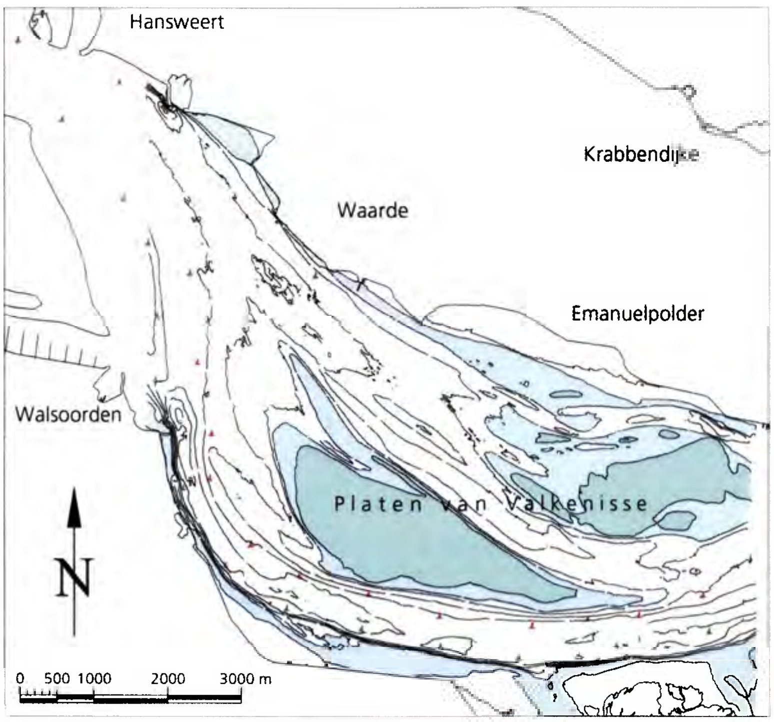
CURRENT MEASUREMENTS IN THE WESTERSCHELDE SEPTEMBER AND OCTOBER 2002



Hochschule Bremen
Institut für Wasserbau
Neustadtswall 30
28199 Bremen

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1. Introduction

The waterway that connects Antwerp with the North Sea is dredged to a depth of −12.2 m LLWS (decreasing to −11.7 m LLWS towards Hansweert) (fig. 1). About 43 sea miles have to be covered from the mouth at Vlissingen to reach the Port of Antwerp. Extensive maintenance dredging is necessary in order to preserve the nominal depths. The average annual dredging effort is about 12 million m³ (information from Waterbouwkundig Laboratorium Antwerpen).

Fig .1: Westerschelde from the Mouth to Antwerp

In connection with this, the question rises, how the costs for the disposal of dredge spoil can be minimized. In principal the dredged material can be either deposited in flushing fields or it can be dumped in a suitable region in the tidal river. For economical reasons it should be aspired to achieve short transport distances between dredging and dumping areas.

The institutions responsible for maintenance work in the Westerschelde are discussing alternatives for the disposal of dredged material in the Westerschelde. Therefore investigations in the region of the Platen van Valkenisse are being carried out (fig. 2).

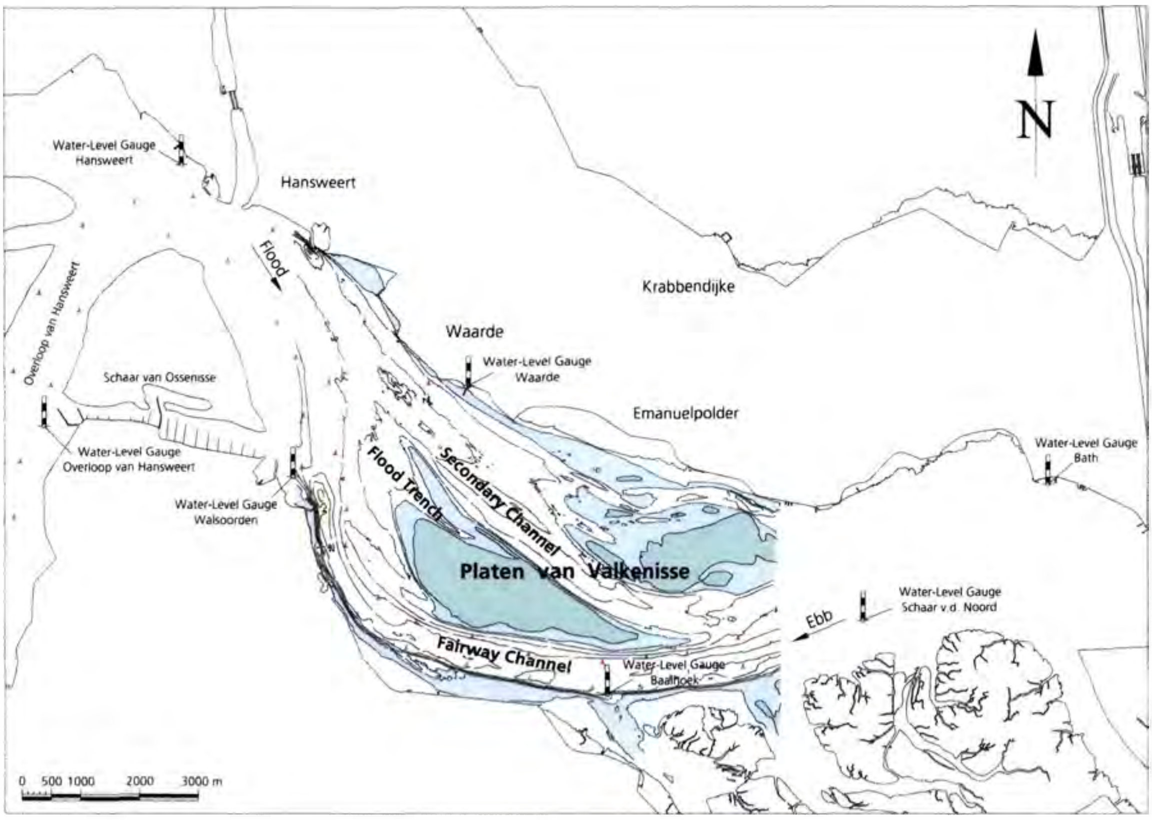

Fig. 2: Investigation Area in the Westerschelde with Gauges

As a basis for the calibration for further investigations with physical and numeric models prototype measurements were necessary. The Institut fuer Wasserbau (IWA) of the University of Applied Sciences, Bremen was commissioned by Projectdirectie ontwikkelingsschets Schelde-estuaium (PROSES) to carry out in situ measurements.

IWA carried out the investigations on site from the 23rd of September until the 8th of October 2002 with support from the Meetinformatiedienst Zeeland, Rijkswaaterstaat.

The current measurements were carried out with a DGPS drifter measuring system developed by the IWA. This system will be briefly described in the following.

2. Current measurements with DGPS Drifter Buoys

2.1. The Positioning System

The Global Positioning System (GPS) is based on satellite ranging and can be used world wide independent of the local geodetic datum.

It is known, that by telemetric measurements in one plane (two-dimensional), all points with the same distance from the transmitter lie on a circle with the transmitter as centre. As GPS is a three-dimensional system, all points with the same distance to a transmitting satellite lie on a sphere centred on that satellite. A measurement to a second satellite narrows down the position to somewhere on the circle where the two spheres intersect. A measurement to a third satellite leaves only two possible points, one in outer space and one on the Earth, for our location. In other words, in a three-dimensional system there are two positions which have the same distances to three "fixed" points. When these measurements are projected onto the Earth's surface we receive the following picture (fig. 3):

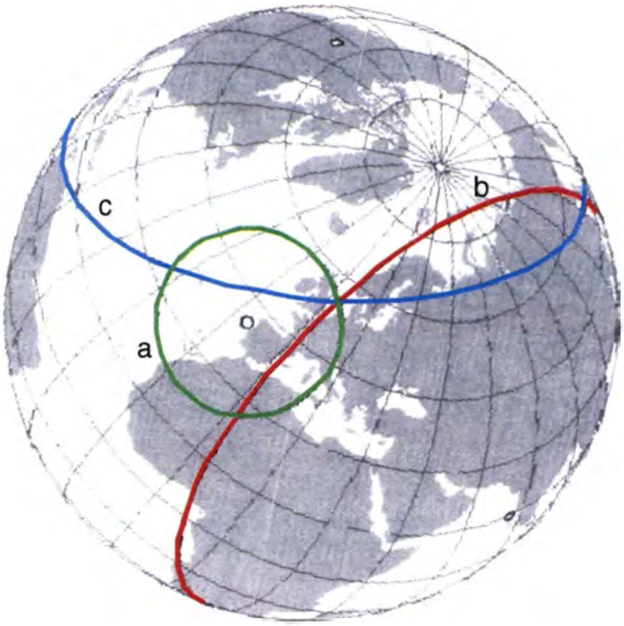

Fig. 3: Intersection of Measurements to three Satellites (KUMM, 1993)

The sphere with equal distances to a satellite "a" intersects the Earth's surface, giving a circle which describes all the possible points on the Earth's surface (green circle in fig. 3). The measurement to a second satellite "b" gives us a second circle (red circle in fig. 3) which results in two intersection points on the Earth's surface. A geometrically defined position is possible with a measurement to a third satellite (blue circle in fig. 3). The position lies where the three circles intersect. Theoretically a measurement to a fourth satellite is necessary to pinpoint the actual position in space. This, however, is not necessary in order to be able to define a position in latitude, longitude and altitude, as one of the two possible positions is a ridiculous result and can therefore be discarded. However, a fourth measurement is necessary for the following reasons:

This fourth measurement eliminates timing errors which occur in our satellite receivers and is important especially when a moving target has to be located.

In fig. 4 the intersection of the thin lines (X) is the true position resulting from true ranges. The intersection of the fat lines (XX, satellites A and B) results from offsets due to receiver clock errors, so called pseudo ranges. The diagrams are simplified to a two-dimensional system, but they are based on the same principle as a three-dimensional system (four satellites).

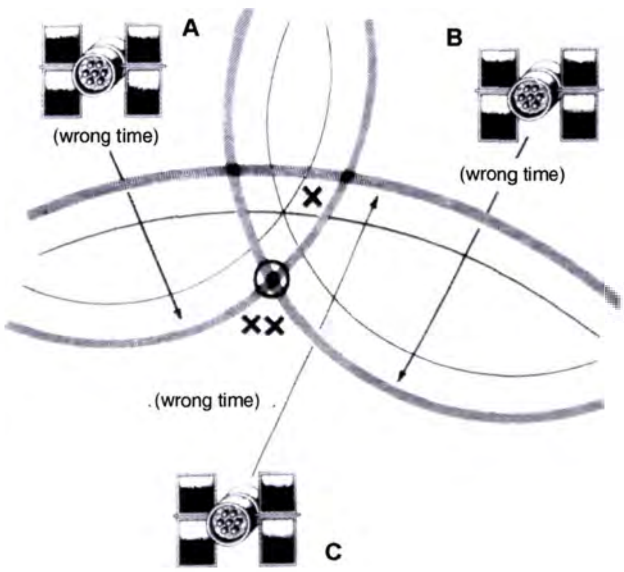

Fig. 4: Clock Offsets and Pseudoranges (HURN, 1989)

By a measurement to a third (fourth satellite in a three-dimensional system) the receiver registers that there is an error caused by an incorrect time in the receiver clock. Using an algorithm, the computer in the receiver calculates and corrects the clock offset.

The measuring of distances to the satellites, which are equipped with highly accurate atomic clocks, works on the ranging of electromagnetic waves, which travel at the speed of light (300 000 km/s). An error of a 1/100 000 of a second would result in a ranging error of three kilometres. According to trigonometric rules, three perfect measurements can locate a position on the Earth, but as perfect measurements are not possible four imperfect measurements are necessary to eliminate any clock errors and to get an exact position. Therefore four satellites have to be in view at all times. There are 28 satellites orbiting the Earth at a minimum altitude of 20 000 km with an orbit time of 12 hours, which guarantees that there are always at least four satellites available. GPS positions are accurate up to 100 metres (KUMM, 1993). This is because civilian users only have access to the C/A code (Coarse Acquisition), the accuracy of which can be purposefully degraded by the American Department of Defence using an operation mode called "selective availability" or S/A. There is, however, a possibility to compensate S/A inaccuracies. By using a method called "Differential Global Positioning System" (DGPS) highly accurate positioning is possible.

2.2. Differential GPS (DGPS)

With DGPS position accuracy of better than on metre can be achieved (HURN, 1989). The trick is to place a GPS receiver at a known position where it acts as a static reference point (fig. 5). The reference station instantly calculates

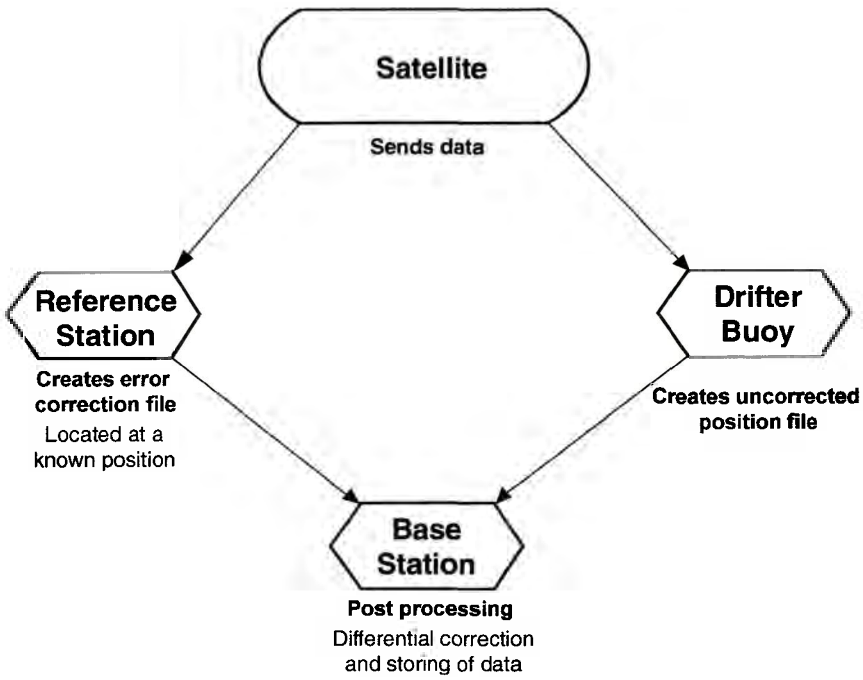

Fig. 5: The DGPS System

differences (hence the name differential GPS) between the position it calculates from satellite ranging and its actual position. The resulting data is used to correct the positions collected and stored in the field receivers (drifter buoys).

This concept works, because the satellites are so high up that the errors measured by the reference receiver are almost exactly the same as those measured by any other receiver within a range of about 500 kilometres of the reference receiver. This method eliminates all possible errors in the system up to a certain extent, whether they are from the receiver clocks, the satellite clocks, the satellite's position, S/A or of ionospheric or atmospheric nature.

Utilising DGPS, a system for monitoring current flow conditions was developed at the Hochschule Bremen by the Institut fuer Wasserbau with drifter buoys as floating survey stations.

2.3. The Drifter Buoy

To record Lagrangian current flow patterns in various depths, the use of drifter buoys with drogues consisting of crossed sheet metal plates has been effective (fig. 6 & 7). The drogues can be hung to the drifter buoy with a rope at any required depth. The drag of the drogue is relatively high compared to that of the immersed buoy which allows an interpretation of the current conditions in the chosen depth. The buoy is a circular container made of aluminium with a diameter of 50 centimetres, a height of 12 centimetres and an immersed depth of 10 centimetres. It contains a GPS receiver/data logger as well as an electric power supply.

The receivers can track up to six satellites simultaneously in order to always have four satellites to calculate positions with, for one reason. The other reason has to do with geometry. As some satellite constellations (i.e. their relative positions to each other as well as their positions to the GPS receiver), are less suitable for accurate positions because of unfavourable angles as known in the terrestrial surveyance. Using a "geometrical dilution of precision" (PDOP, HDOP) the receiver selects the satellite constellation which is likely to give the best results.

The integrated data logger in the receiver can store up to 10 000 positions. The rate of positioning can be set at will. A rate of one position every two seconds allows a running time of about 5.5 hours.

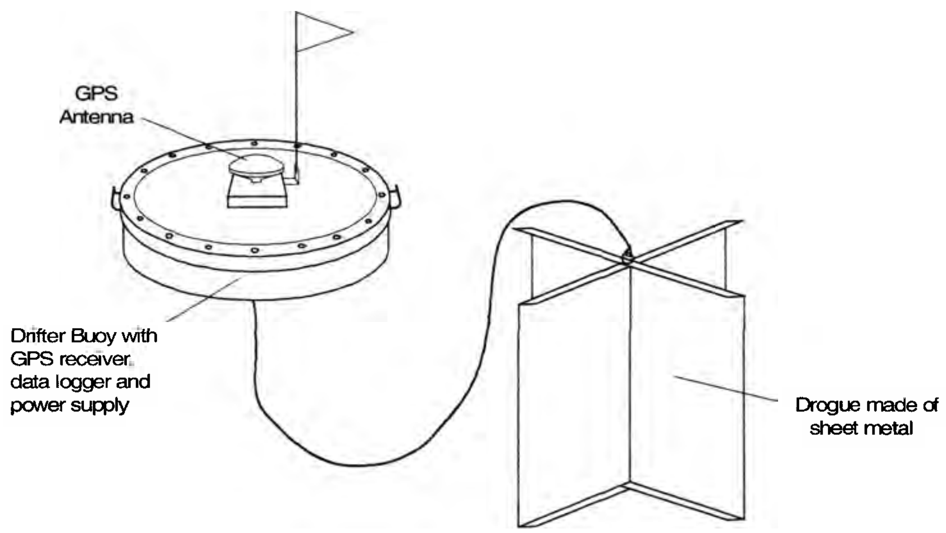

Fig. 6: DGPS Drifter Buoy with Drogue

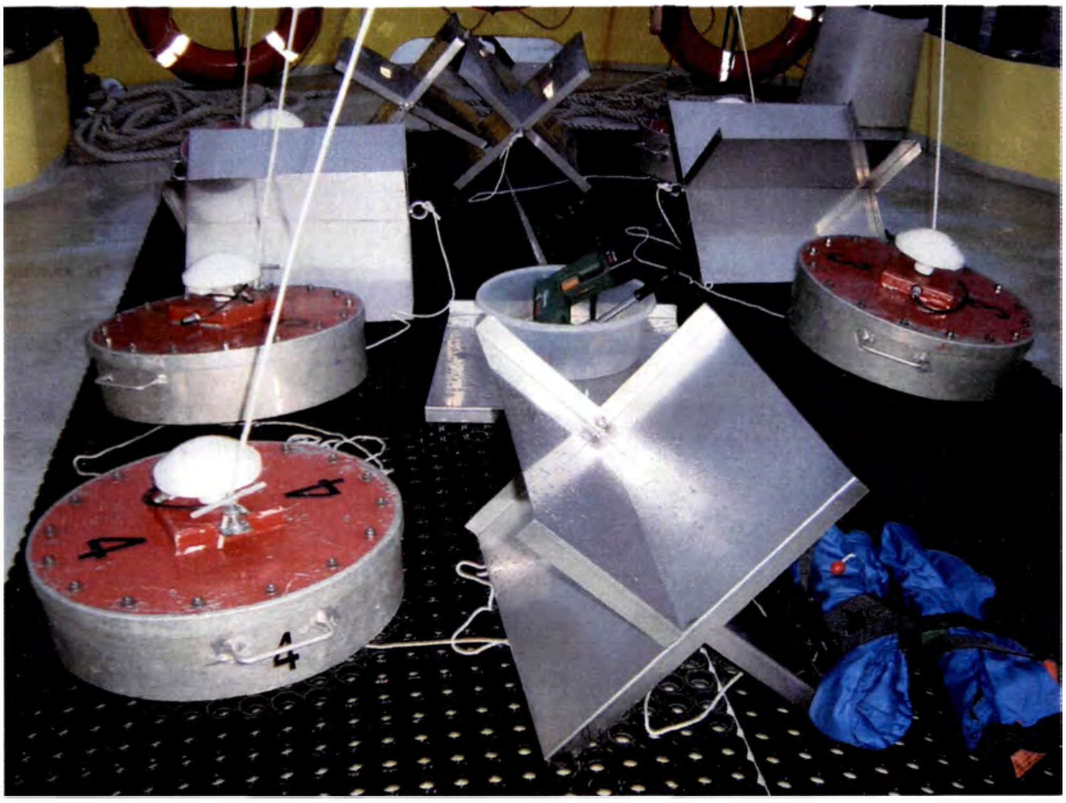

Fig. 7: Drifter Buoys on the "SCALDIS"

3. Hydrological Boundary Conditions

Semi-diurnal tides prevail on the North-Sea Coast. Tide recordings from seven gauges along the Westerschelde between Overloop van Hansweert and Bath were available (fig. 2 and 8). The graph shows monthly as well as daily tidal irregularities. During new moon, spring tidal ranges up to 5.82 m were registered on 7th and 8th October 2002 at the Gauge Walsoorden. The smallest neap tidal range occurred on the 2nd October with 3.28 m.

The tide entering the estuary from the North-Sea is subject to constant changes. The ascending seabed and form of the estuary lead to increasing tidal ranges by raising of the HW and lowering of the LW between Westkapelle and Vlissingen. The capacity of the tidal wave is weakened by bed friction as it proceeds. Obstacles such as the bends at Hansweert and narrowing cross-sections (e.g. upstream of Bath) cause reflections, that lead to energy transformation and thus to increasing tidal ranges. The slack water time after HW (or LW) is a measure for the reflection of the tidal wave. In the open sea the turn around of the current occurs at mean tidal water level (about 3 hours after HW or LW). With total reflection the turn around of the current coincides with the tidal vertices. The above remarks concerning tidal action are common to estuaries.

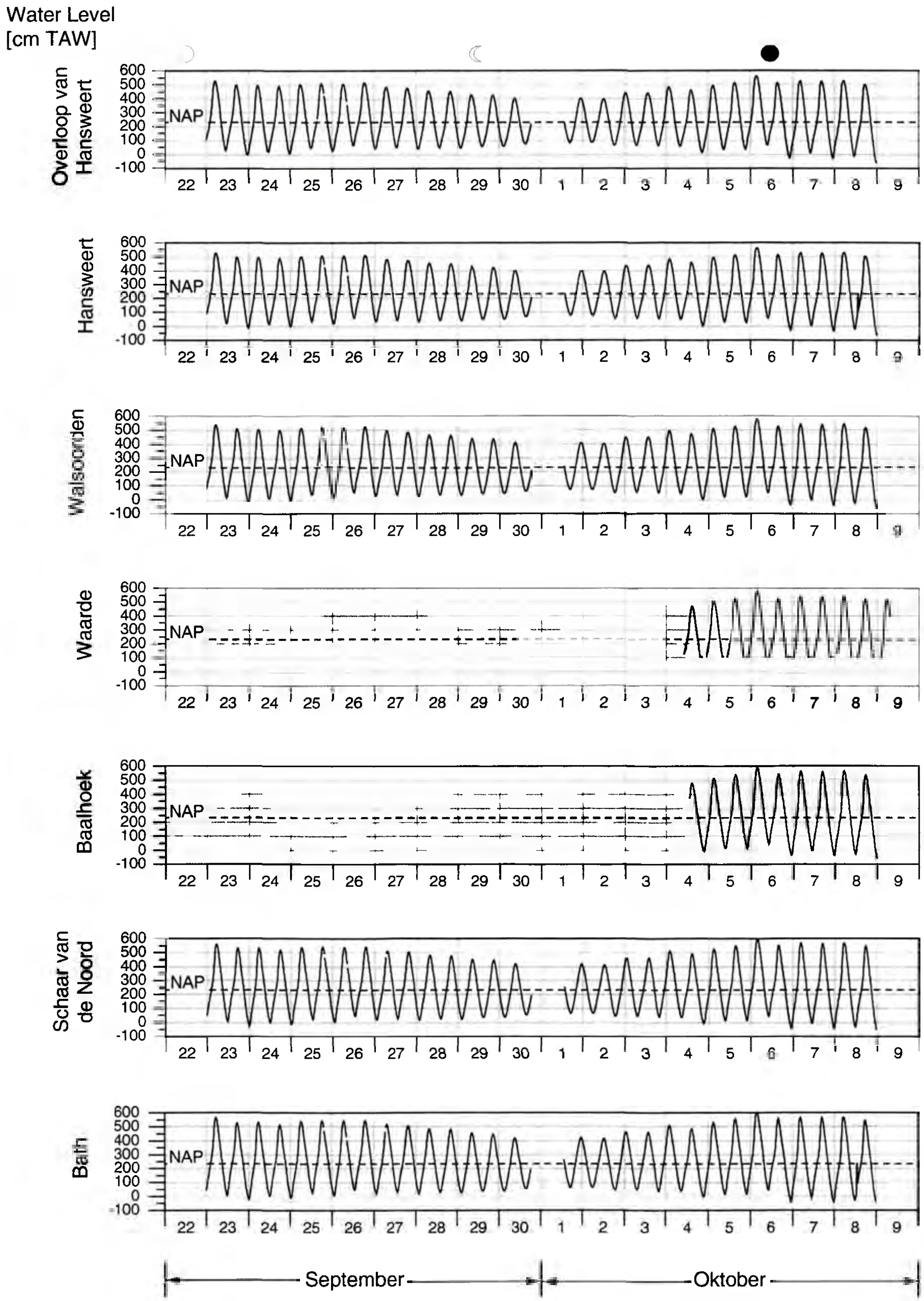

Fig. 8: Water Levels during the Measuring Period at the Gauges in the Investigation Area

The long term 1991/2000 averages for HW, LW and tidal range along the Westerschelde from Westkapelle to Bath are shown in figure 9. The increase of the average tidal range of 152 cm from 338 cm (Westkapelle) to 490 cm at Gauge Bath result from a distinct rise of the HW of 92 cm and a descent of the LW of 60 cm.

