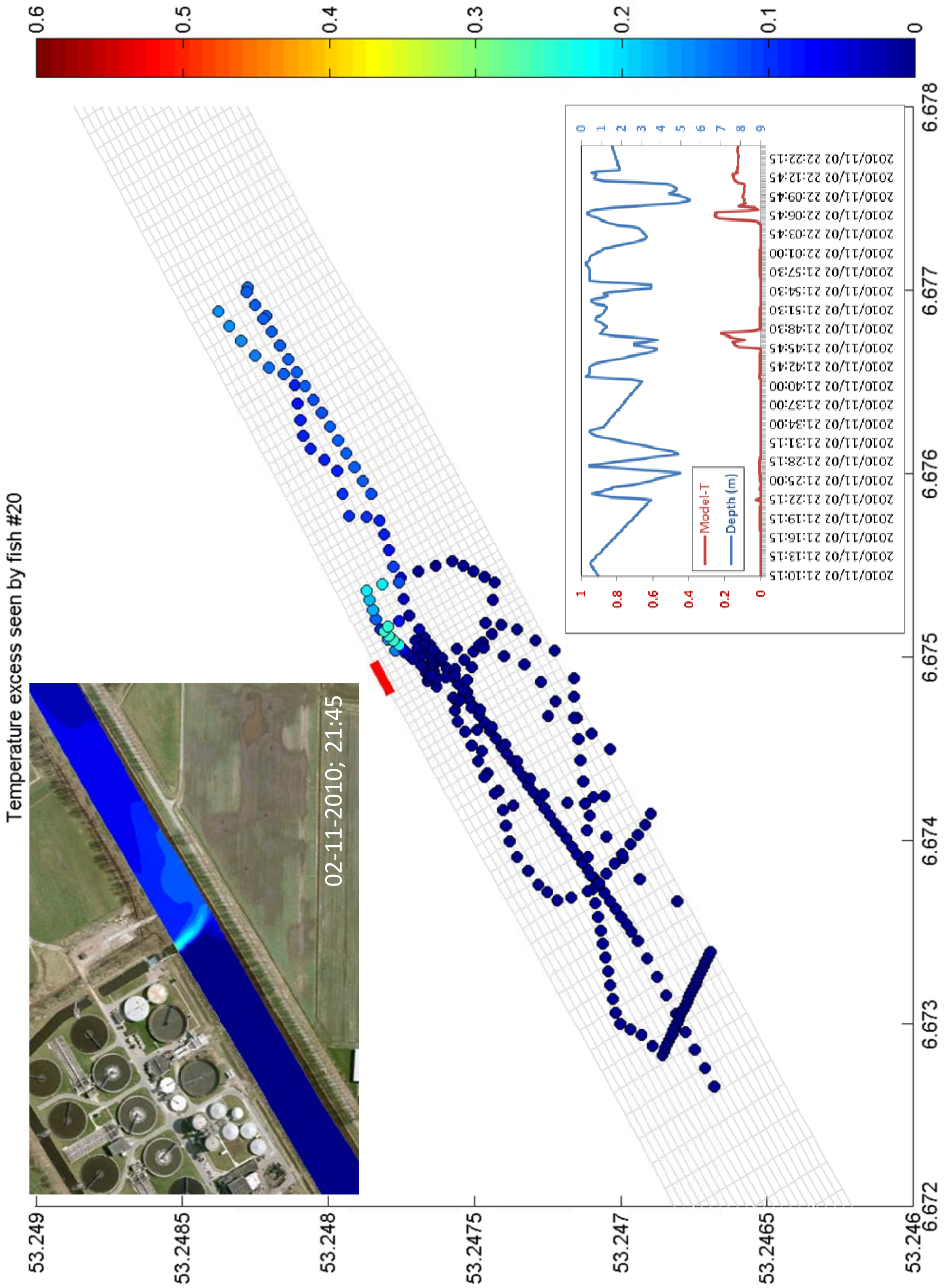

Temperature excess seen by fish #16
02-11-2010; 18:12
Model-T
Depth (m)



Temperature excess seen by fish #18
03-11-2010; 13:00
Model-T
Depth (m)
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
6.673
6.674
6.675
6.676
6.677
6.678
0
0.1
0.2
0.3
0.4
0.5
0.6



Temperature excess seen by fish #19
05-11-2010; 15:20
Model-T
Depth (m)


Temperature excess seen by fish #20
02-11-2010; 21:45
Model-T
Depth (m)
53.249
53.2485
53.248
53.2475
53.247
53.2465
53.246
6.672
6.673
6.674
6.675
6.676
6.677
6.678
0
0.1
0.2
0.3
0.4
0.5
0.6