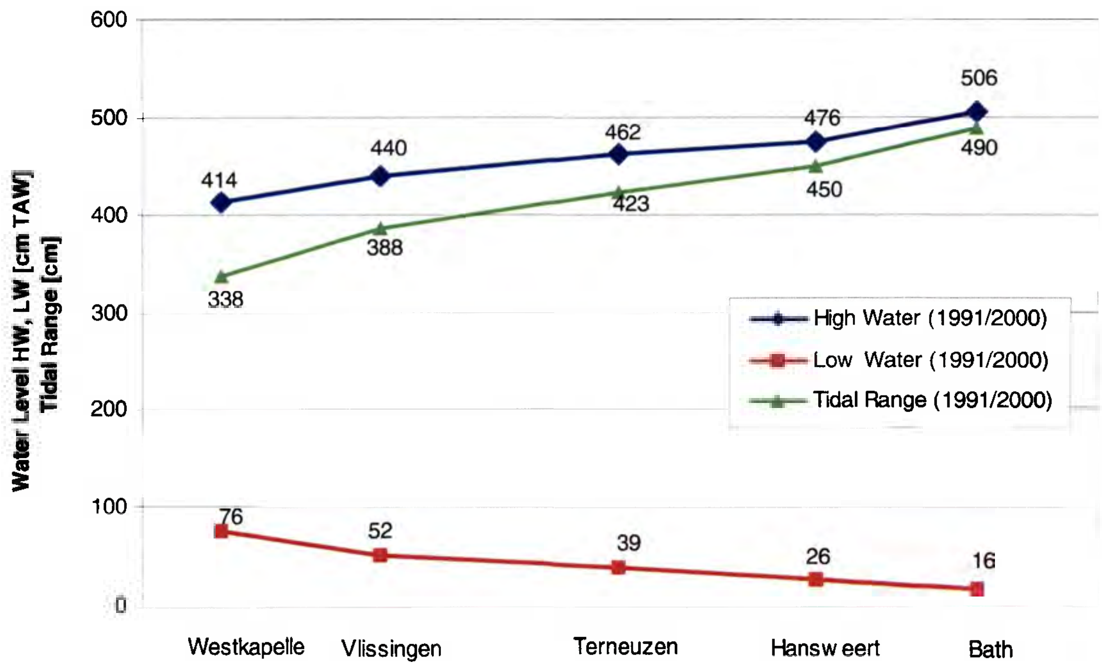

Fig. 9: Average Water Levels And Tidal Range (1991/2000) in the Westerschelde from Kapelle to Bath (see also Fig. 1)

4. Current Measurements

4.1. Preliminary Remarks

The depth contours in annex 1 to 31 with the drifter tracks are from bathymetric surveys carried out by the Meetinformatiedienst Zeeland of Rijkswaterstaat. The depths are related to NAP (Nieuw Amsterdam Pijl). The area of investigation is situated in a bifurcation. A secondary channel passes through the northern region of the Platen van Valkenisse. The fairway channel runs along the river bend (fig. 2).

The current measurements shown in the annexes were related to the Gauge Walsoorden. Gauge zero is defined at TAW = -2.33 m NAP. The tide graph for the investigation period in figure 10 shows that the Platen van Valkenisse regularly fall dry up to the –2.5 m depth contour within the tidal rhythm during spring tides. The mean tidal water levels in figure 10 were interpolated between Hansweert and Bath.

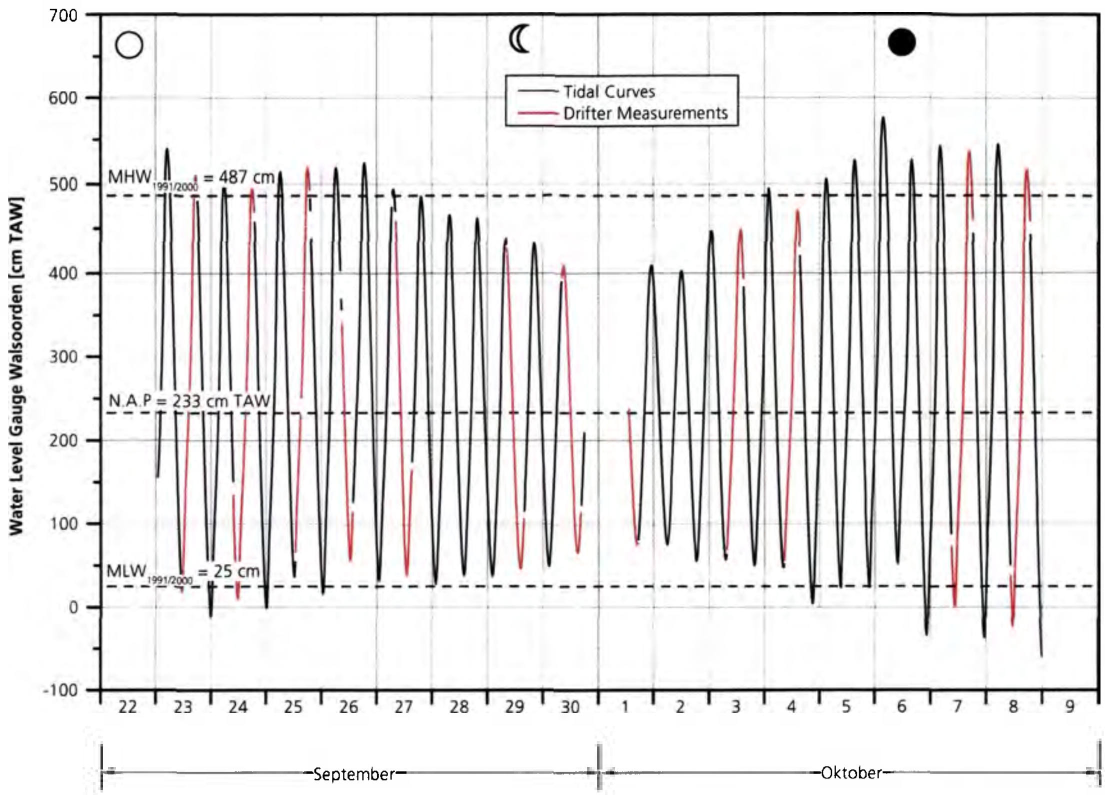

Fig. 10: Water levels at the Gauge Walsoorden during the Measurements

The flow tracks were measured in depths of 5.0 m; 2.0m and 0.8 metres, in order to capture the current conditions in the shallow water regions. The positioning interval of the drifters was 20 seconds. The tide graph from Gauge Walsoorden from the 23rd September to the 8th October 2002 is shown in figure 10. The periods during which measurements took place are marked red. The current measurements shown in the annexes will be commented in the following.

4.2. Current Measurements in the Secondary Channel

4.2.1. Flood Measurements on the 23-24/09/2002 (Annex 1 to 5)

The first current measurements were carried out in the northern part of the investigation area during spring tides. Annex 1 shows the diminishing current intensity in the secondary channel during the final ebb phase. About two hours before low water, ebb tide currents of v_e = 90 cm/s were recorded in 2 metres depth. These became slower in the further tidal progress. The blue lines give information about the velocity gradient. The absolute values in 5 m water depth are significantly lower. Remarkable are the slow currents in the shallow water area at the tip of the Platen. The currents were additionally influenced by wind drift. Moderate north-eastern wind prevailed with velocities of 6 and 8 m/s (Bft 4) between 9.00 and 11.00 o'clock. The turn of the ebb tide occurred about quarter of an hour after low water.

The current conditions during the first flood phase, with similar tidal ranges on the 23-24/09, are shown in annex 2. Also on the 23rd September slack water was 15 minutes after low water.

The flood branch of the tidal curve at Gauge Walsoorden has an irregular development (annex 2). After a steep rise of the water level until about one hour after LW, the gradient of the flood branch is relatively flat until about two hours before HW. The last flood phase is distinguished by a remarkably high rise of the water levels.

In accordance to the tidal development, the current velocities in the deep water and still in 5 m water depth reach values of v_f > 70 cm/s during the first flood phase. In the southern region of the shallow water area they are notably lower.

The slow rising of the tide in the following tide phase is the cause for the low current intensity in the secondary channel (annex 3).

Annex 3 demonstrates how important the suspended drogues are to record the currents in different depths. The influence of the wind is clearly recognisable by drifter tracks recorded on the 23rd September at about 13.30h. Strong north-eastern wind with 12 m/s (Bft 6) caused the drifter that lost its drogue to considerably drift in a southward direction.

The streamlines in annex 3 demonstrate the stagnating effect at the tip of the Platen. This causes a separation of the currents and flood water mass into the northern and southern Schelde regions.

In accordance with the tidal curve, the maximum flood tide current velocities were measured in the following flood phase (annex 4). The current pattern gives an insight into the horizontal and vertical velocity in the discharge cross-section of the secondary channel. The absolute values were of equal magnitude in 2 m and 5 m depth. In deep water velocities of v_{max} = 135 cm/s were measured.

From about half an hour before high water, the intensity of the flood currents clearly diminished (annex 5). The turn of the tide occurred almost half an hour after high water on both days.

4.2.2. Flood Measurements on the 25/09 and 04/10/2002 (Annex 6 to 10)

On the 25th September flood current measurements were carried out in the secondary channel. The tidal range was 484 cm and therefore comparable with the preceding days. The following annexes were completed with current measurements carried out on the 4th October in the south-western region. The green and blue streamlines in the secondary channel are near to parallel with velocities of almost 1 m/s in 2 m and v_{max} = 80 cm/s in 5 m depth.

Special conditions prevail in the downstream section at the beginning of flood tide. The drifters on the surface (0.8 m depth, red lines) were displaced from west to east across the main stream to the secondary channel. This can not be explained with wind drift. There was only light north-east wind with a force of 2 on the Beaufort Scale (3 m/s). The streamline pattern that was repeatedly observed during the field campaign is caused by the eastward current coming from the channel on the Hoek van Ossenisse (fig. 11).

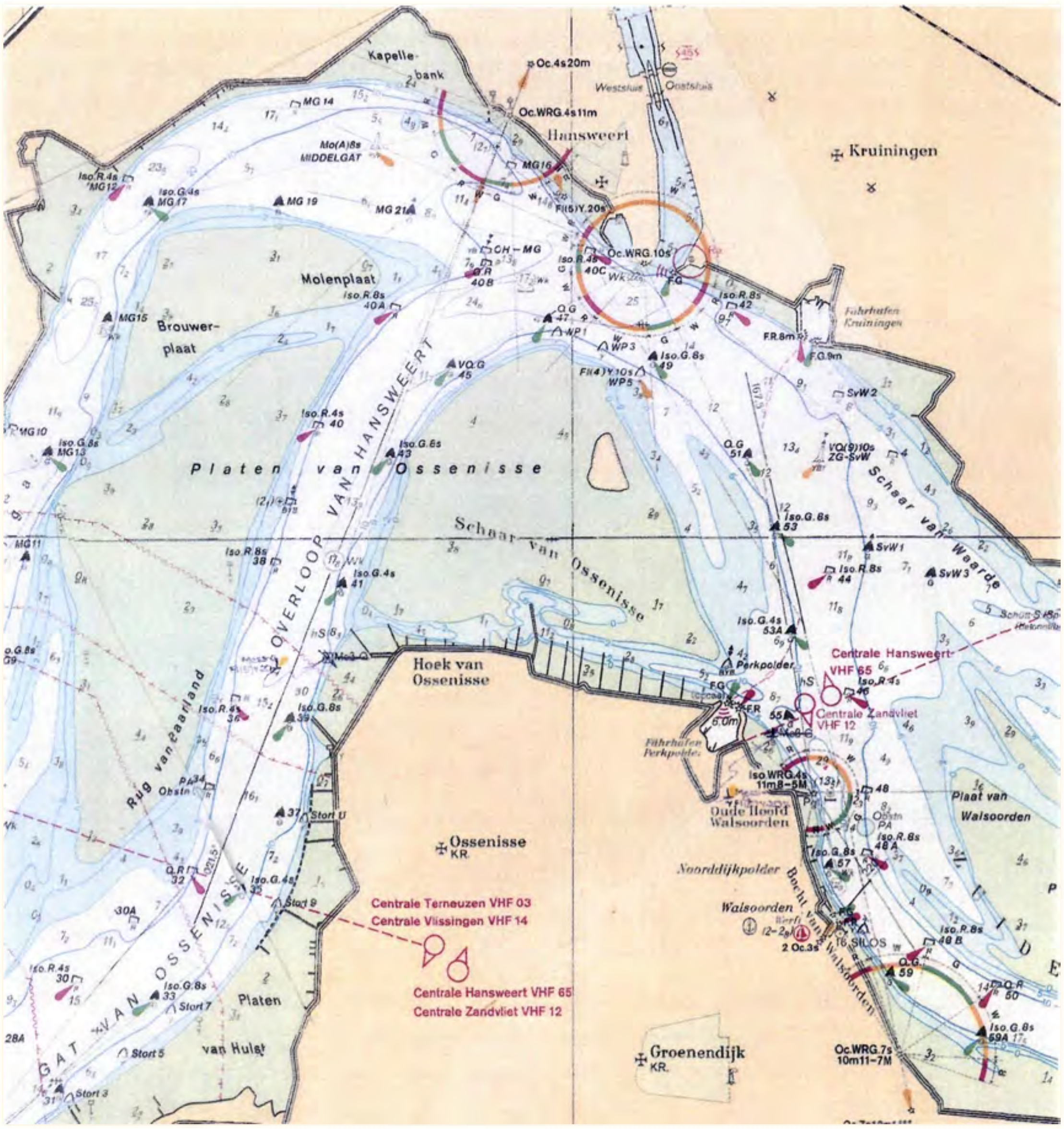

Fig. 11: Section from the Sea Chart No.209 with Southern Cross Channel at the Schaar van Ossenisse (Bundesamt fuer Seeschiffahrt und Hydrographie (BSH), 2001)

In the following tide phase the drifter tracks on the 4th October were diverted southwards by the dominating currents in the fairway channel and split at the tip of the Platen (annex 7). Low current velocities were registered in the shallow water region.

Complying with the tidal curve, notably weaker currents were measured as to the beginning of the flood also in the side-fairway. Remarkable are the low velocities of $v_f \leq 40$ cm/s in the downstream section of the secondary channel.

Annex 8 displays the similar current conditions concerning intensity and direction in the progress of the flood duration in the stagnation area of the Platen.

The diverging current pattern persists during the rising water levels (annex 9). Significant are the southward orientated currents in the blue shaded area between the 0 and –2.5 m depth contour and also in the narrow flood trench with $v_{f\ max} \approx 80$ cm/s. These flood current velocities erode the sandy bed material, which is transported as bed load. The resulting morphologic changes could be documented with the analysis of sounding charts.

In the secondary channel, the results of the previous days were confirmed (annex 9). The steep rise of the flood branch increases the water masses flowing upstream as well as the velocities. The water masses were accelerated up to $v_{f\ max} \approx 170$ cm/s.

Annex 10 shows that the flooding of the shallow water region on the 4th October was intensified even more until about 0.5 hours before HW. After that, the flood current velocities became continuously less until the slack water about half an hour after HW.

4.2.3. Ebb Measurements on the 26-27/09/2002 (Annex 11 to 14)

Mean tidal conditions prevailed during the ebb current measurements on the 26th and 27th September. The tidal range with slightly higher vertices corresponded with the long term average. Corresponding with the tidal development, the ebb water masses and the ebb current velocities are more evenly distributed over the whole ebb phase.

On the 27th September the drifters in 5 m depth (blue lines) in the upstream region of the secondary channel run parallel downstream (annex 11). The surface drifters (green lines) crossed the deeper streamlines in the upstream section. Also in the shallow water region they were diverted southwards with distinctly decreasing velocity. This can be additionally caused by meteorological conditions. During the measurements between 8 and 10 o'clock there was north wind with 2 Bft (3 m/s).

About 1.5 hours after HW the ebb currents were fully developed with constant velocities just over 1 m/s. The values in greater depths (5 m) were about 10 to 20 % lower than in 2 m depth.

Similar current intensities were measured in the following ebb phase on 26/09/2002 in the secondary channel (annex 12). The northern drifter had contact with the bottom near the 5 m depth contour and was therefore taken out of the water. It is apparent that the current directions in the different water layers are more uniform than in annex 11. This is demonstrated with the parallel course of the green and blue streamlines, caused by the different wind conditions. Between 9 and 10 o'clock on the 26th September west wind with a force of 3 (5 m/s) was recorded (annex 12).

Three hours before LW the ebb currents slowly get weaker. This is demonstrated with the measurements from the 27th September in the downstream section (annex 12, left). The different directions are also explained with the wind drift currents that mainly take effect in the upper water layers.

The last ebb phase is shown in annex 13. The current pattern in the upstream section is comparable with the previous tide phase. The surface drifter passed the sand bank (flat) (annex 13, middle) on the north and south sides. A 5 m drifter was again stranded near the 5 m contour.

As the current intensity decreased, the influence of the wind drift on the upper water layer increased on both days. On the 26th September, before the turn of the tide, the drifters were displaced north-eastwards, and south-eastwards on the 27th. Slack water was about 10 to 20 minutes after LW.

It is remarkable that on the 27th September, after the turn of the current, the drifters did not drift southwards into the main fairway but instead north-eastwards into the secondary channel (annex 13). The current into the northern channel during the first flood phase is mainly found in the upper water layers. This is demonstrated by the crossing streamlines in annex 14. In this connection it is referred to annex 6, in which the currents in 0.8 m and 2.0 m depth showed a similar current condition.

4.3. Current Measurements in the Southern Area of Investigation

4.3.1. Ebb Measurements on the 29/09/2002 (Annex 15 to 17)

During a meeting on site on the 28th September 2002, the results that were achieved until then and the further program was discussed. It was decided that the following investigations should be mainly carried out in the upper water layers (in 0.8 m an 2.0 m depth) with the aim to capture the hydrodynamic process in the shallow water regions more precisely.

The ebb currents south of the Platen van Valkenisse and outside the fairway buoyage in the area of the slope were of interest. The measurements on the 29th September commenced shortly after the turn of the tide (annex 15). There was only little wind from southern direction and a neap tidal range of 392 cm. The current tracks followed the depth contours. During the first ebb phase the ebb tide currents, also those in deeper water, were clearly below 1 m/s. There were hardly any current velocities between the 2.5 m and 0 m depth contours.

Also in the following ebb phase similar conditions were encountered along the slip off slope of the Platen to the downstream tip (annex 16). The ebb water masses are transported downstream with high velocities mainly along the talweg on the left fairway side along the undercut bank. This is demonstrated by the bed of the Schelde with scour depths of more than -30 m NAP at Walsoorden (annex 17).

Consequently ebb current velocities of $v_e > 160$ cm/s were recorded during the last measurements on the 29th September in the region of the 15 m depth contour (annex 17). Owing to the morphology, no distinct transport effective currents develop in the boundary region along the Platen to the downstream tip during the whole ebb phase. The flood trench between the blue shaded 2.5 m depth contours is in this area formed by the more morphologically effective flood currents.

Again the turn of the ebb tide was about 0.5 hours after HW (annex 17). As it was explained above, the water during the first flood flows northeastwards to the secondary channel of the Westerschelde.

4.3.2. Ebb Measurements on the 30/09 and 01/10/2002 (Annex 18 to 22)

On the 30th September and 1st October 2002 ebb measurements were carried out during neap tide in the region of the bifurcation of the Platen van Valkenisse. As all the gauges were out of order on the 1st October, the tidal curve for Walsoorden in annex 18 to 22 was completed accordingly. The steady neap tide flood curve at Gauge Walsoorden compared to the spring tides is remarkable.

The drifter tracks recorded on the 1st October about 2 hours before HW diverge at the downstream end of the Platen van Valkenisse (annex 18). The northern tracks in 0.8 m and in 2 m depth were diverted towards the secondary channel. Owing to the low water levels, no water passed through the narrow flood trench in between. Notable flood currents of v_f = 50 to 70 cm/s were recorded outside the fairway in the region of the Platen tip.

The drifters that were put in the water in the southern region on the 29th September turned around about 30 minutes after HW (annex 19, bottom). During the following first ebb phase, maximum velocities of 70 to 80 cm/s were reached in 0.8 and 2.0 m depth. The currents in the blue shaded shallow water area were only half as fast. Similar low ebb currents were measured in the same tide phase on the 1st October in the flood trench (annex 19, top right). With the sinking water levels, the green shaded areas to the 0 m contour (= NAP) in annex 19 fell dry.

At medium ebb current velocities of just $v_e \approx$ 1 m/s north and south of the Platen, no notable water movement took place owing to lack of receiving water. The special conditions found there are also documented with the surface currents from the 1st October (annex 21). The drifters moved westwards with low velocities. This was not due to the light south-eastern winds. In the fairway channel of the Schelde the drifters were caught by the northward orientated ebb currents. The continuous decrease of the ebb current velocities towards the turn of the tide can be taken from annex 22.

4.3.3. Flood Measurements on the 03/10/2002 (Annex 23 and 24)

The above explained ebb measurements were supplemented with measurements on the 3rd October during a neap tidal range of 392 cm (average tidal range 1991/2000 = 462 cm at Gauge Walsoorden). The current measurements for the first flood branch are shown in annex 23.

At first the known current pattern at low tide water levels (below TAW) at Gauge Walsoorden was observed. The drifters were diverted past the blue shaded area north-eastwards into the secondary channel. There the flood currents reached values of up to $v_f \approx$ 60 cm/s. With the rising water levels, flood currents with decreasing intensity were observed in the southern channel, but with increasing intensity nearer to the fairway.

Remarkable are the hydrodynamic processes in the last third of the flood (annex 24). In accordance with the steeper tidal rise, relatively high velocities of up to about 70 cm/s were registered in the flood trench. Remarkable is the diversion of the current across the shallow water area towards the northern secondary channel.

It is important to know that the transport capacity of the tidal currents are obviously higher during flood than during ebb. According to this, the morphology in this region is formed also by the flood currents. Until now there are no sufficiently precise theoretical solutions to quantify the sediment transport process. It is known that the solid material transport depends on the bed material and the potential effect of the current velocity. The investigations made by HJULSTRÖM (1935) and Graf (1971) have shown that non-cohesive bed material, such as fine sand with grain sizes up to d = 0.2 mm, is already moved by current velocities of about v = 20 cm/s (fig. 12).

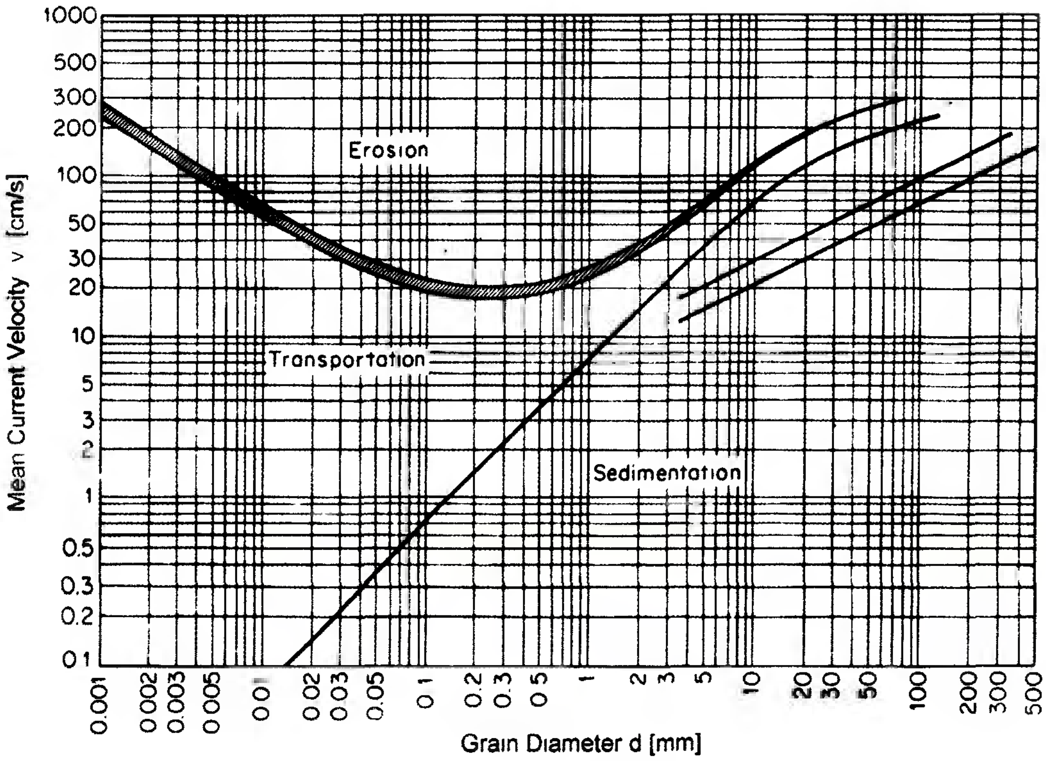

Fig. 12: Erosion, Transport and Sedimentation as a Function of the Current Velocity and Grain Size (GRAF, 1971 after HJULSTRÖM, 1935)

Figure 12 also shows that the eroding force and the transport ability rises over-proportionally with the current velocity. It is often the case that sand waves with a stabilizing effect are formed in rivers with sandy bed material (e.g. FÜHRBÖTER, 1967). The bed load transport takes place by local displacement in the direction of the current from the stretched luff side, over the crest to the shorter lee side. Sand waves are especially stable in tidal rivers (NASNER, 1974). The form is adapted to the prevailing current direction. Echo soundings made during the field campaign on the Schelde have shown that flood tide orientated sand waves are present on the bed in accordance with the dominating currents. The asymmetric shapes are characterized by the flat luff slope and a shorter steep lee slope on the side of the flood current direction.

The following explanations show that flood currents are especially strongly developed during spring tides.

4.3.4. Flood Measurements on the 07/10 and 08/10/2002 (Annex 25 to 31)

The last ebb phase was registered with the begin of the current measurements on the 7th and 8th October during tidal ranges of 542 cm and 568 cm respectively (annex 25). Slack water was about half an hour after LW on both days. The streamline picture displays once more the low movement of water in the shallow water areas of the Platen. No discharge took place through the flood trench. Already 1 hour after LW weak inward currents were recorded in the same place (annex 26, top). During the relatively flat water level rise at Gauge Walsoorden, the drifters west of the Platen reached flood current velocities of $v_f > 80$ cm/s (annex 26, bottom).

With progressing flood on the 8th October and with almost same current intensity, the drifters set out in the same place were displaced a little more towards the fairway (annex 27). On the 7th October, at a water level below NAP, the current tracks were divided at the stagnation point of the Platen tip. The flood water masses were diverted southwards (annex 27).

This influence is increased in the following tide phase with a constant gradient of the flood curve (annex 28). The maximum flood current velocities were here still clearly below 1 m/s.

A completely different picture presents itself in the last third of the flood (annex 29). From a water level of +1 m NAP onwards, with an accelerated water level rise, the current was divided at the stagnation point of the Platen. Large water masses from the shallow water area even passed through the flood trench to the secondary channel. In doing so, the flood current velocities accelerated up to $v_{f\ max} = 150$ cm/s. With the above explanation (see figure 12) it is not necessary to go into further detail about the transport capacity and erosion force connected with this. Flood current dependant erosions are recognisable from the morphologic situation in the trench. If it is left to the natural hydrodynamic process, this area will deepen itself and a connection with the northern secondary channel will be established. The above could be confirmed by an analysis of sounding charts for the previous morphologic development. It is of importance that if further erosion takes place, larger water masses will be transported through the northern secondary channel. As a result, the transport capacity of the fairway channel will be weakened. Corresponding unfavourable changes concerning the sedimentation processes in the region of the fairway channel would be the logical consequence. One possibility to counter this development is given by the currently discussed dumping of suitable spoil. It is expected that the planned hydraulic and numeric investigations will give a additional knowledge.

The direction of the currents that were measured on the 8th October outside the fairway during the same tide phase remains constant. The maximum velocities doubled with a value of $v_{f\ max}$ = 190 cm/s (compare annex 29 with annex 28).

In the area of current to the Platen, velocities clearly higher than 100 cm/s were measured also during the last flood phase (annex 30). The streamline picture in the fairway channel was hardly different to the previous measurement. On the 7th October the drifters were diverted more southwards. The flood current progressed with remarkable transport effective velocities towards the tip of the Platen. Half an hour before HW the absolute values in the area of the 0 m depth contour were still $v_f \approx 70$ cm/s.

The weak surface currents during the first ebb current phase are of minor morphological importance (annex 31). The slightly higher values at the end of the field campaign on the 8th October were cause by eastern wind (Bft 4, v = 6 m/s).

4.4. Supplementary Remarks

The above explanations to the current process in the region of the Platen van Valkenisse have demonstrated the influence of the very different and periodically changing tidal conditions. The following consideration about tidal activity will make this evident.

For this, a comparison of mean, neap and spring tides during the field campaign was made between the Gauge Walsoorden and Schaar v. d. Noord and displayed in figure 13. The different hydraulic boundary conditions are obvious.

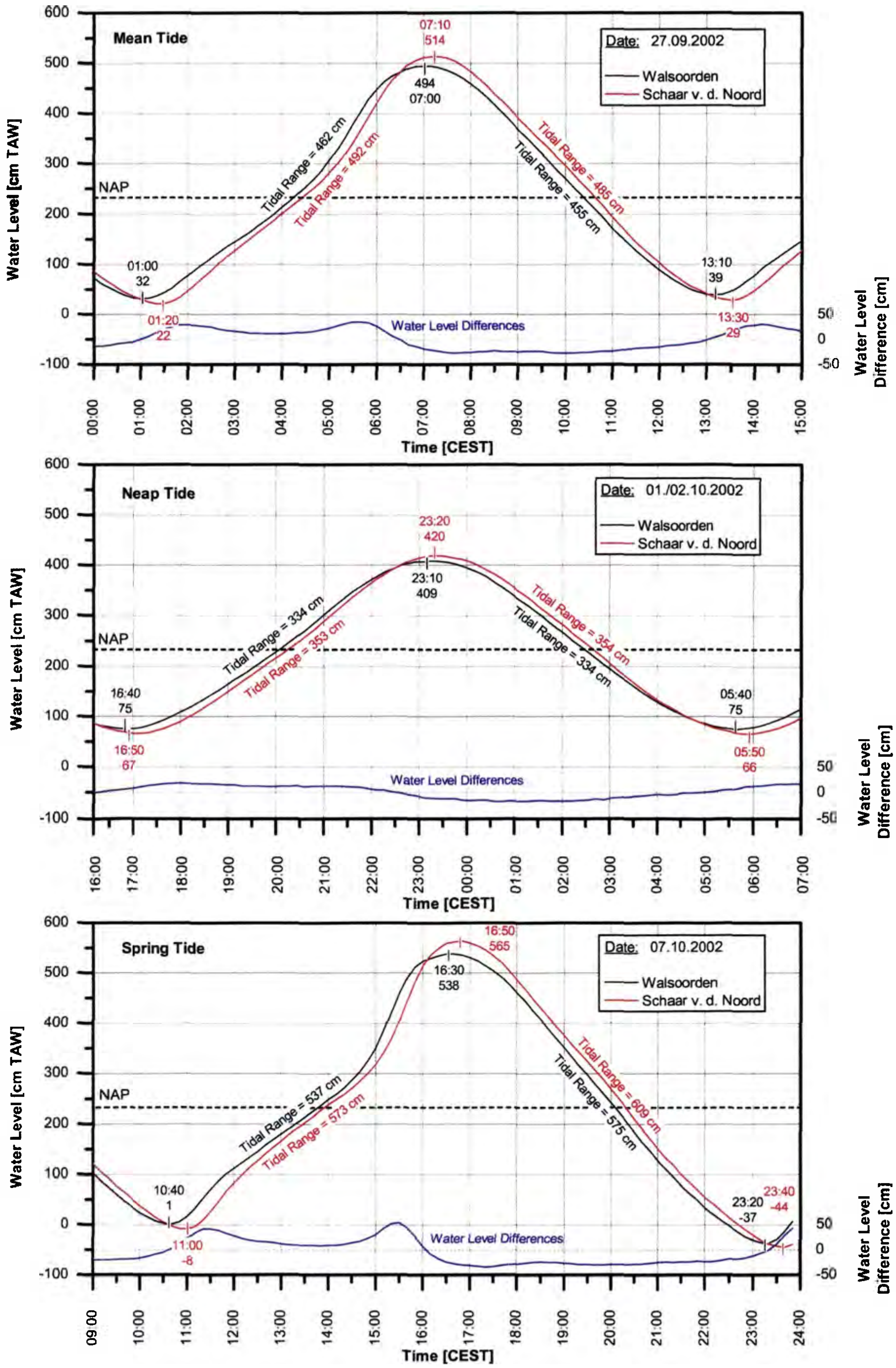

Fig. 13: Tide Curves at Gauges Walsoorden and Schaar v. d. Noord (see also Fig. 8)

During the spring phases significantly more tidal water masses with correspondingly high current velocities were in alternating motion in the Schelde. The greater transport capacity of the tide does not only result from the 2 m higher tidal range on the 7th October compared with the neap tide from the 1-2/10/2002. The flood water masses ran up in a shorter time with correspondingly high transport capacity. Thus the HW at Gauge Schaar v. d. Noord, which is situated about 11.5 km upstream of Walsoorden, on the 1st October was 11 cm higher, during the mean tide on 27/09/2002 20 cm and at spring tide 27 cm higher. The higher tidal energy leads to stronger reflections.

Especially obvious is the different shape of the flood branch of the tides in figure 13. Only during neap periods a steady rise and fall of the tide curve can be observed. During mean and higher tides the course of the tide graph during flood, which is evidently typical for this region, is visible. After the first flood phase the branch flattens. The highest water level rise takes place in the last third of the flood phase. This is the period in which the flood currents are especially developed and reach correspondingly high transport capacities. This is the flood phase with the steepest water surface gradient between the gauges. During the mean tide the maximum water level difference was Δh = 36 cm and during the spring tide Δh = 55 cm between Walsoorden and Schaar v. d. Noord. Differences of this magnitude are not nearly reached during mean and spring tide ebb phases. The conditions during neap tides are with differences of about 18 cm of minor importance.

The above considerations were made to demonstrate that the morphologically effective currents occur during higher tides and water levels above NAP during flood tide. This also effects the shallow water regions of the Platen.

5. Conclusion and Final Remarks

The current measurements were part of an investigation program into alternative strategies for the disposal of dredged materials in the Westerschelde. The results from the in situ measurements serve as a basis for further investigations with physical and numerical models.

The results of the field experiments can be concluded as follows.

The region of the Platen van Valkenisse is situated in a bifurcation of the Westerschelde. The tidal water masses are divided into the fairway channel in the bend south of the Platen and into the direct connection via the secondary channel.

The current picture resulting from the in situ measurements during ebb phases is shown in figure 14. The overview gives an impression of how the currents divide themselves into both of the discharge channels around the Platen. According to the boundary conditions, the currents were measured in 0.8 m depth in the shallow water in lee of the Platen (red lines in figure 14). There are no significant, morphologically effective ebb current velocities in this area. This was explained in more detail in connection with the annexes.

The tidal process in the region of the Platen van Valkenisse is dominated by the flood currents. The current picture in figure 15 documents how the flood water masses divide themselves into the main and secondary channel. The field experiments have shown that especially during mean and spring tides high flood currents with high transport capacity occur. The current direction changes with the flood current duration (fig. 16). During the first flood phase the water passes the tip of the Platen in a west to east direction into the northern secondary channel. Afterwards the current is diverted into a more north to south direction. In the last third of the flood phase during mean and spring tides the currents reach remarkably high intensities and transport capacities. With rising water levels the northern hook of the Platen is increasingly subject to the current attack. Even without the knowledge of the previous morphologic development it is possible, with the aid of the drifter tracks, to derive that this area is subject to erosion. If it were left to itself, i.e. without anthropological intervention, it can be predicted that the future hydrodynamic changes would be in favour of the northern secondary channel. The proceeding erosion would lead increasing flood water masses with a higher self-clearing effect directly, with a higher gradient, upstream.

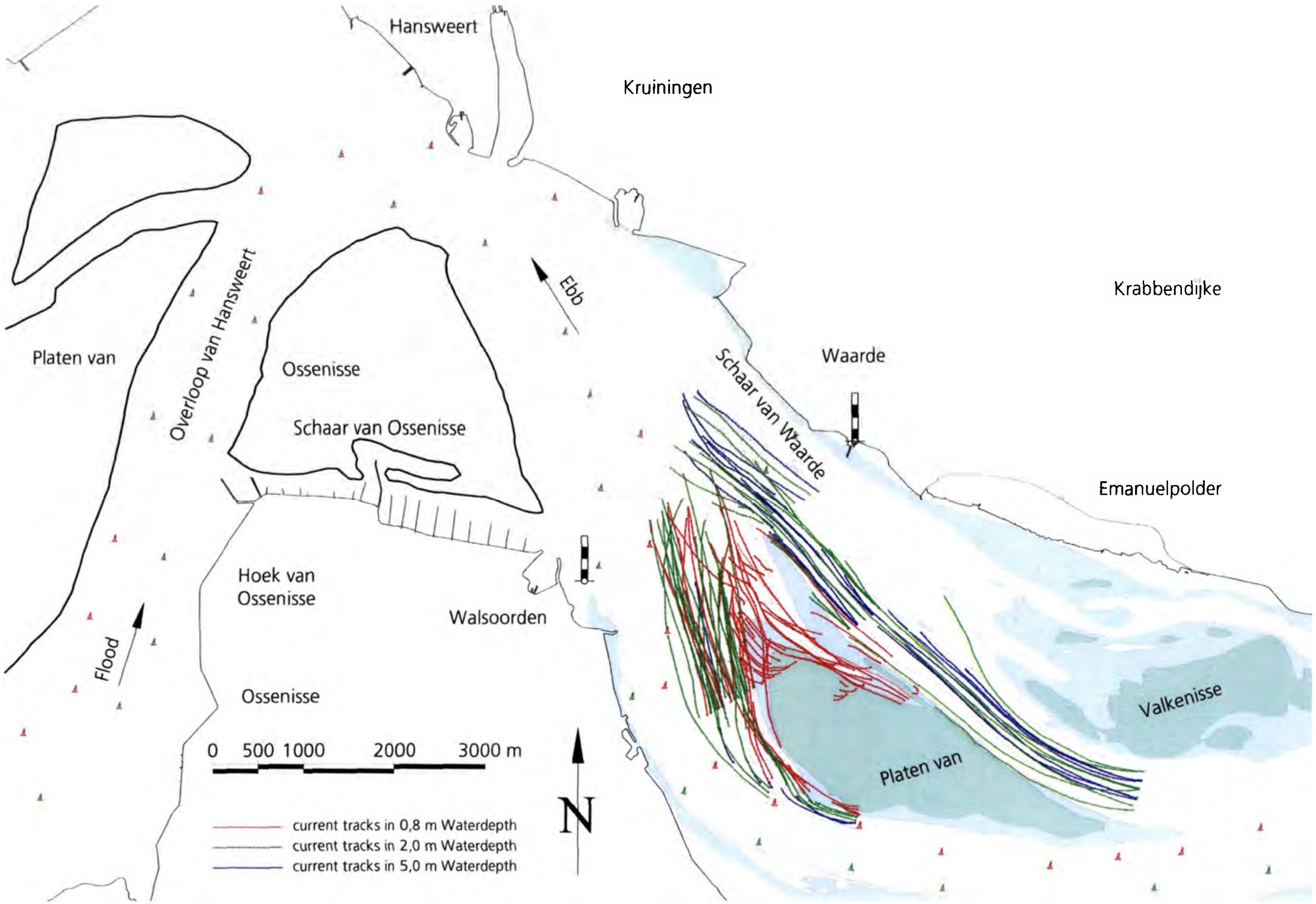

Fig. 14: Main Ebb Currents

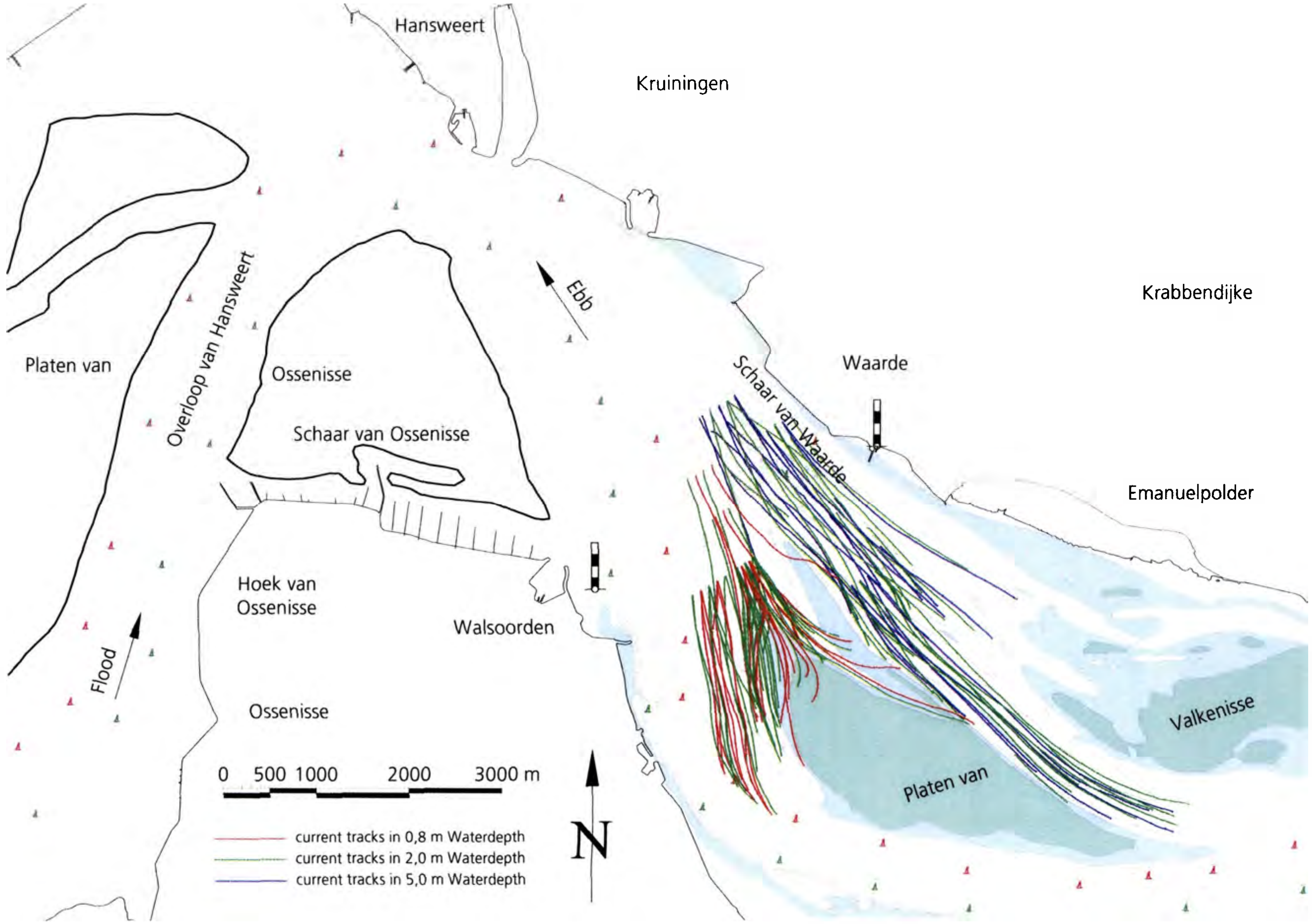

Fig. 15: Main Flood Currents

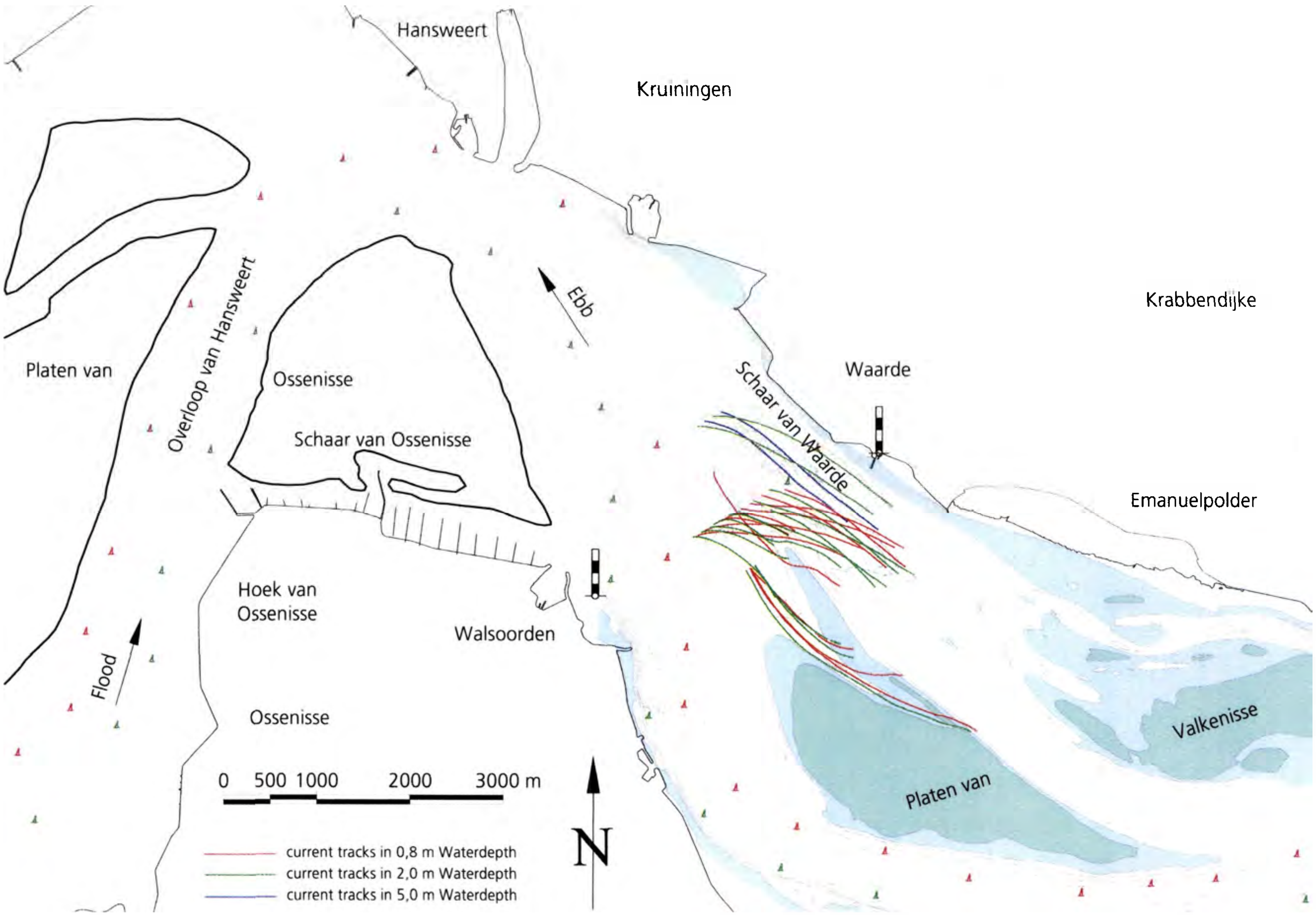

Fig. 16: Drifter during different Flood Phases

Consequently, the clearing capacity of the current in the fairway channel would be reduced and unfavourable conditions created for its maintenance. From the hydrodynamic and morphological point of view the question can be posed about the possibility of turning the northern secondary channel into a fairway. Advantages and disadvantages from the nautical and maintenance aspect will not and cannot be discussed here in further detail.

The results of the in situ measurements permit the conclusion that the southern tip of the Platen van Valkenisse presents a good possibility to dump suitable, preferably coarse grained dredged material. This can prevent the proceeding erosion and the redistribution of the flood water masses. Filling up the tip of the Platen opens the possibility to divert greater water masses into the fairway channel with a correspondingly positive morphodynamic effect.

H. Nasner R. Pieper H. Kuhlenkamp

(Prof. Dr.-Ing. H. Nasner) (Dipl.-Ing. R. Pieper) (Dipl.-Ing. H. Kuhlenkamp)

Bremen, 06.02.2003

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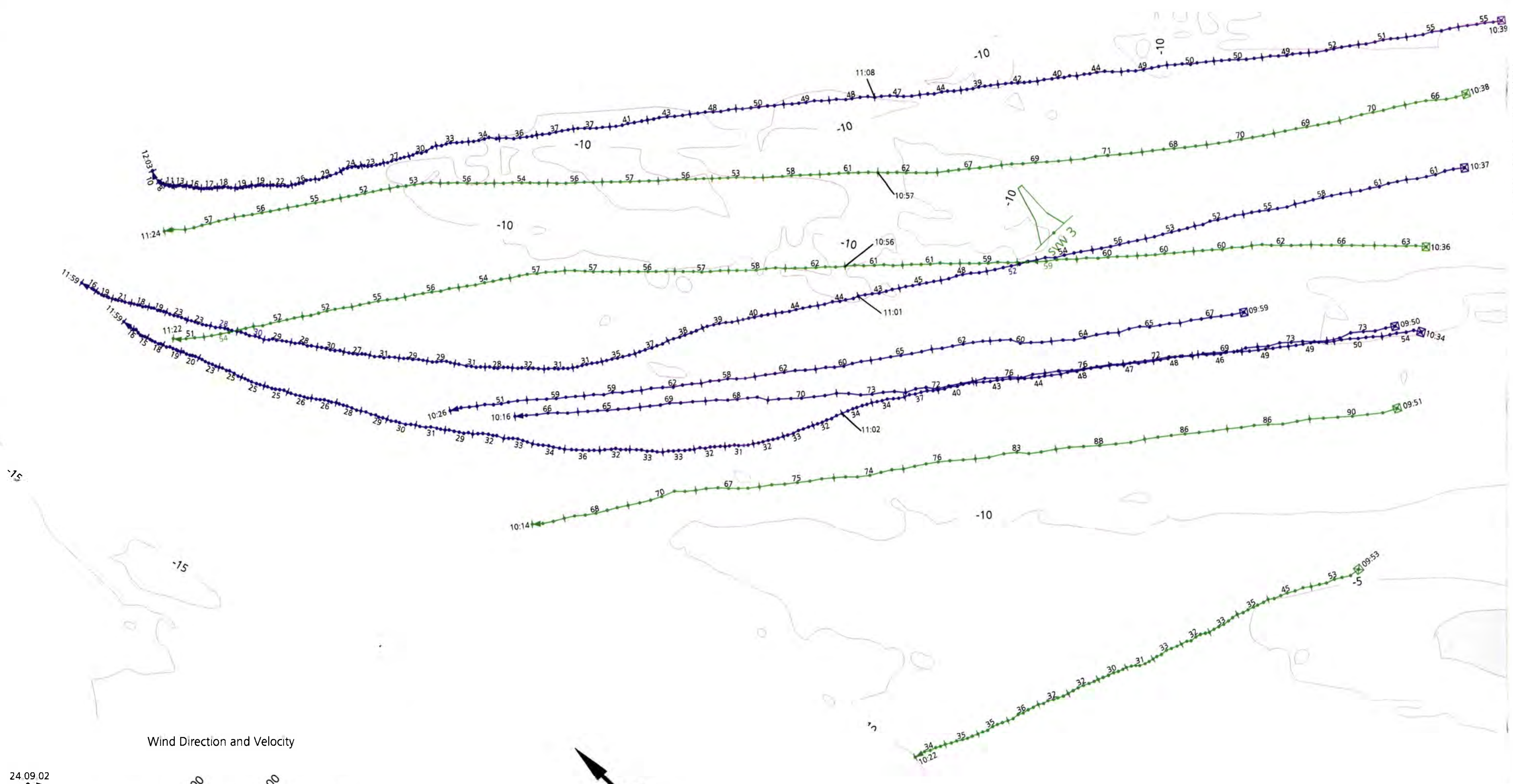
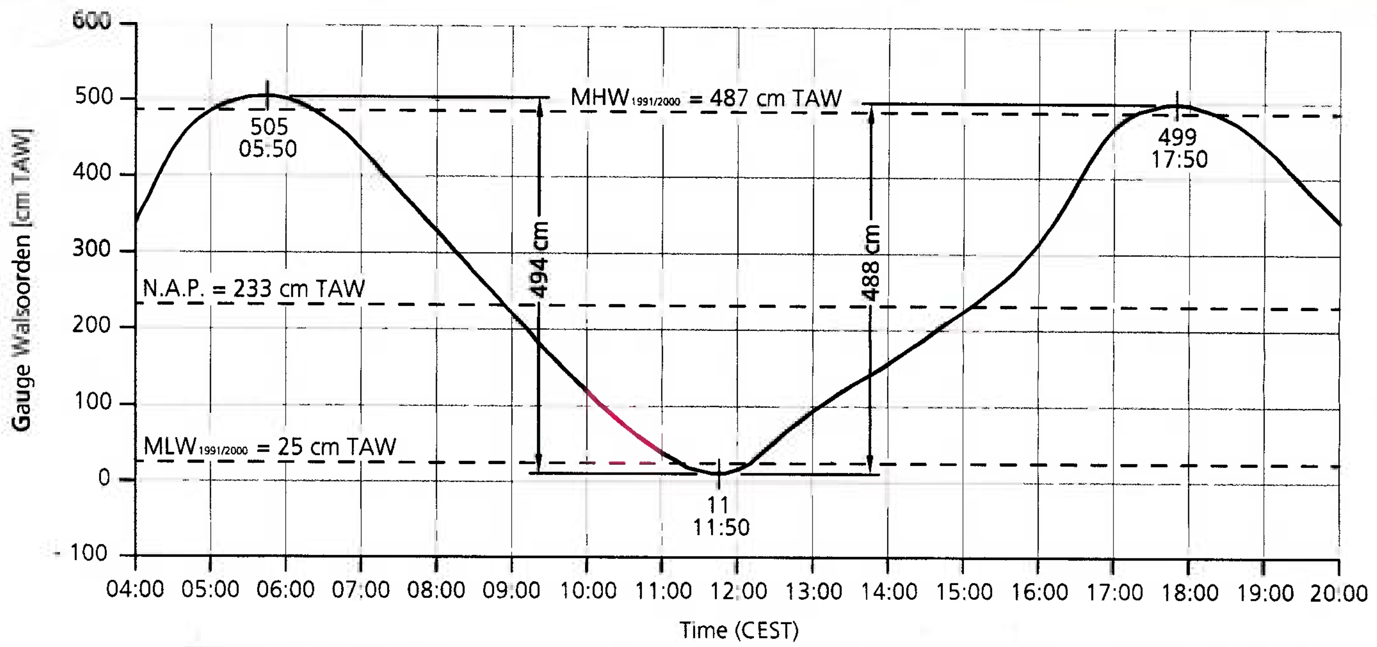
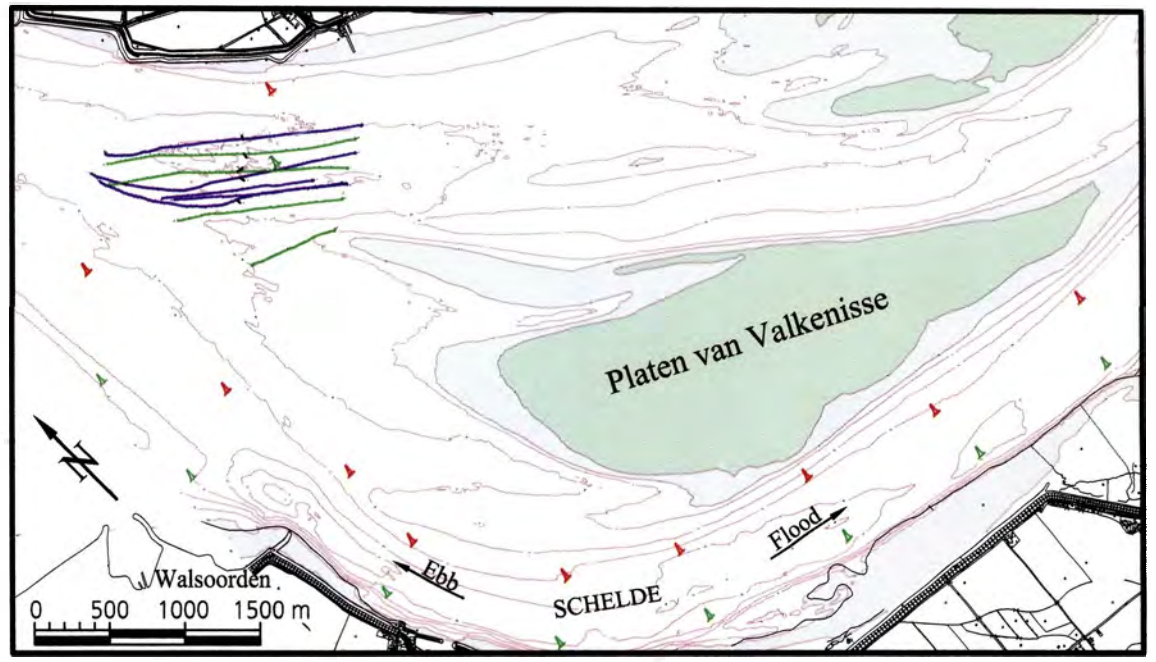
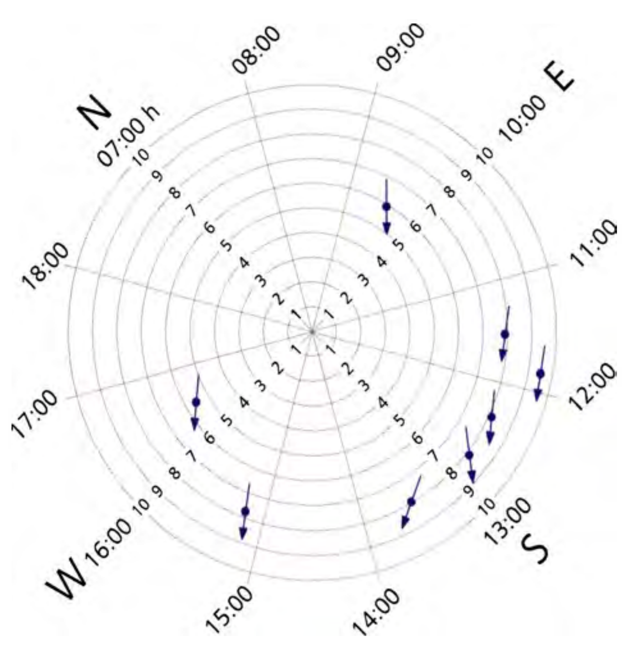
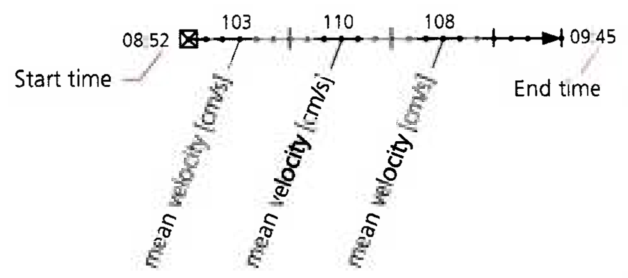






Wind Direction and Velocity





Current Tracks in 2,0 m Water Depth
Current Tracks in 5,0 m Water Depth

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IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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ANNEX 1

Current Measurements: 24.09.2002

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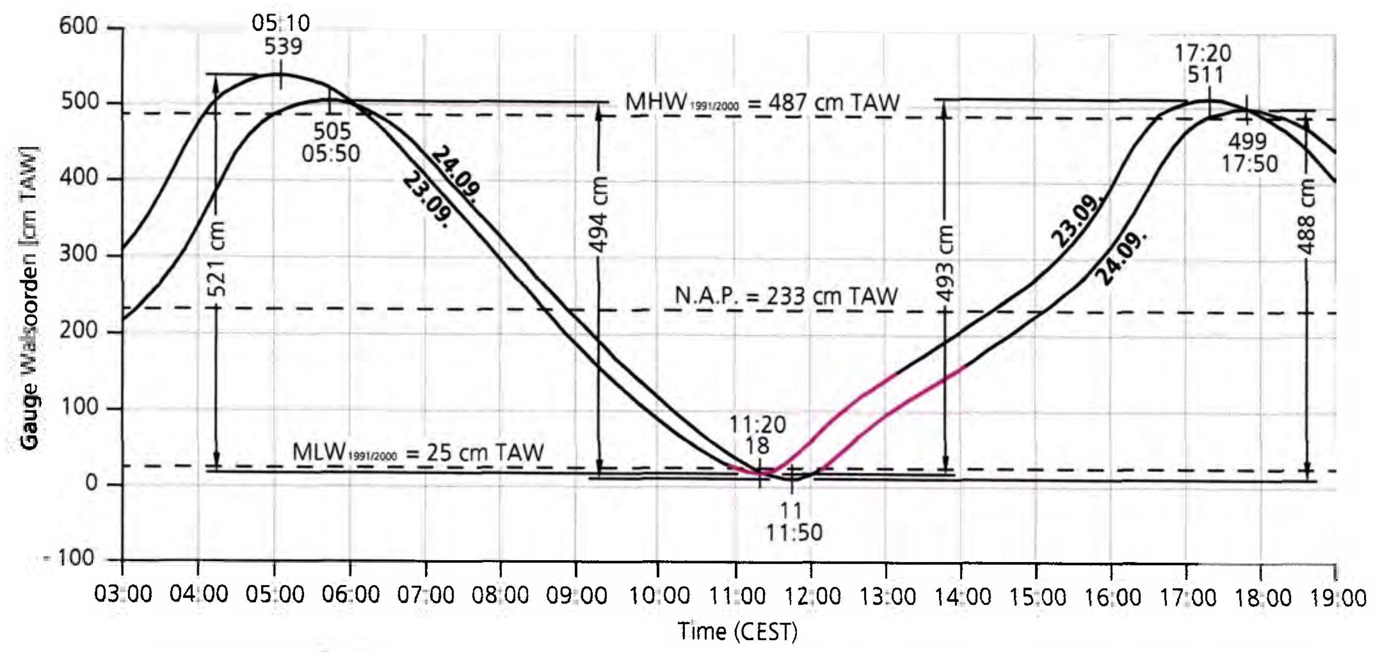

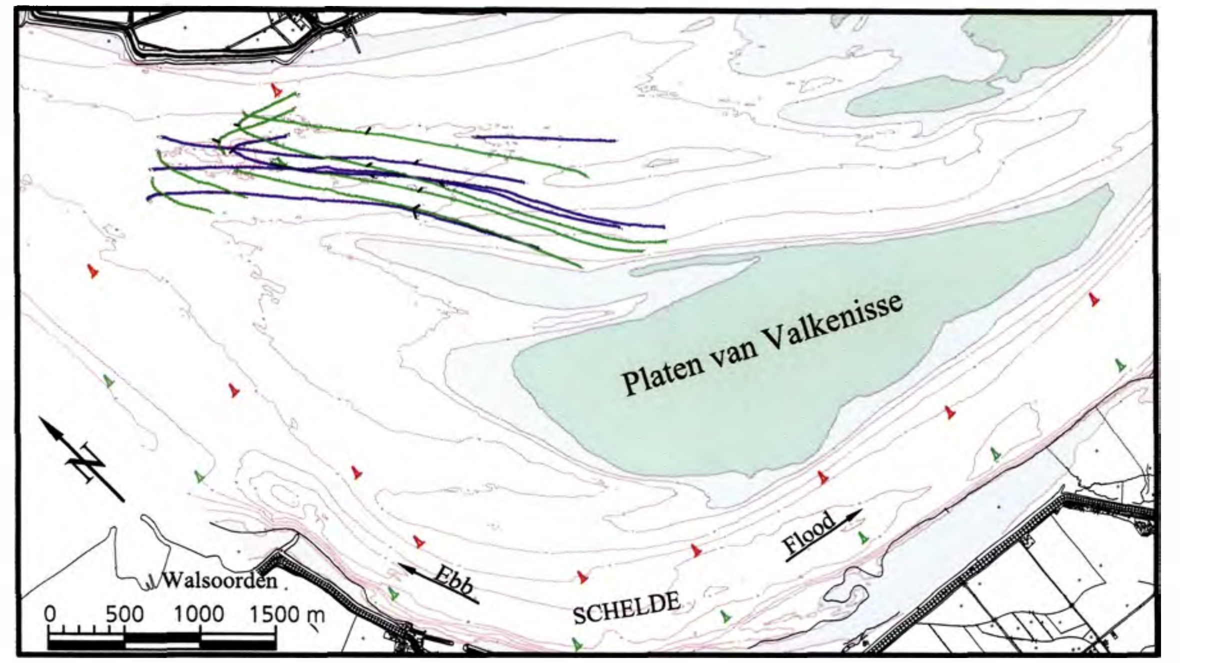

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September / October 2002

IWA
Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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ANNEX 2

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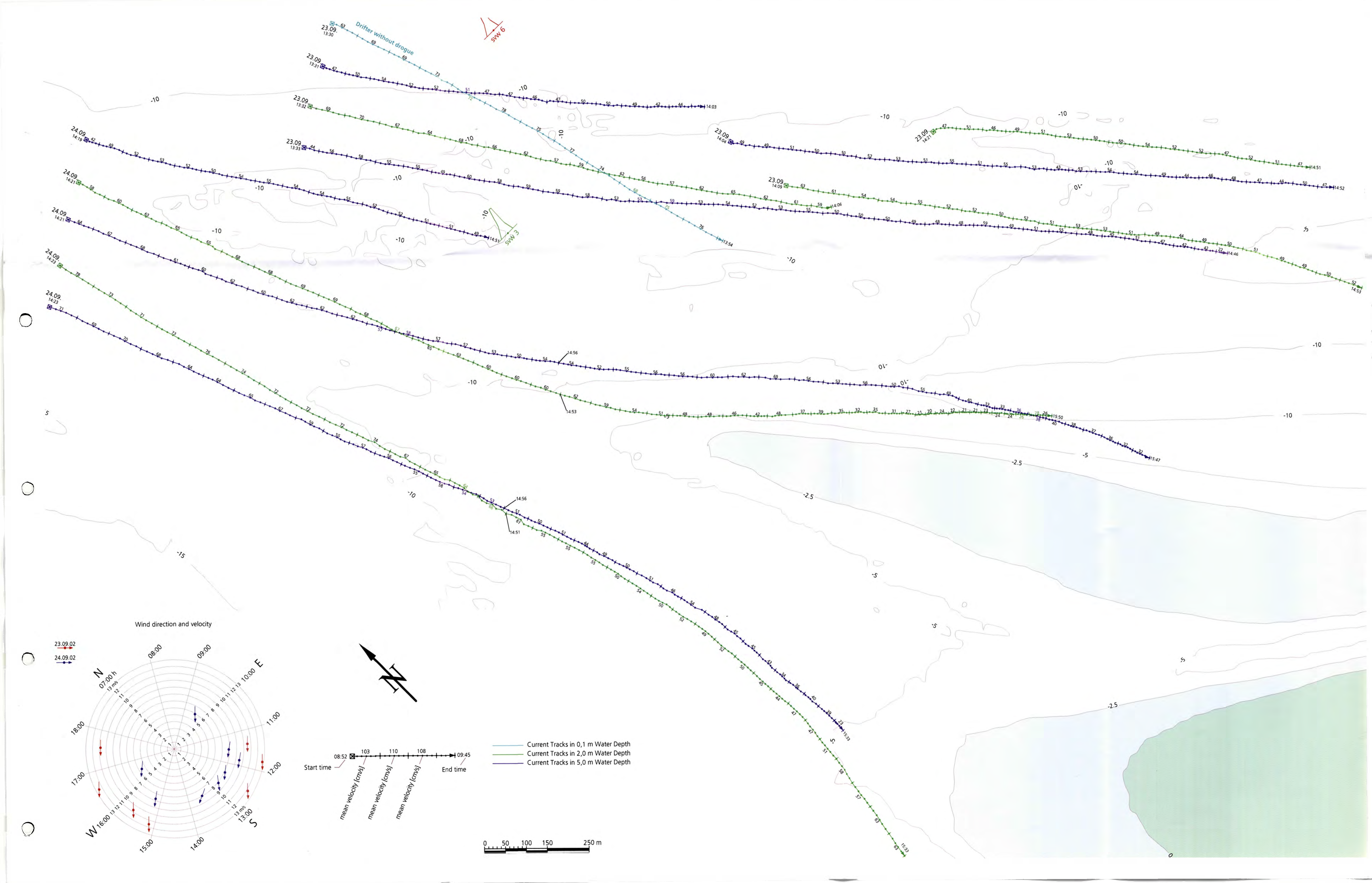

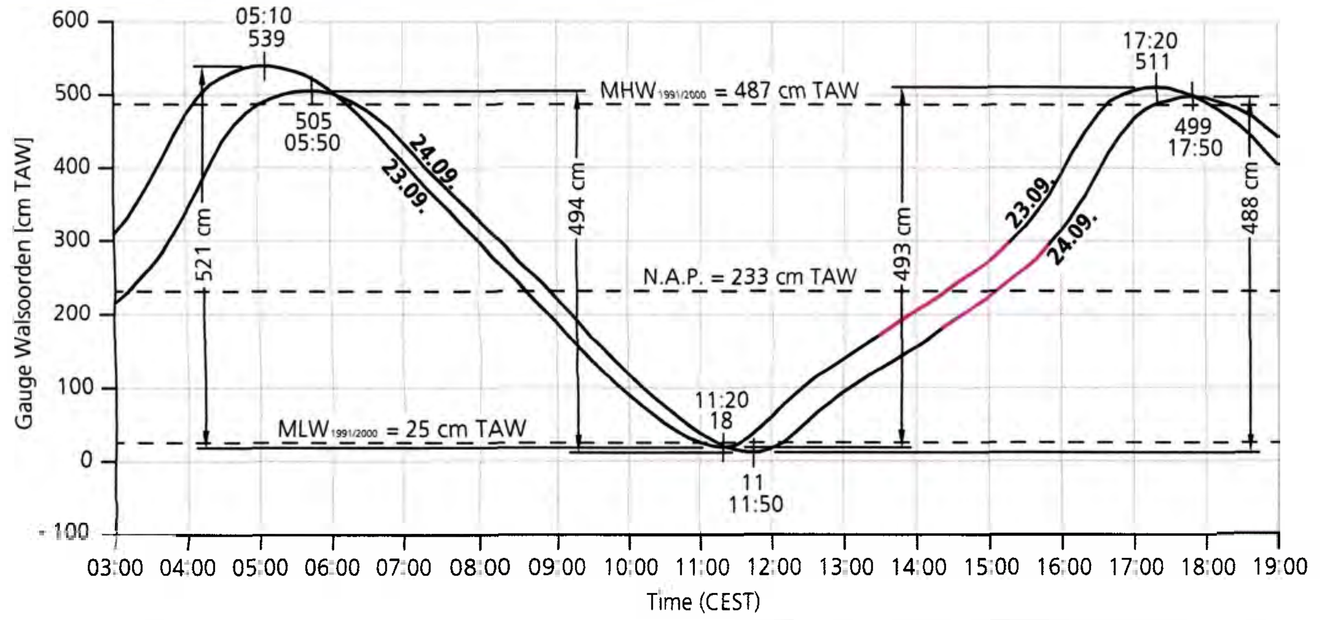

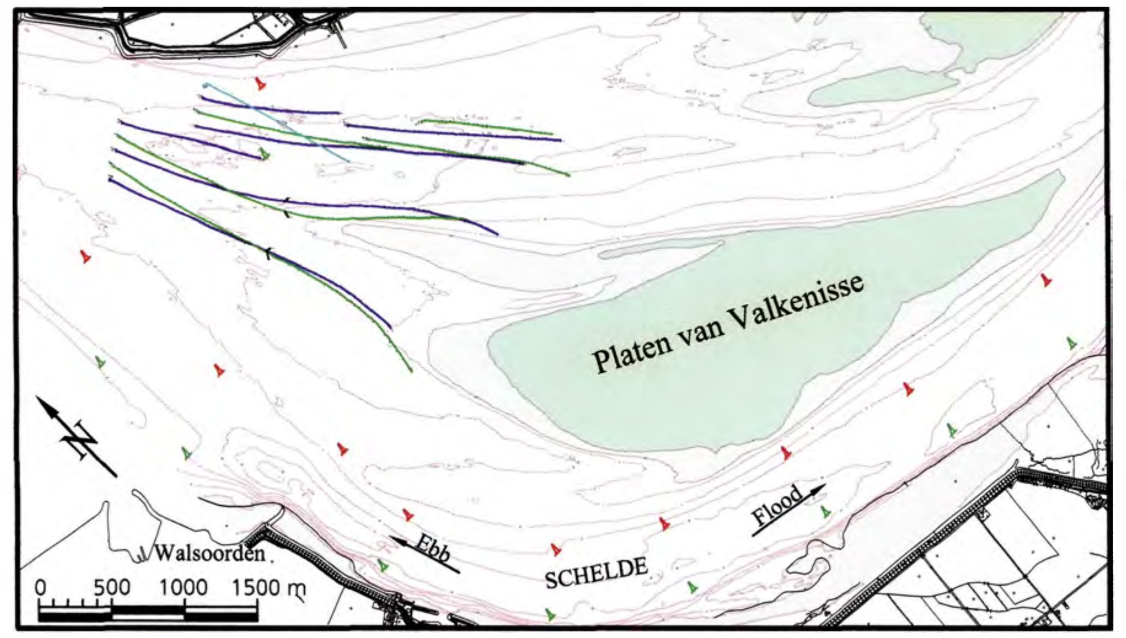

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IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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ANNEX 3

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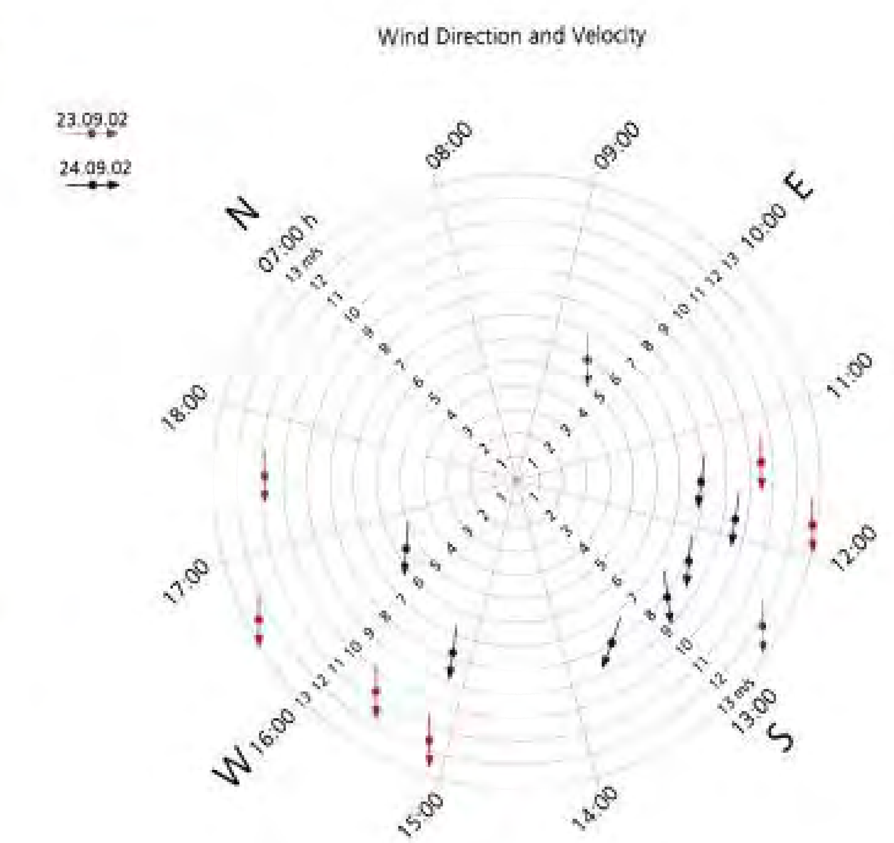

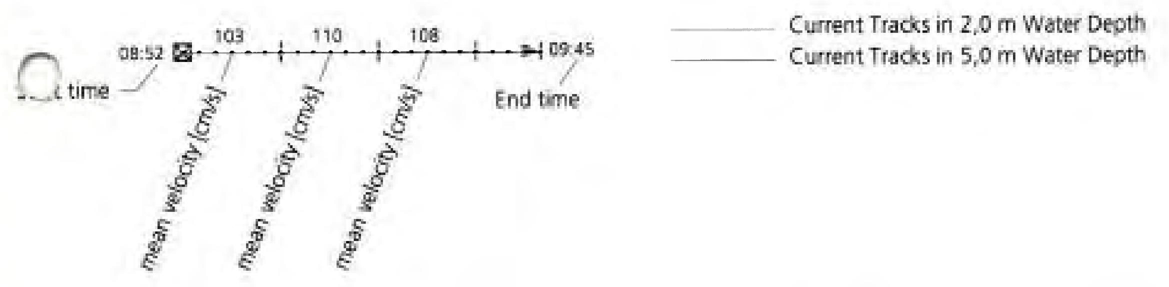

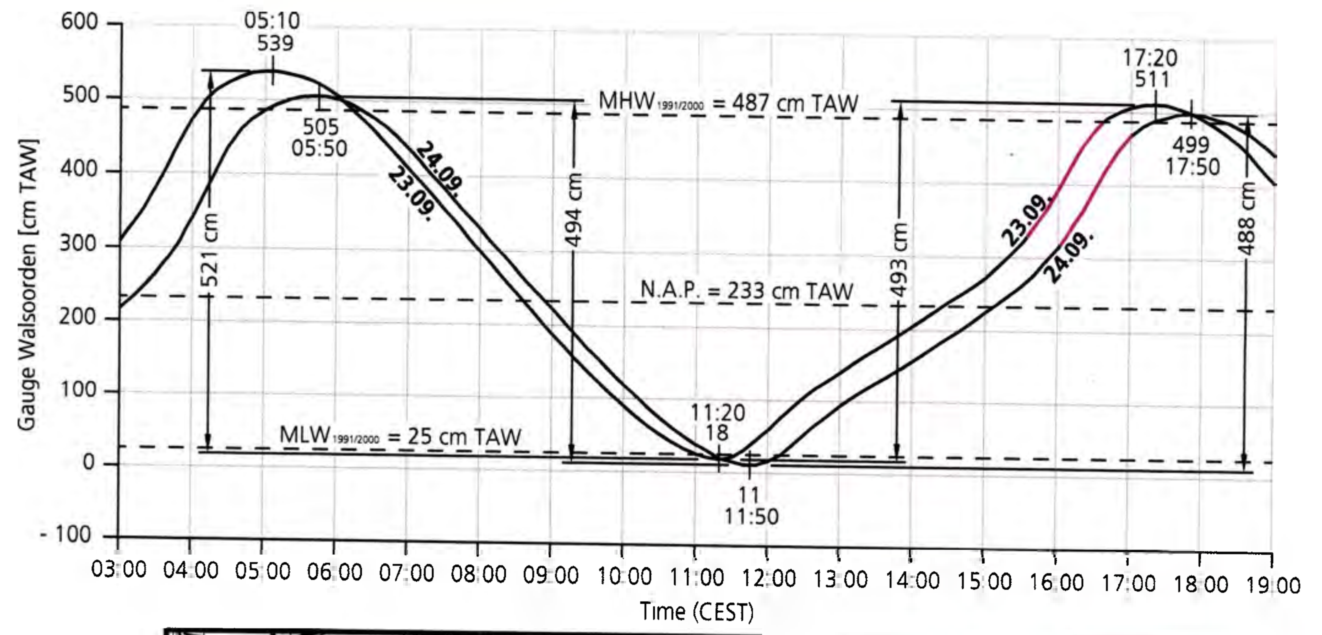

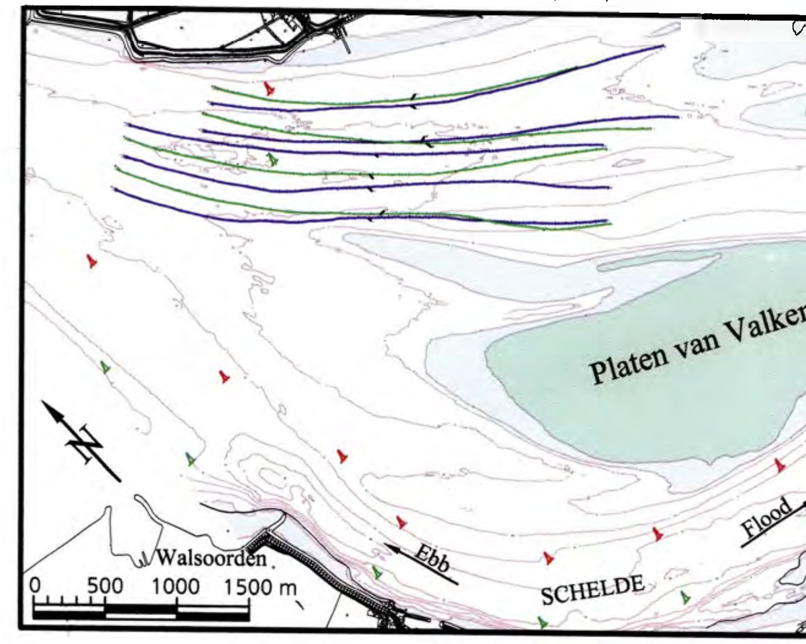

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Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel 0421-5905 2313
Fax 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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Current Measurements: **23.09. and 24.09.2002**

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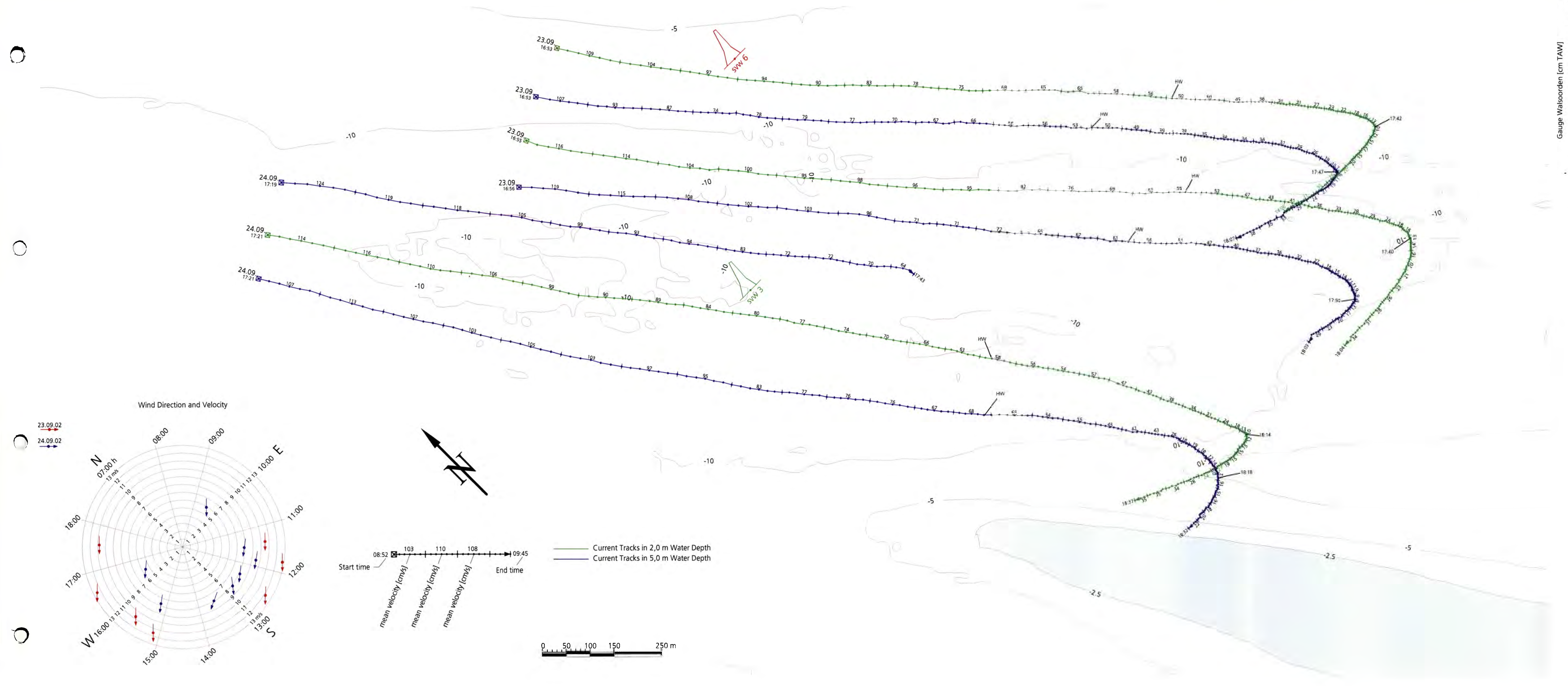
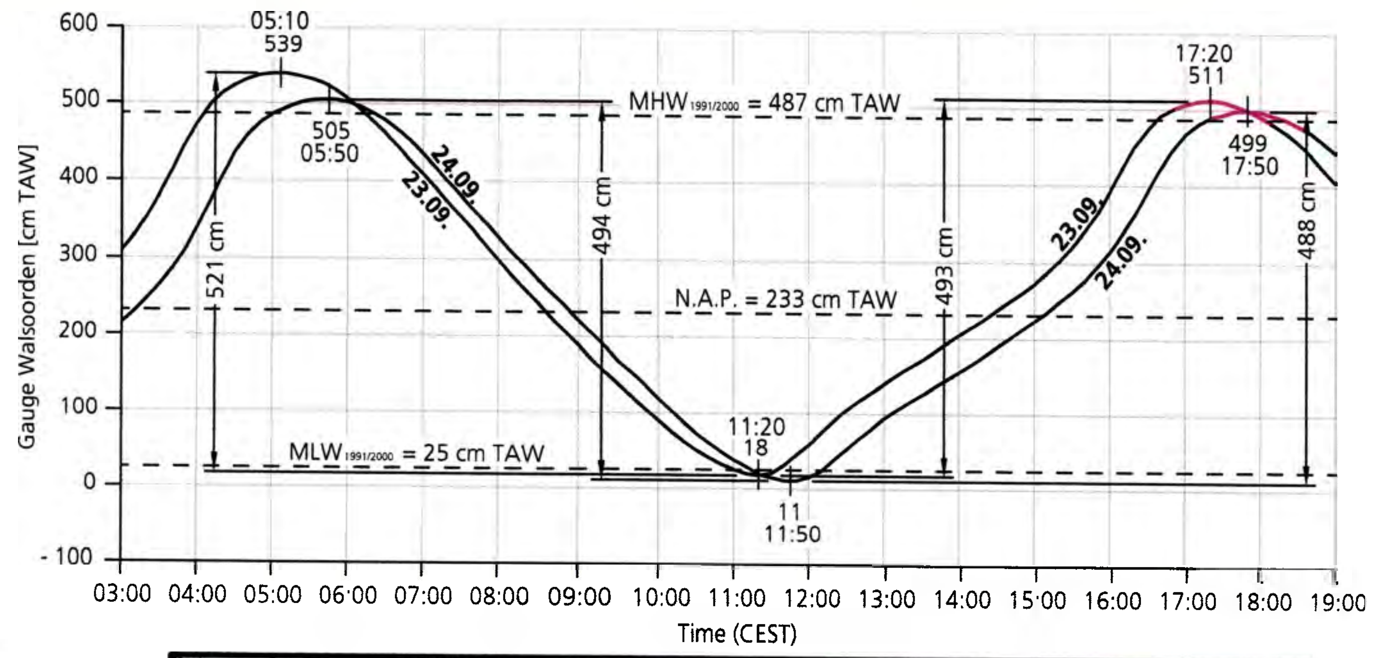
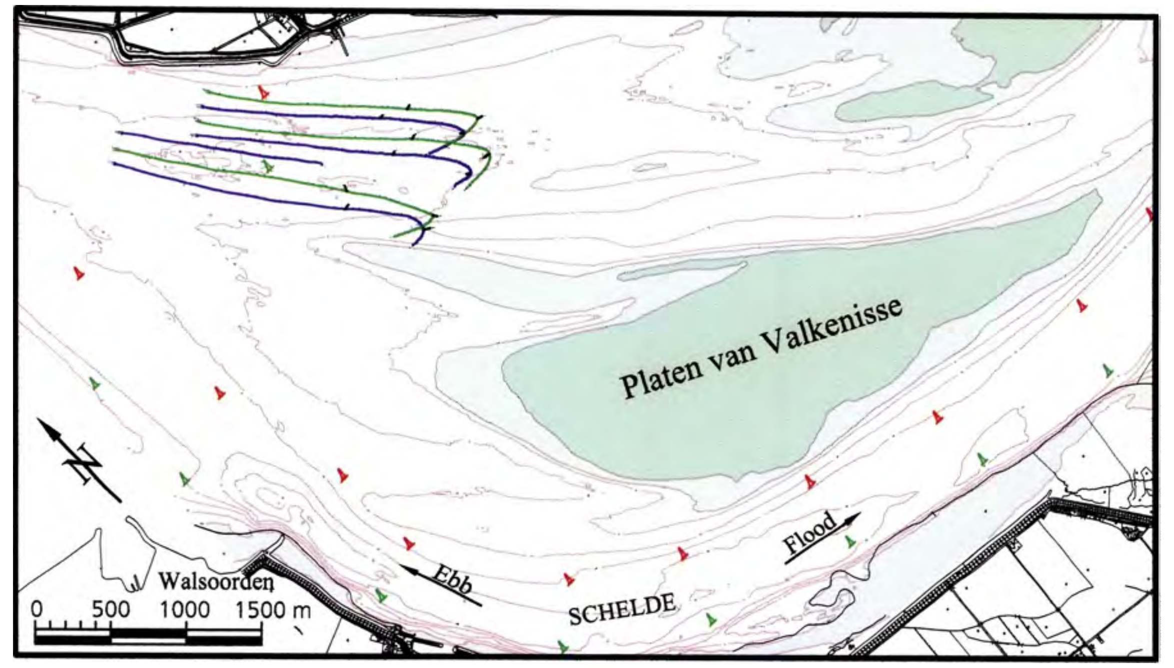
ANNEX
4







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IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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ANNEX 5

Current Measurements: 23.09. and 24.09.2002

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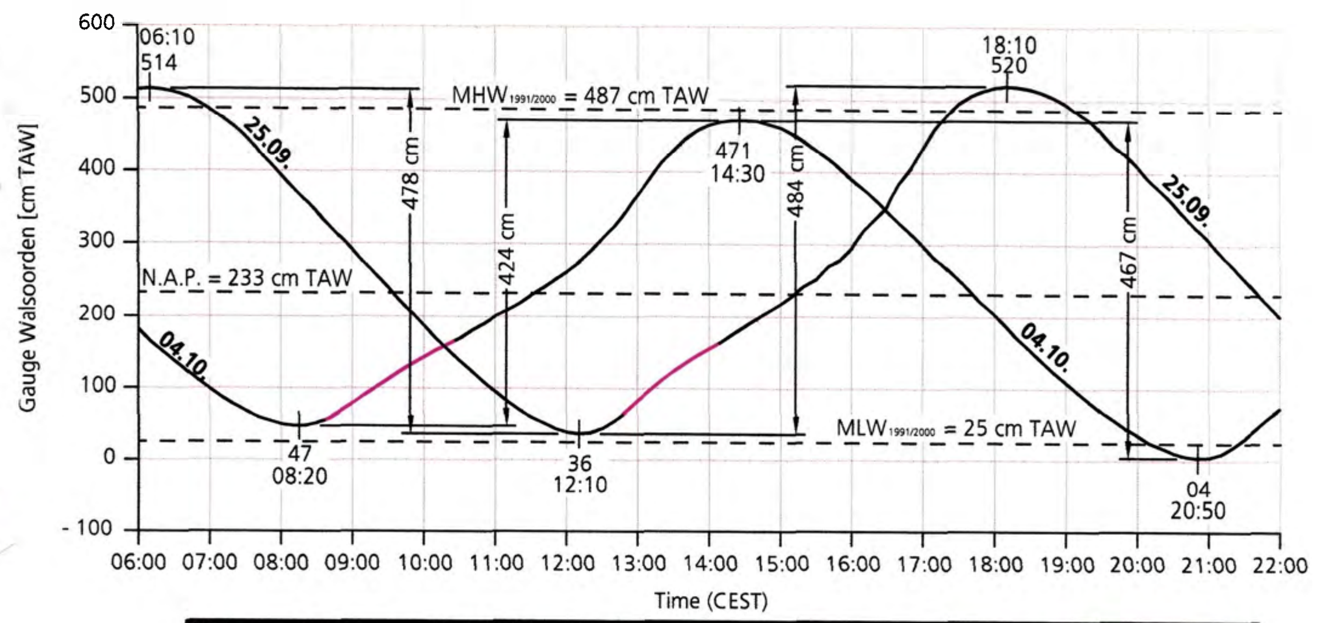

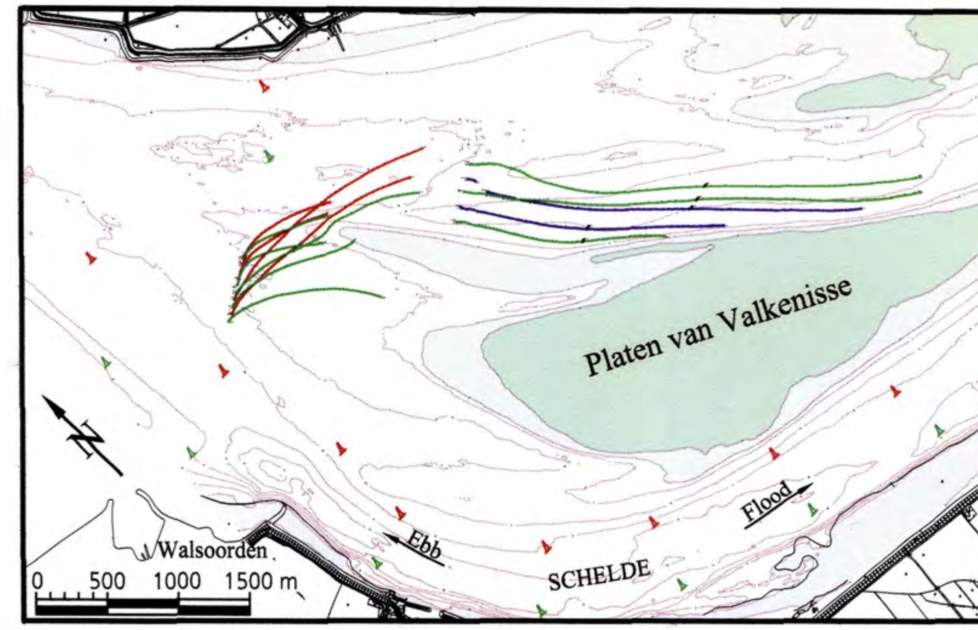

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Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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ANNEX 6

Current Measurements: 25.09. and 04.10.2002

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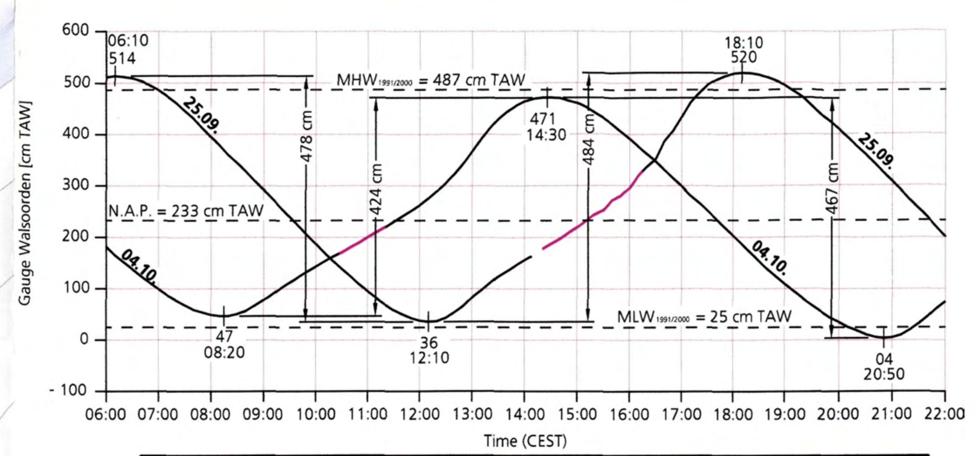

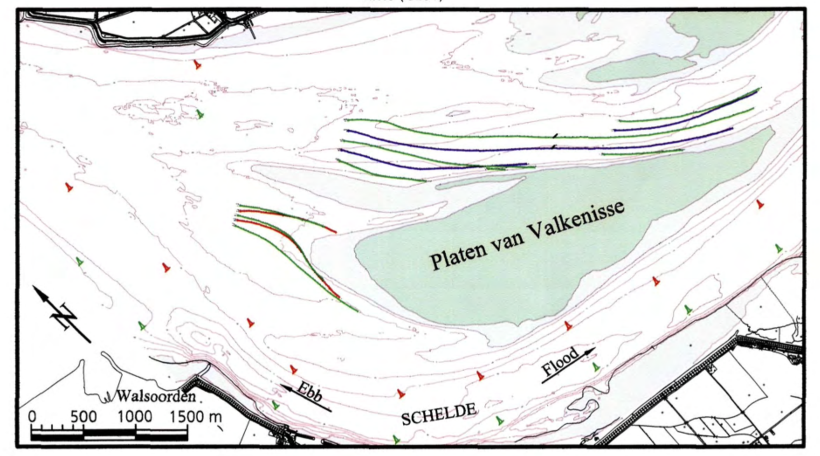

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Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
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ANNEX 7

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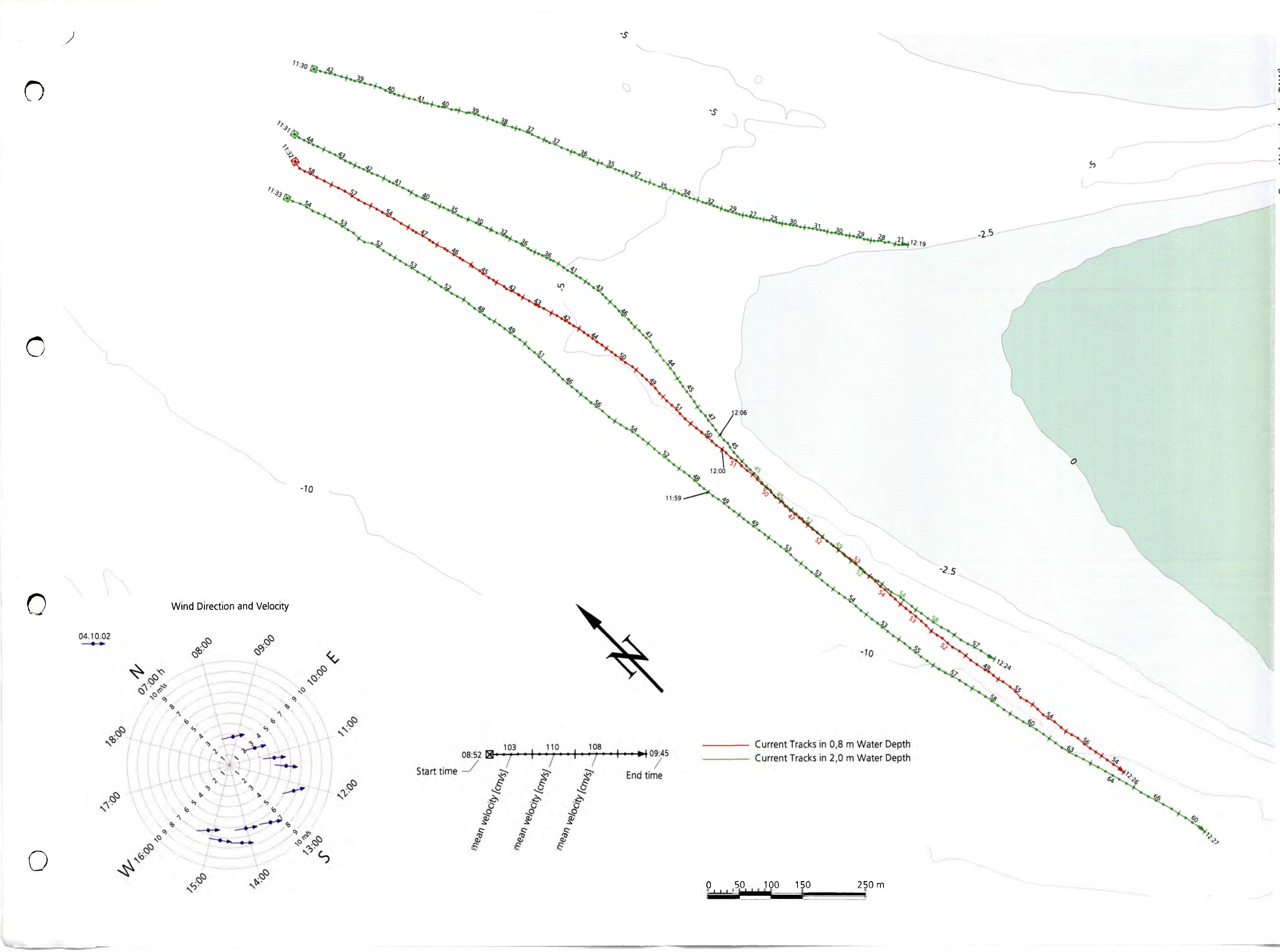

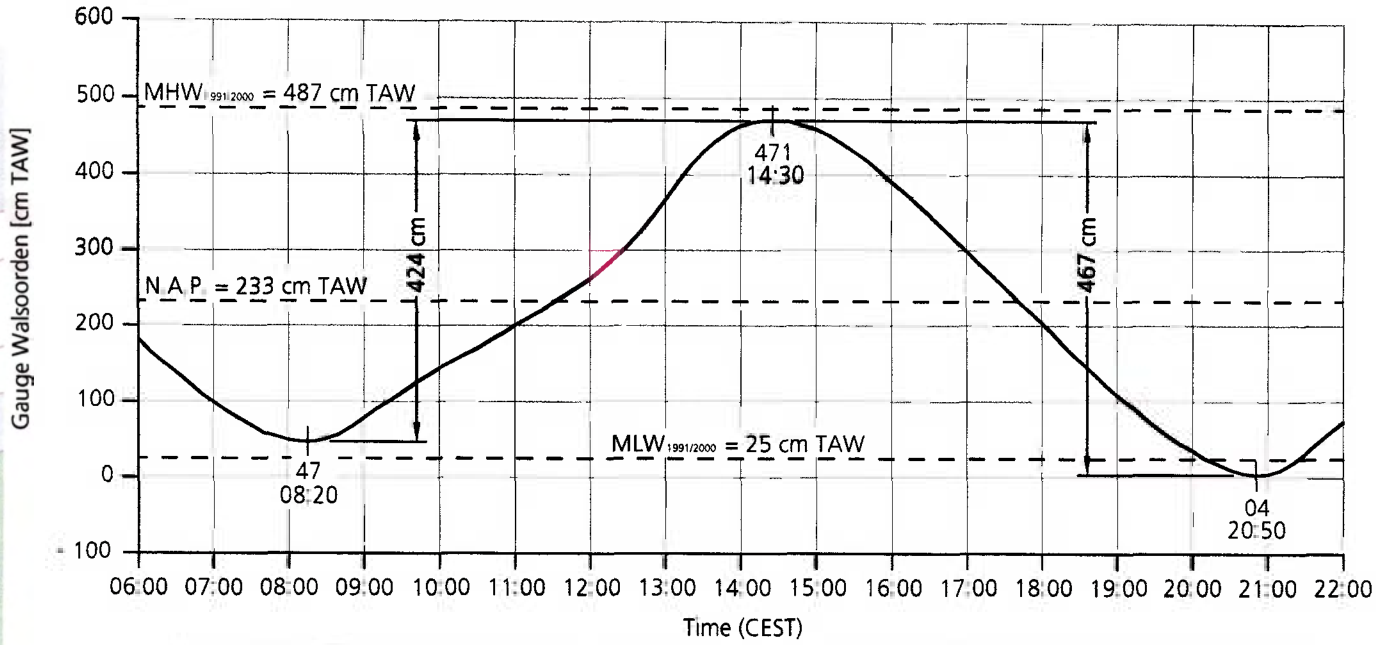

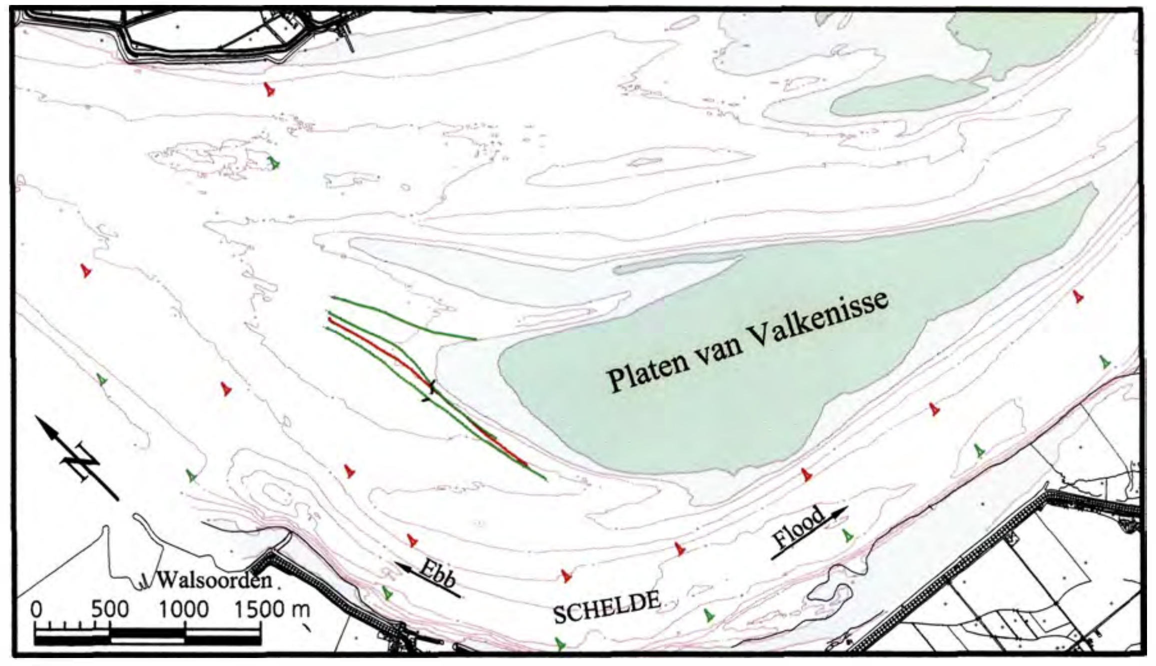

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IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

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Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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8

Current Measurements: **04.10.2002**

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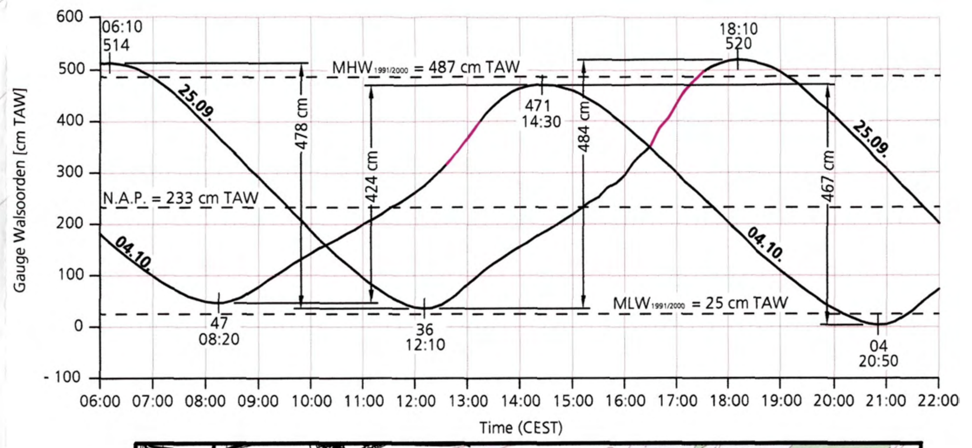

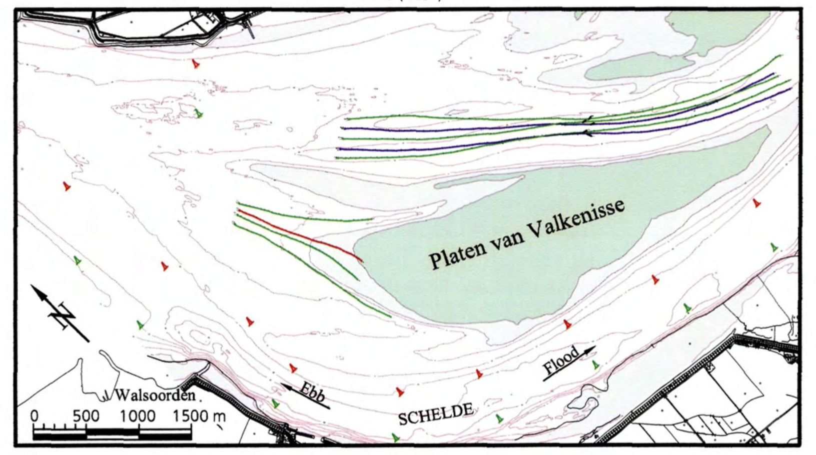

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Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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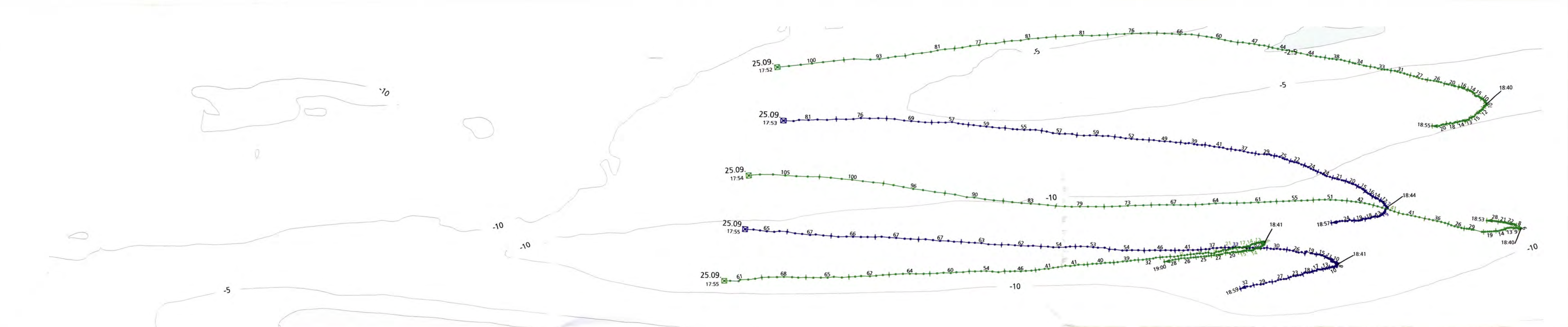
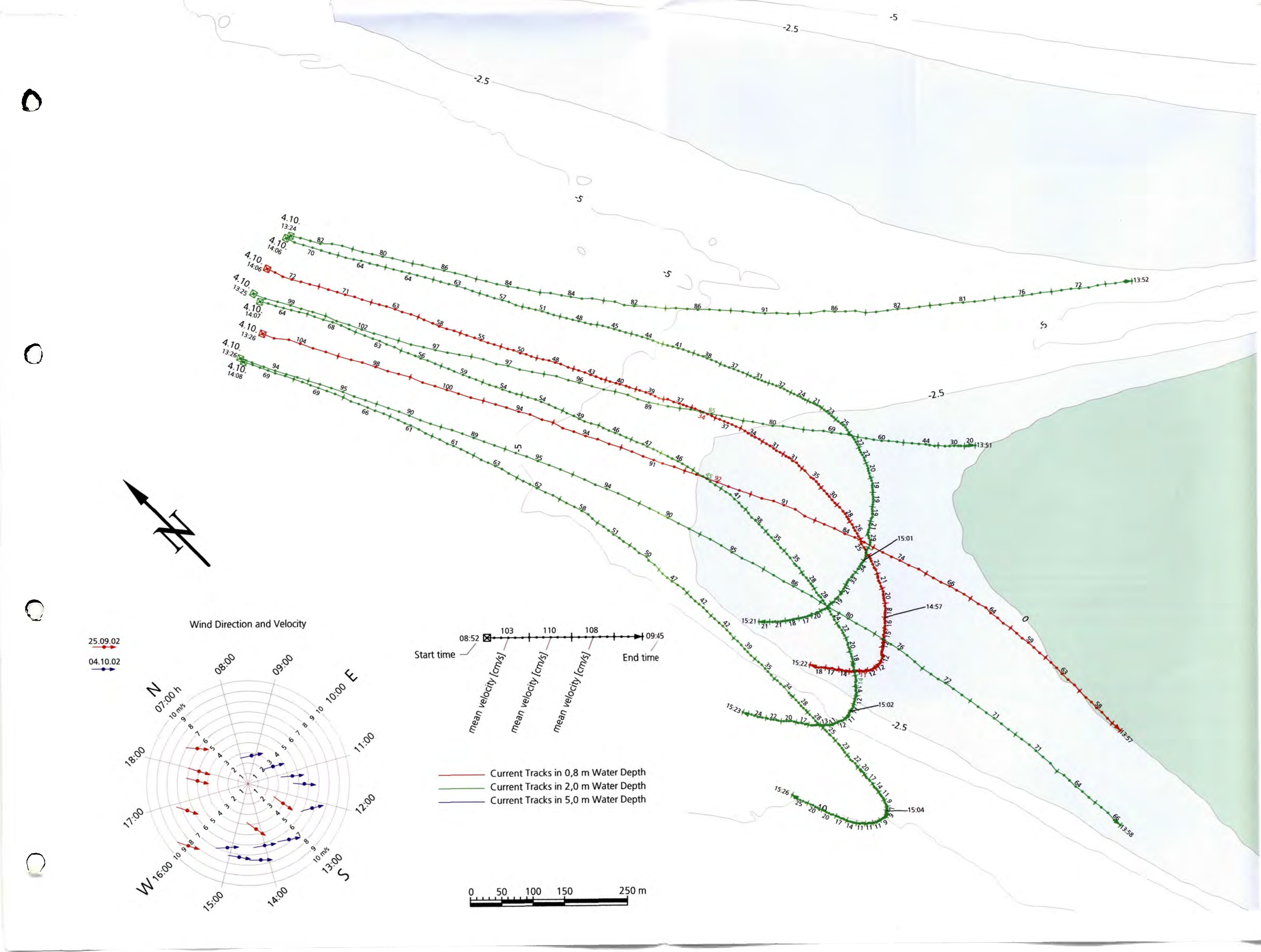
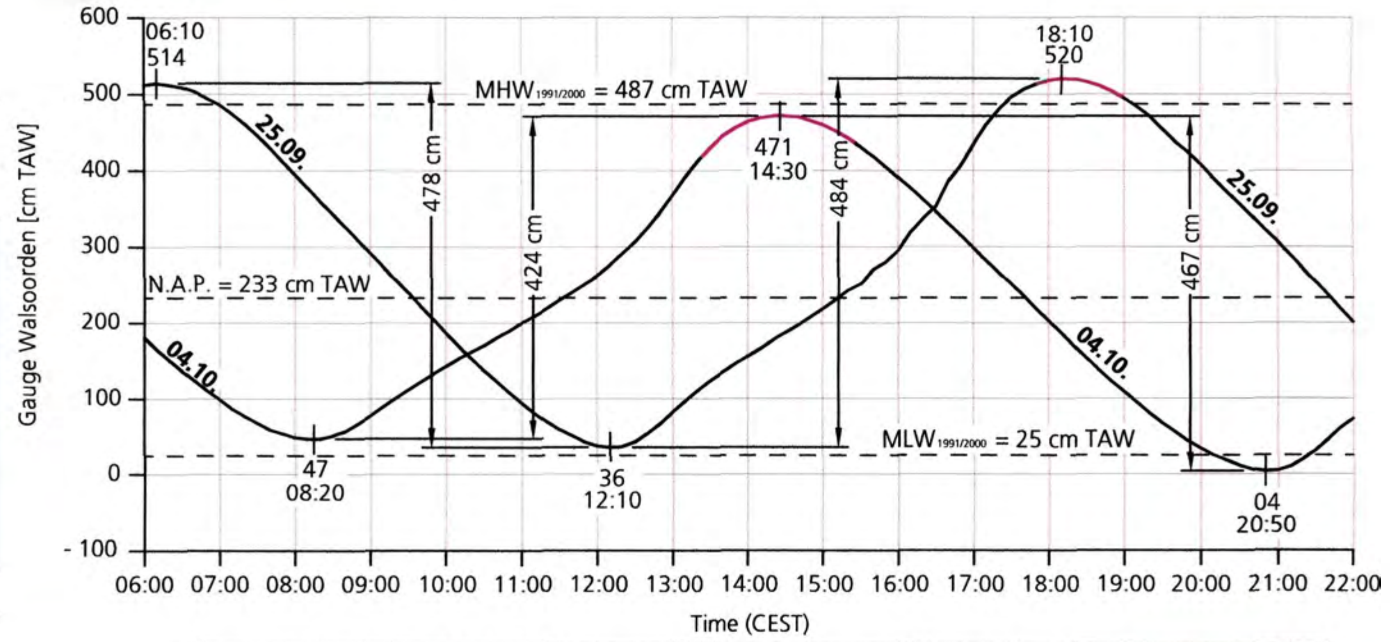
ANNEX 9

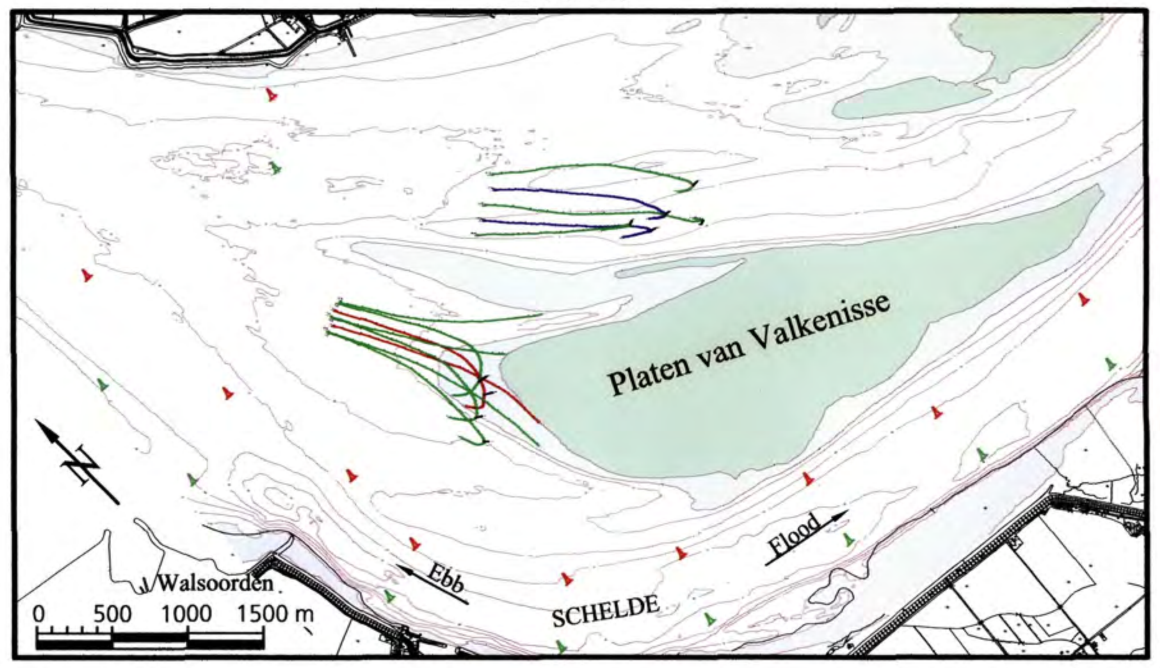
Current Measurements: **25.09. and 04.10.2002**

Chart Datum: N.A.P. [m]









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IWA
Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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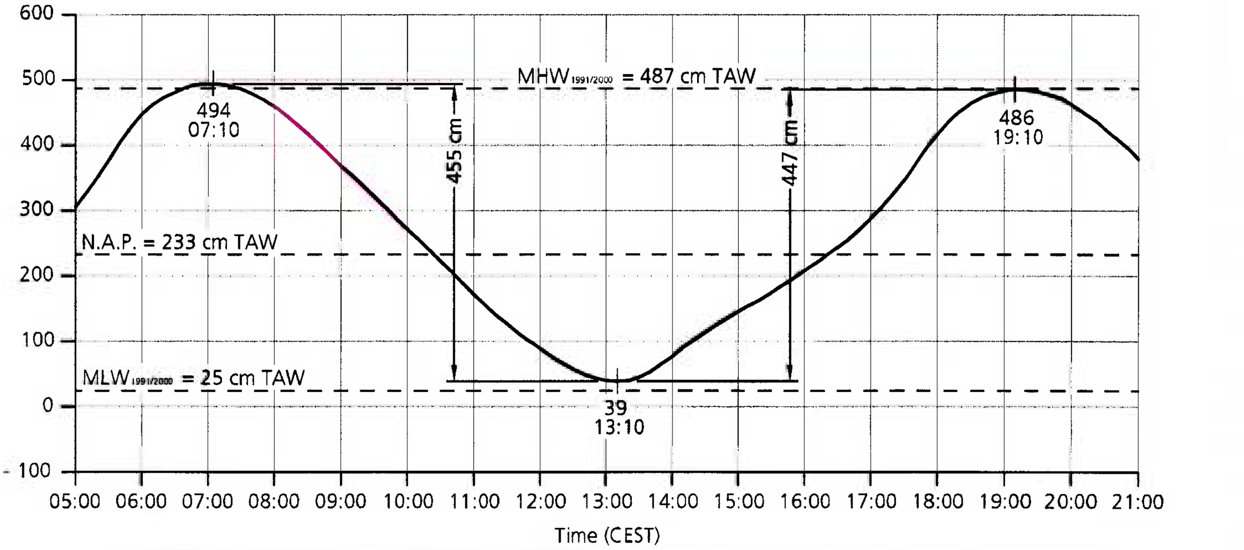
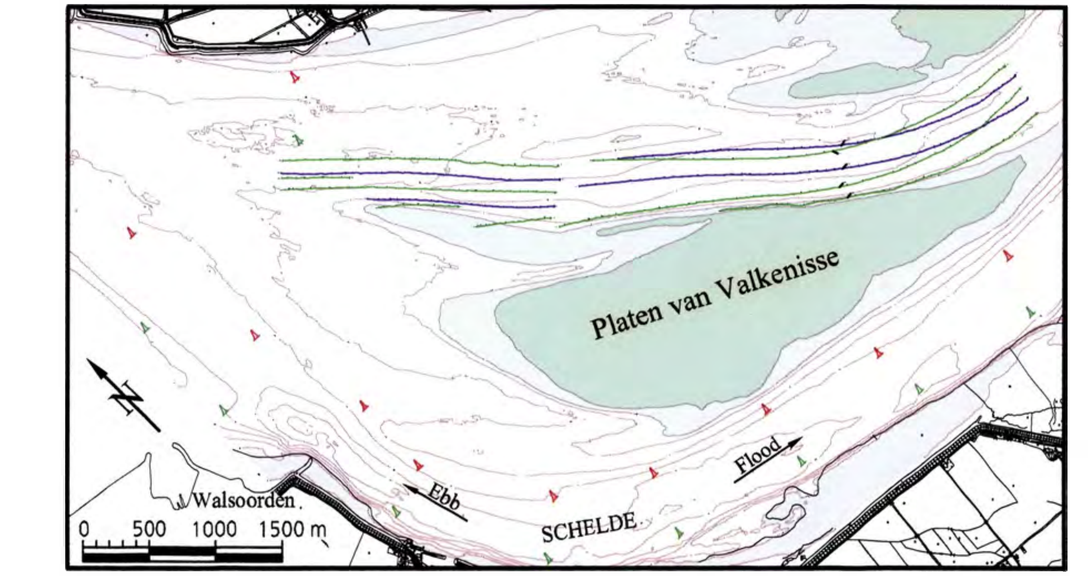
ANNEX 10

Current Measurements: 25.09. and 04.10.2002

Chart Datum: N.A.P. [m]





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Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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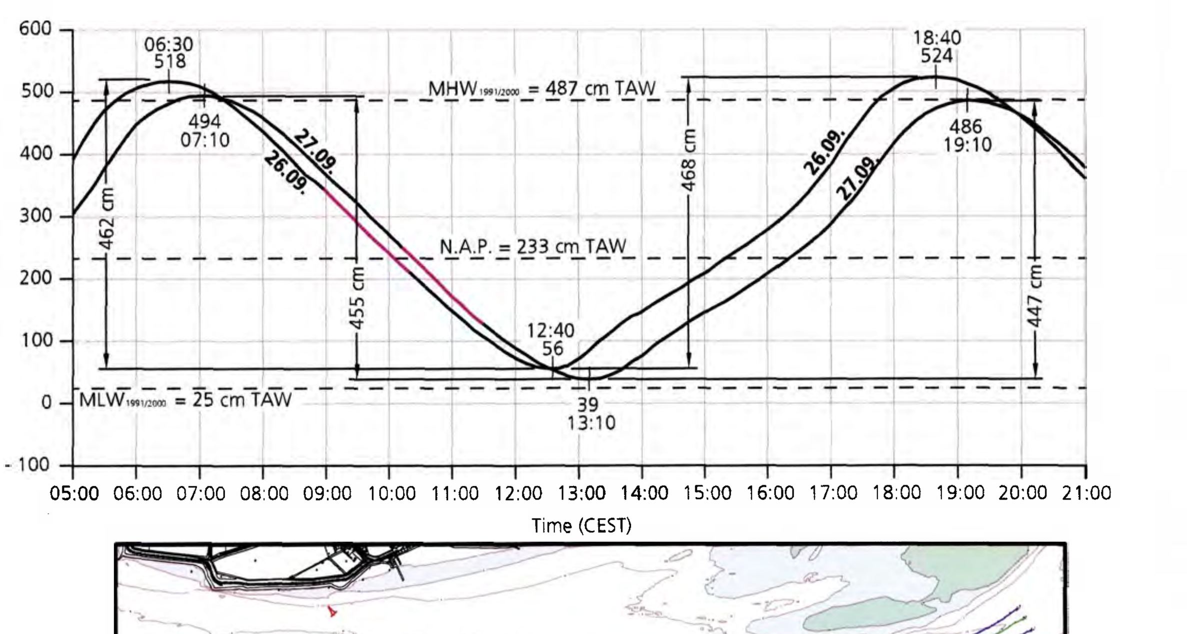
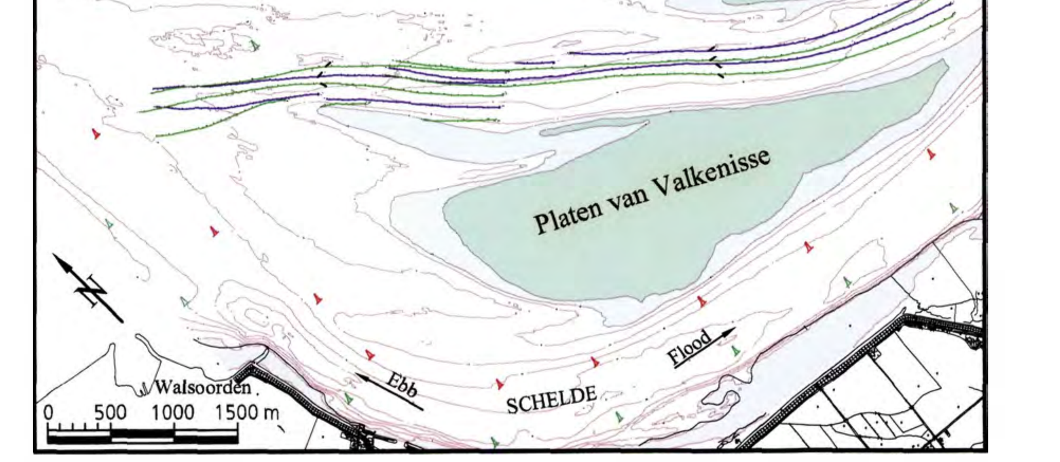
Current Measurements: **27.09.2002**

Chart Datum: N.A.P. [m]

ANNEX

11





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September / October 2002

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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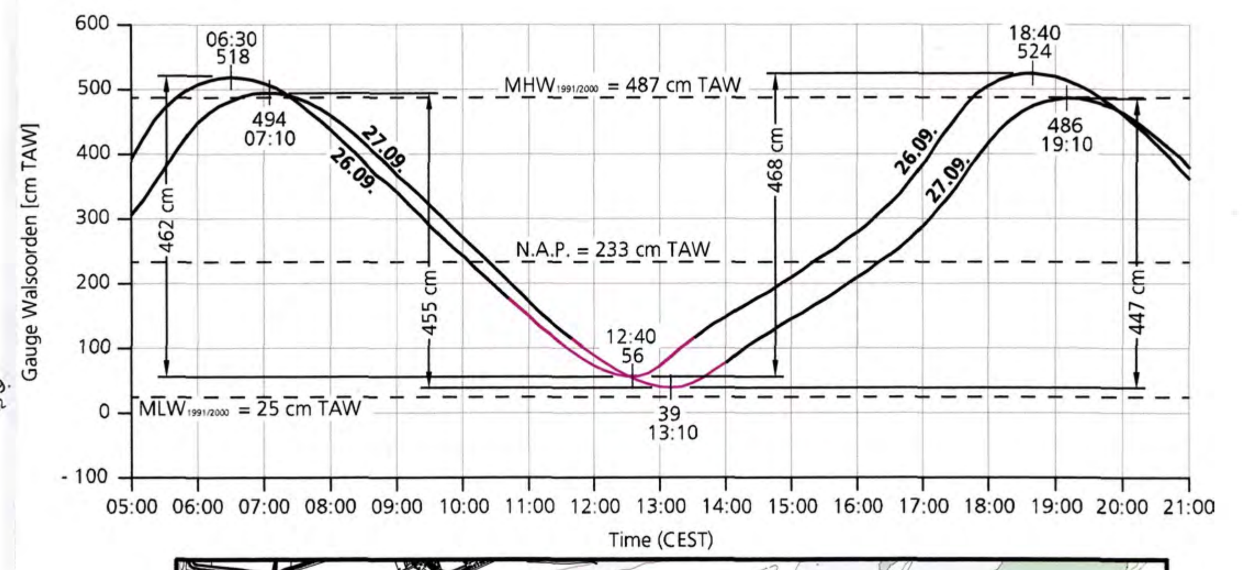
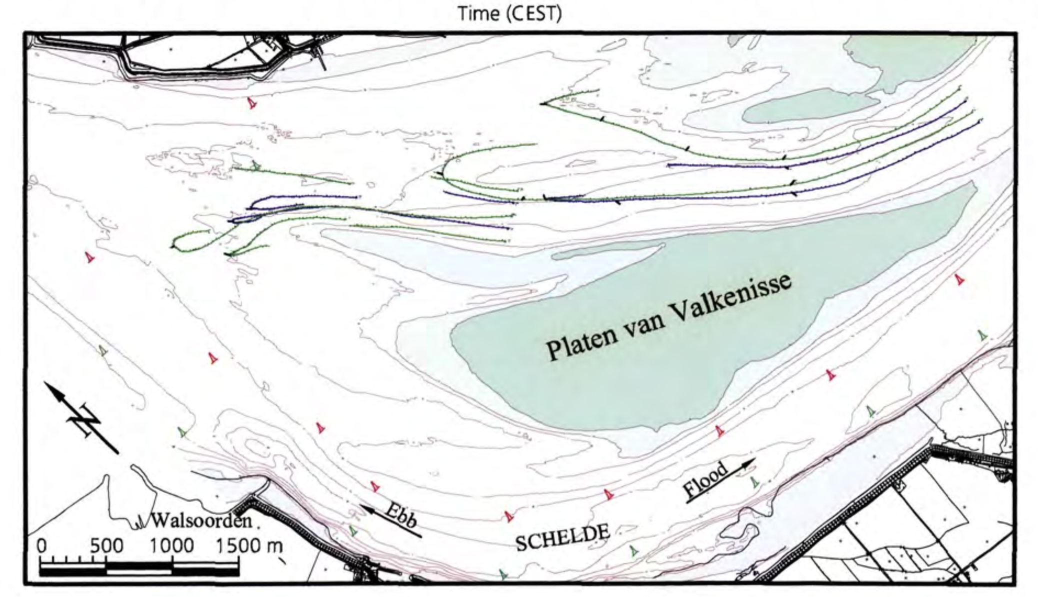
ANNEX 12

Current Measurements: **26.09. and 27.09.2002**

Chart Datum: N.A.P. [m]





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Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

in association with:

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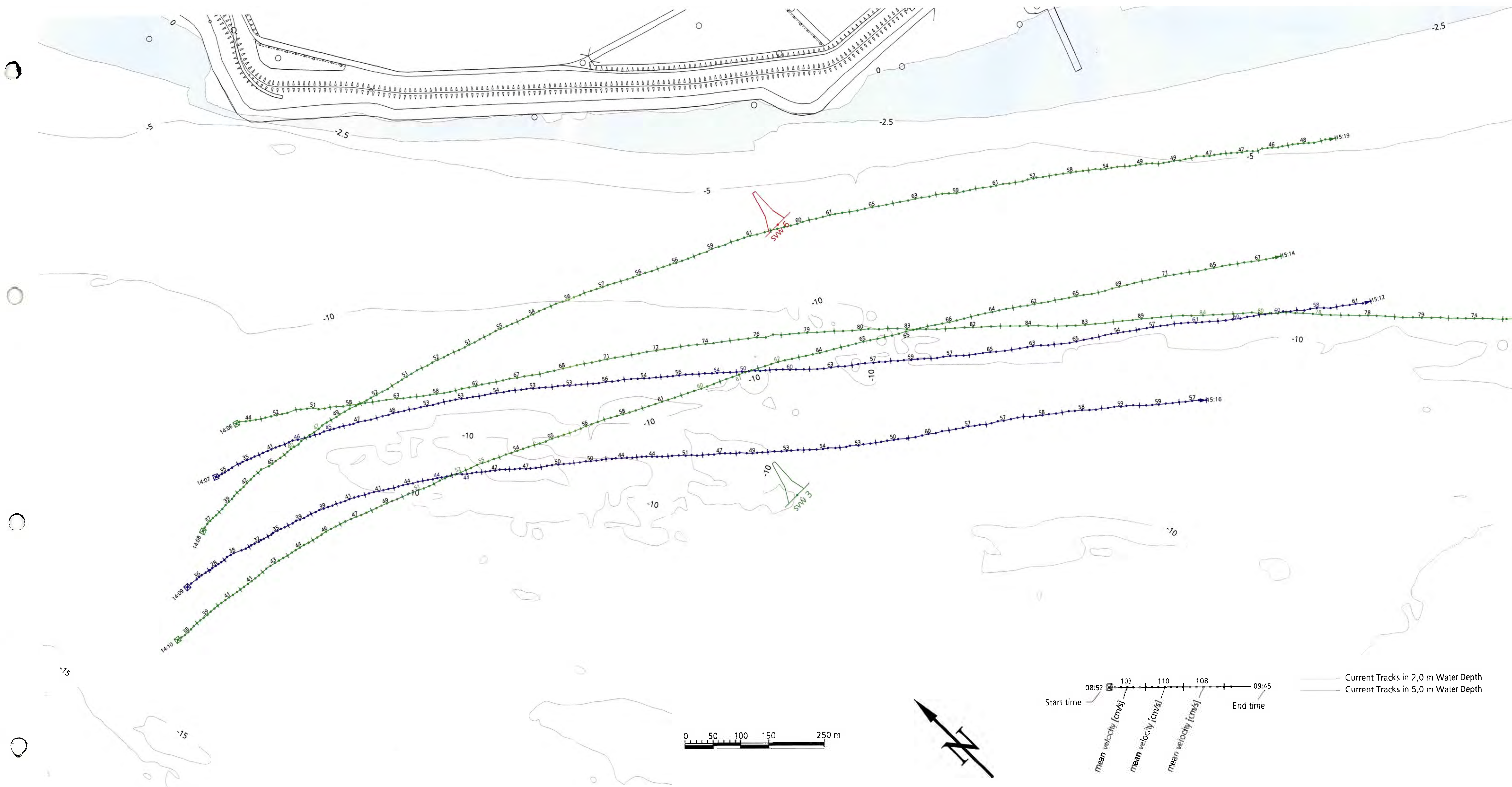
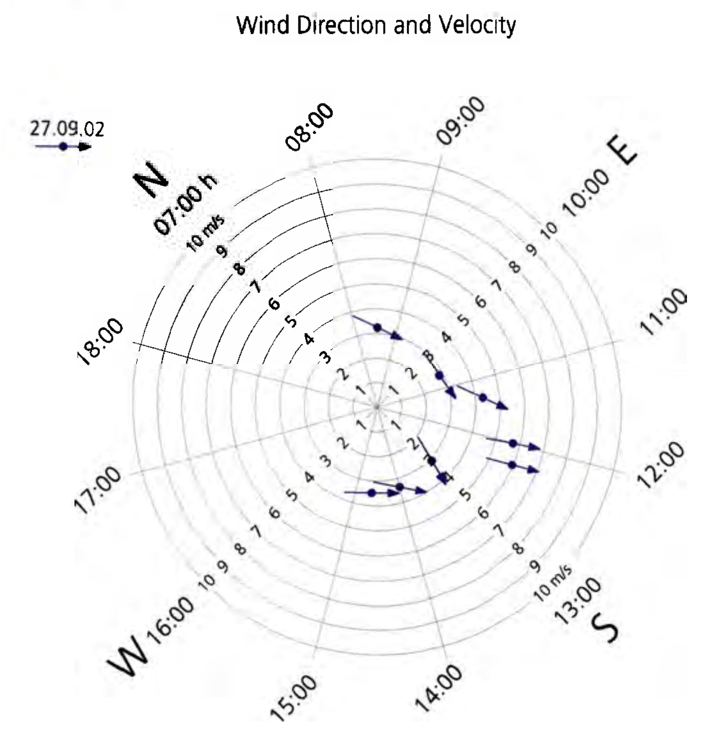
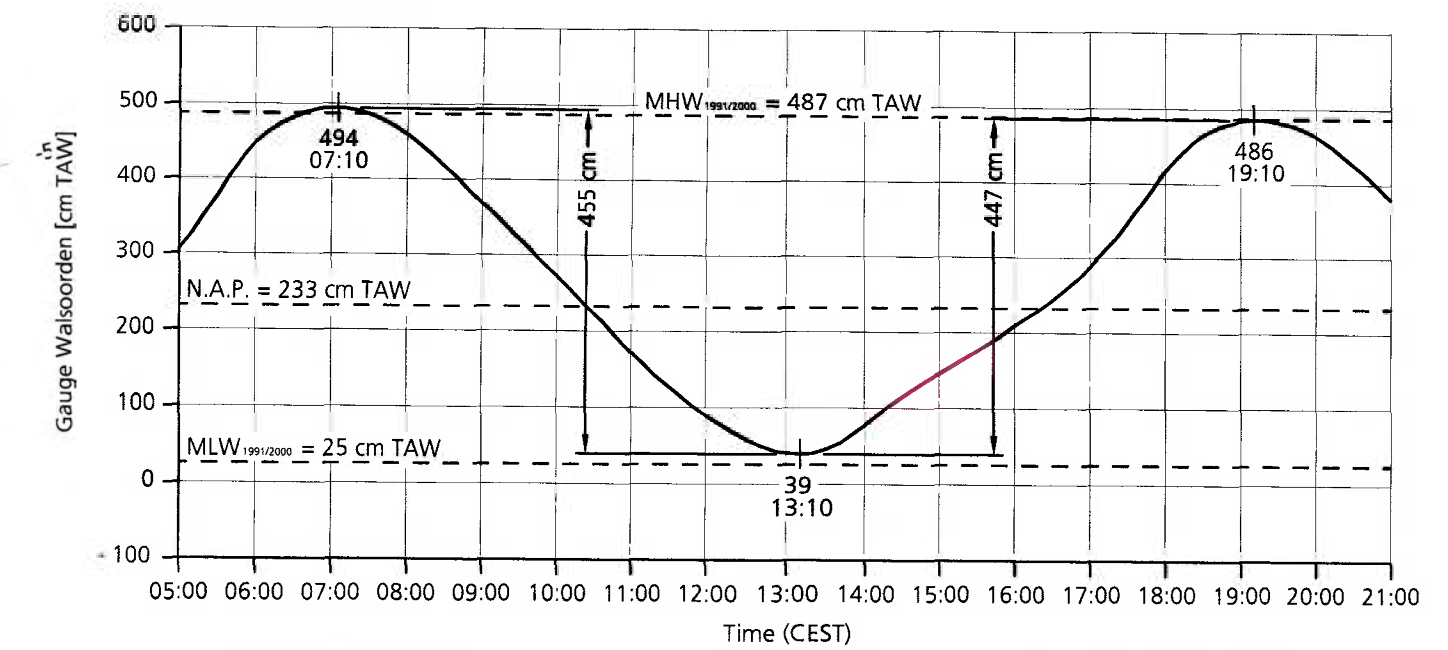
ANNEX 13

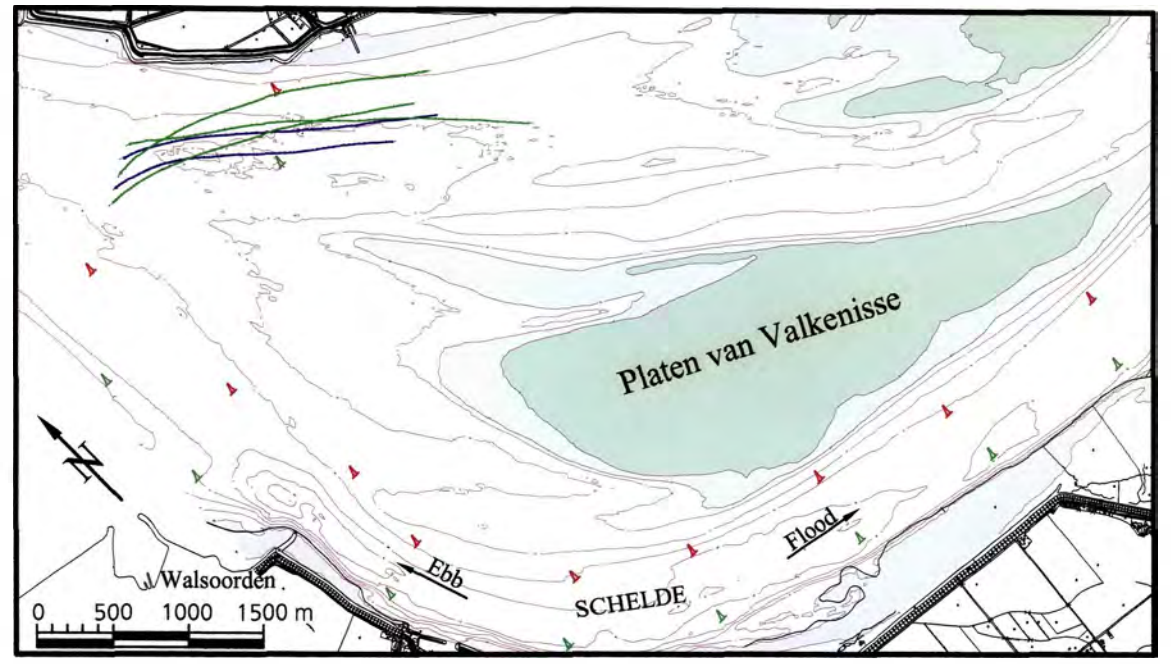
Current Measurements: 26.09. and 27.09.2002

Chart Datum: N.A.P. [m]









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Current Measurements in the Westerschelde
September / October 2002

IWA
Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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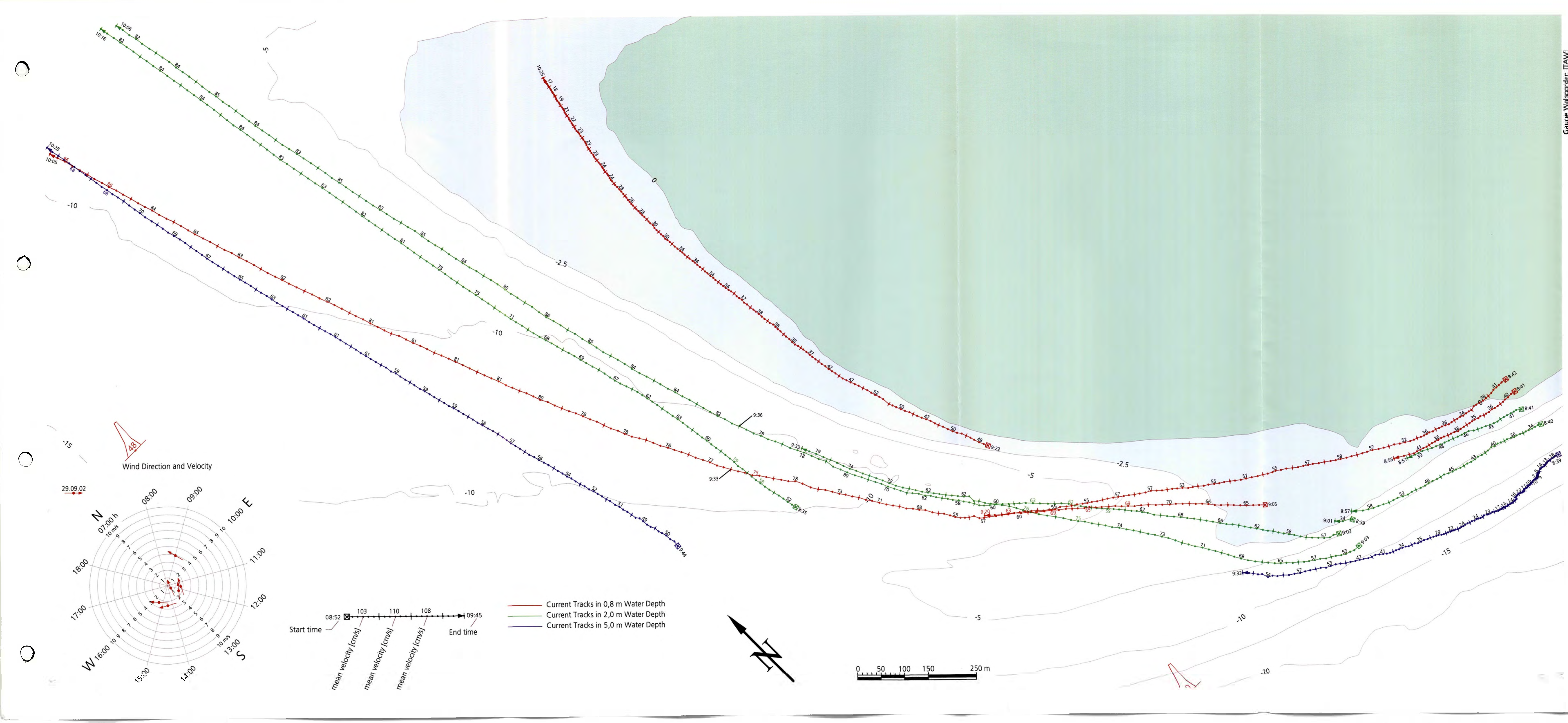
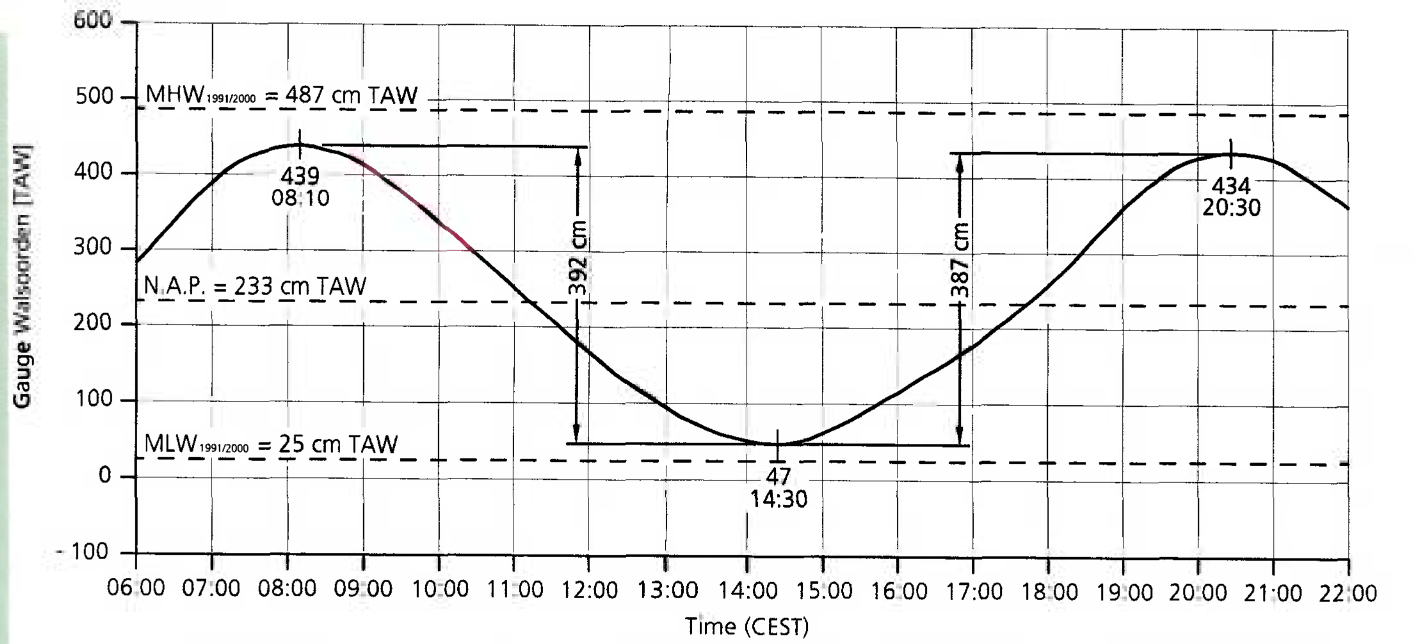
ANNEX

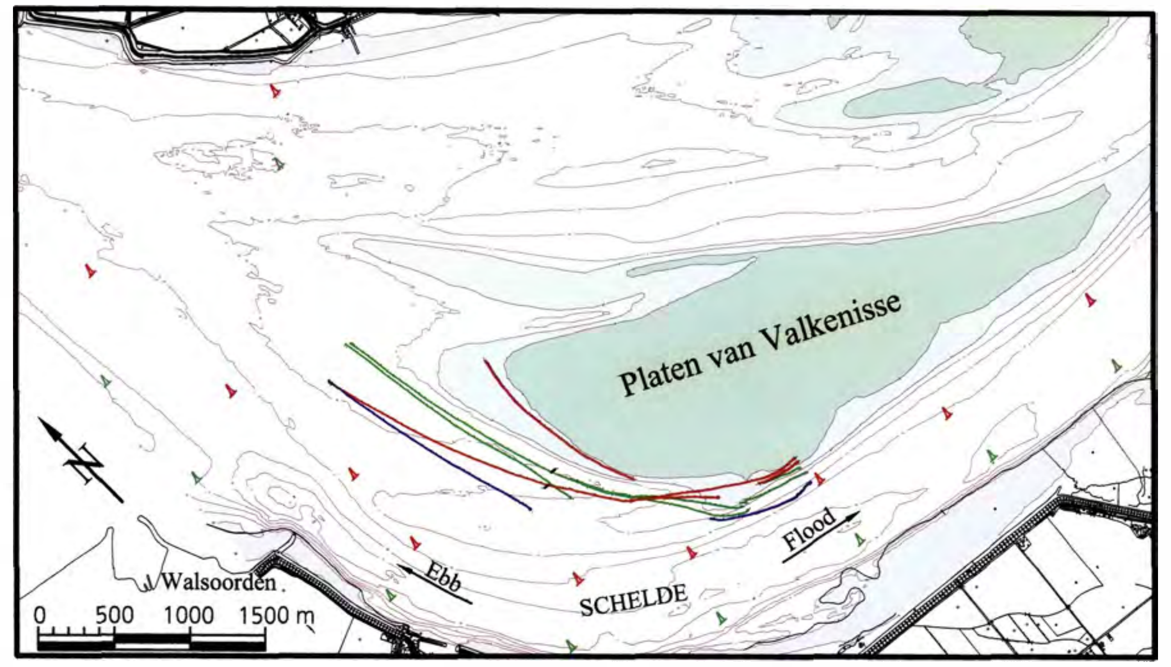
14

Current Measurements: 27.09.2002

Chart Datum: N.A.P. [m]







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Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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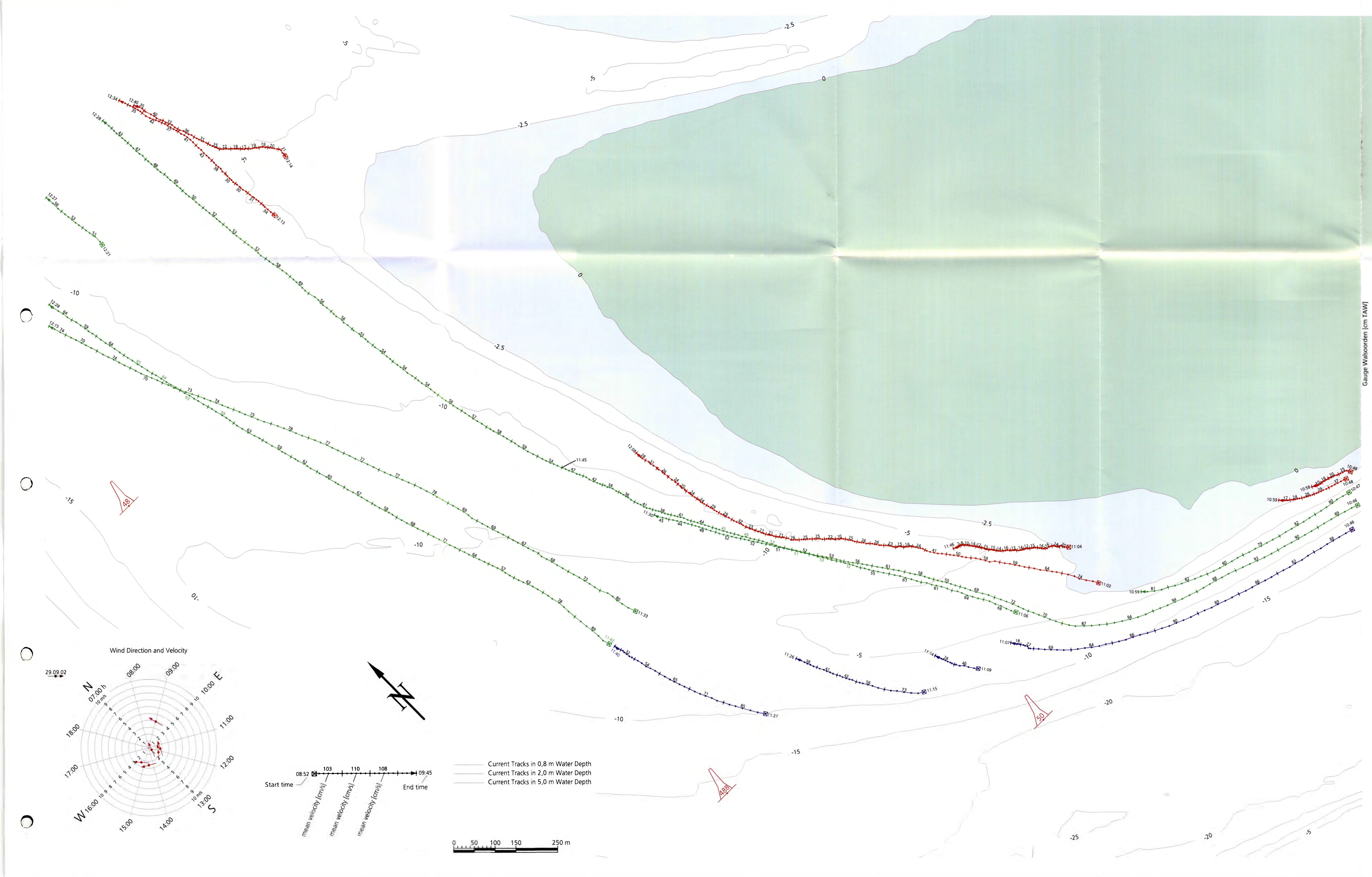
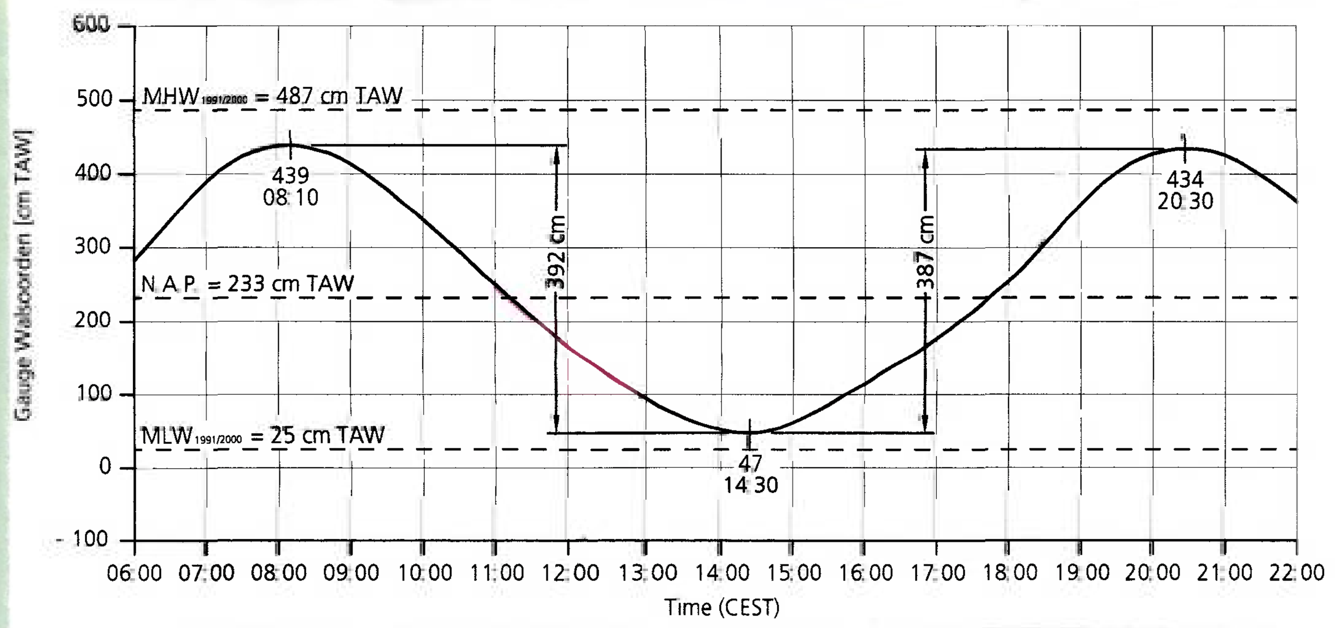
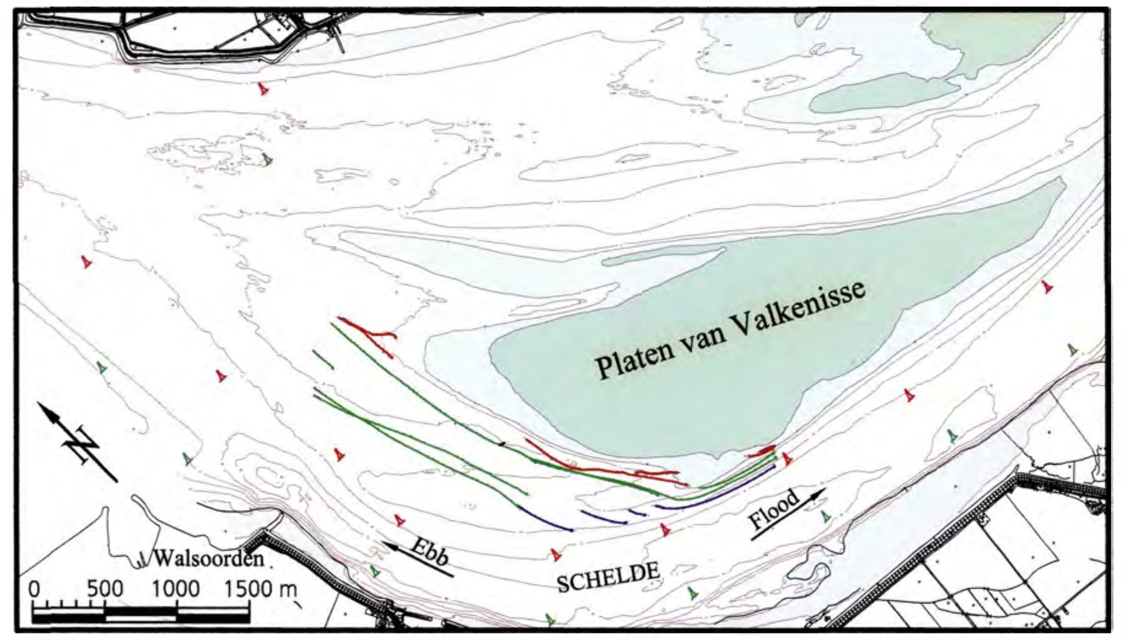
ANNEX 15

Current Measurements: 29.09.2002

Chart Datum: N.A.P. [m]







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Current Measurements in the Westerschelde September / October 2002

IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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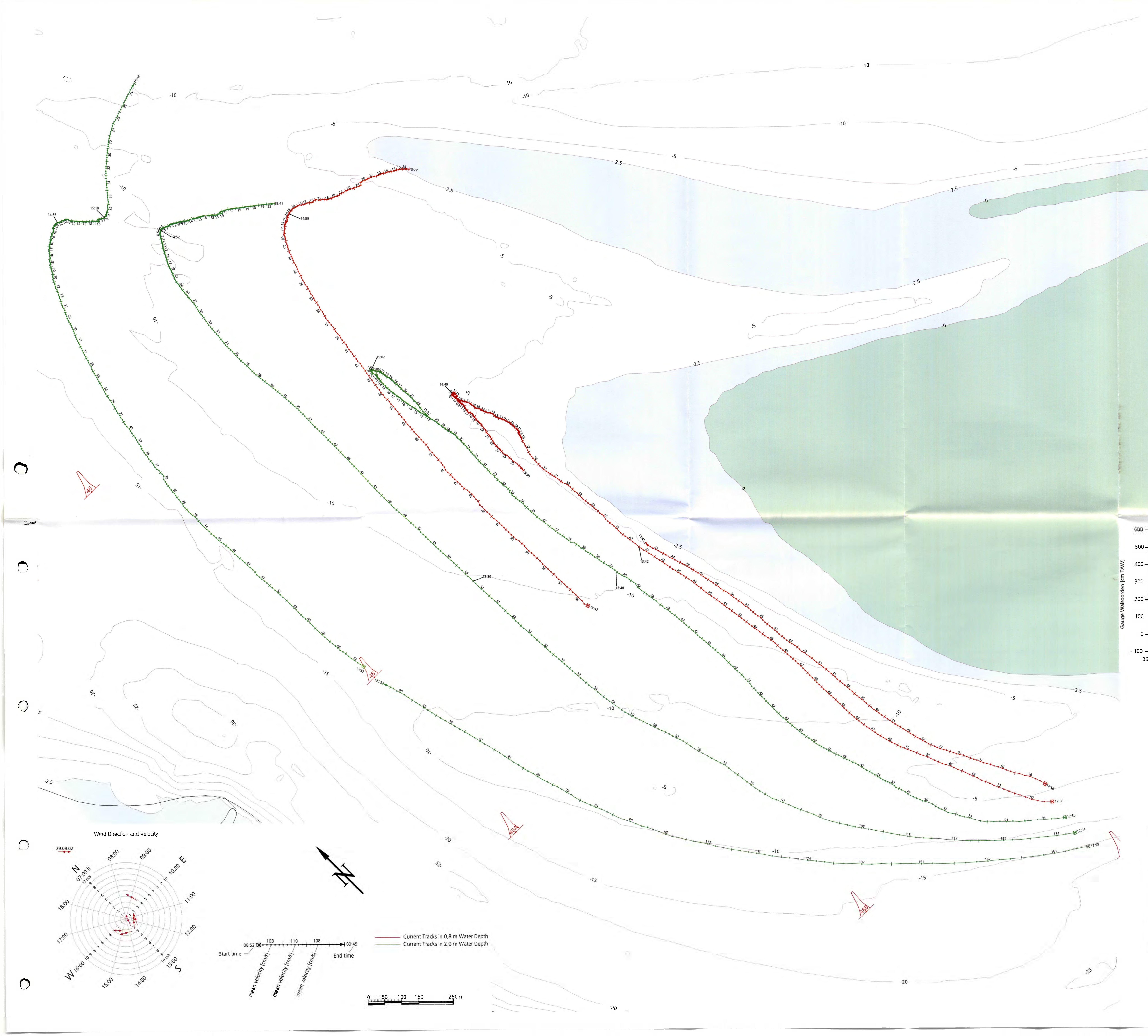
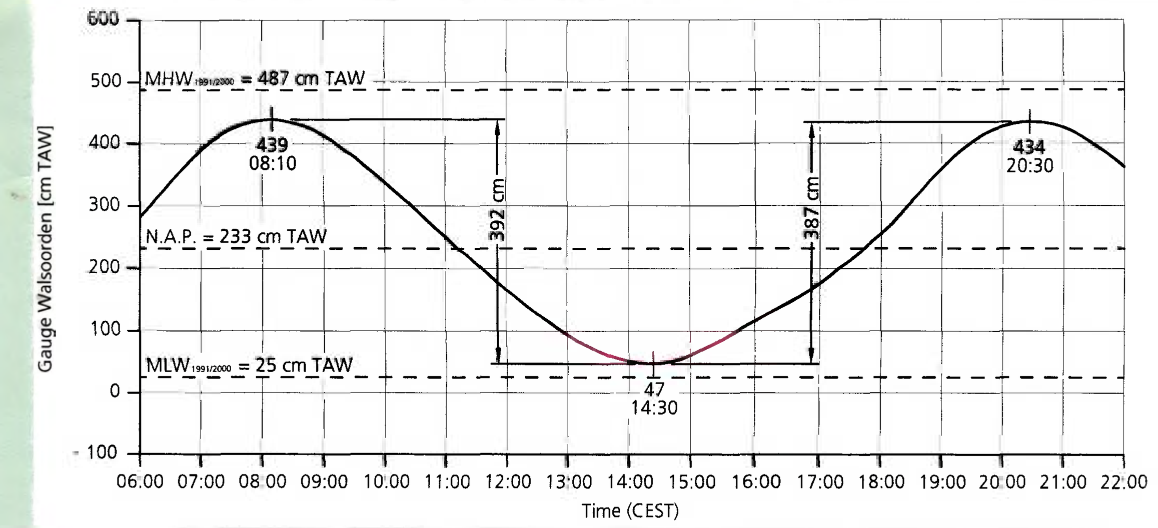
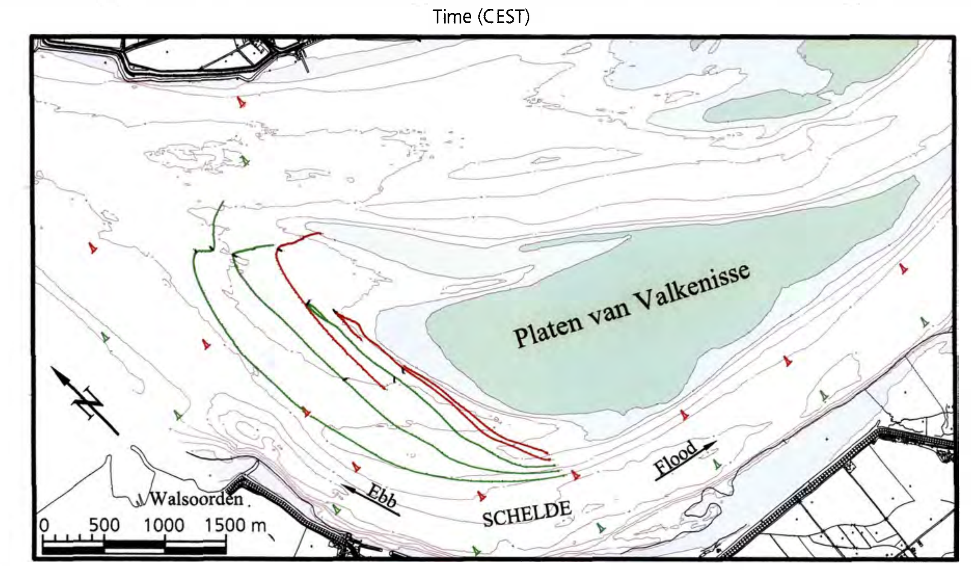
ANNEX 16

Current Measurements: 29.09.2002

Chart Datum: N.A.P. [m]







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Current Measurements in the Westerschelde
September / October 2002

IWA
Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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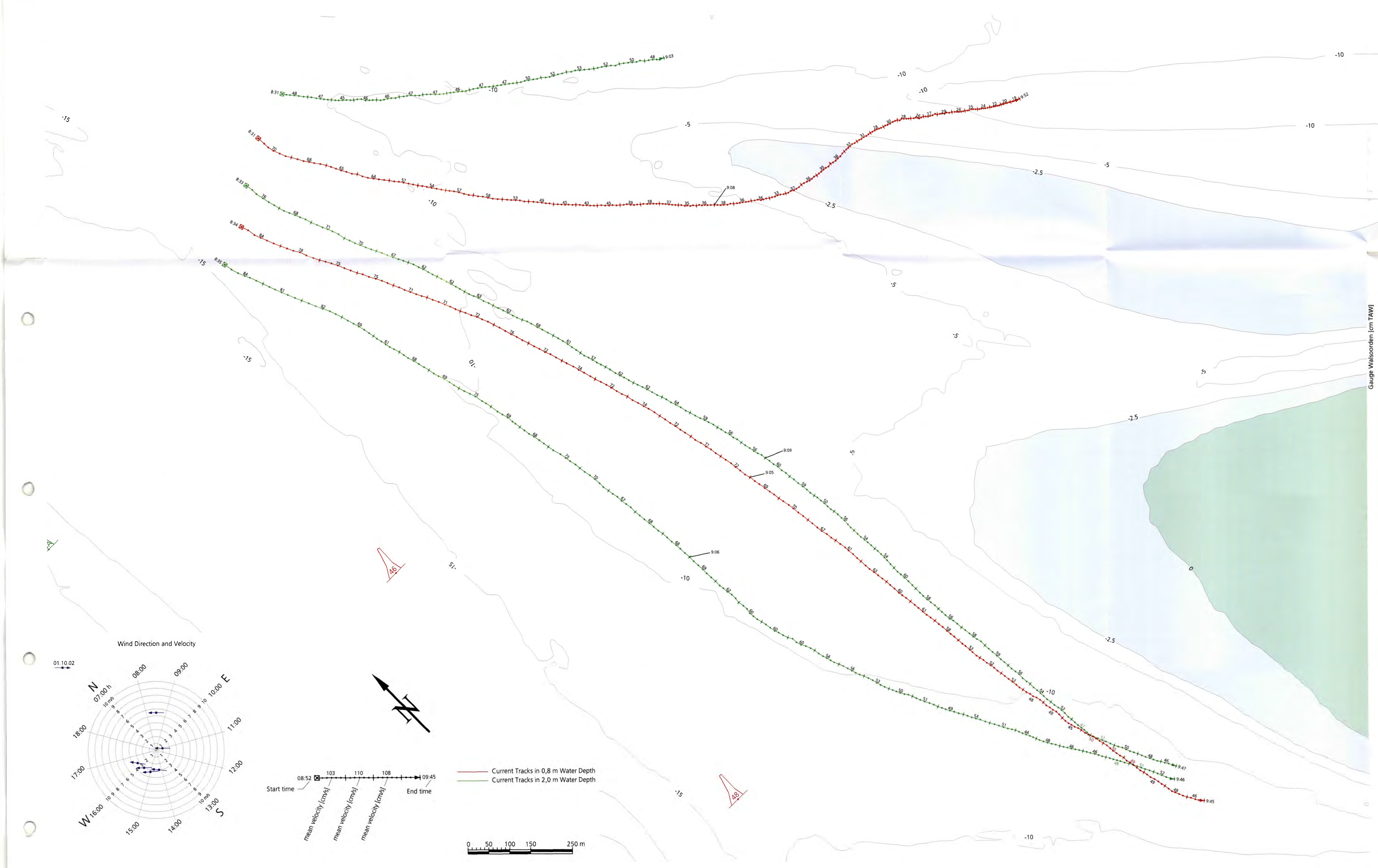
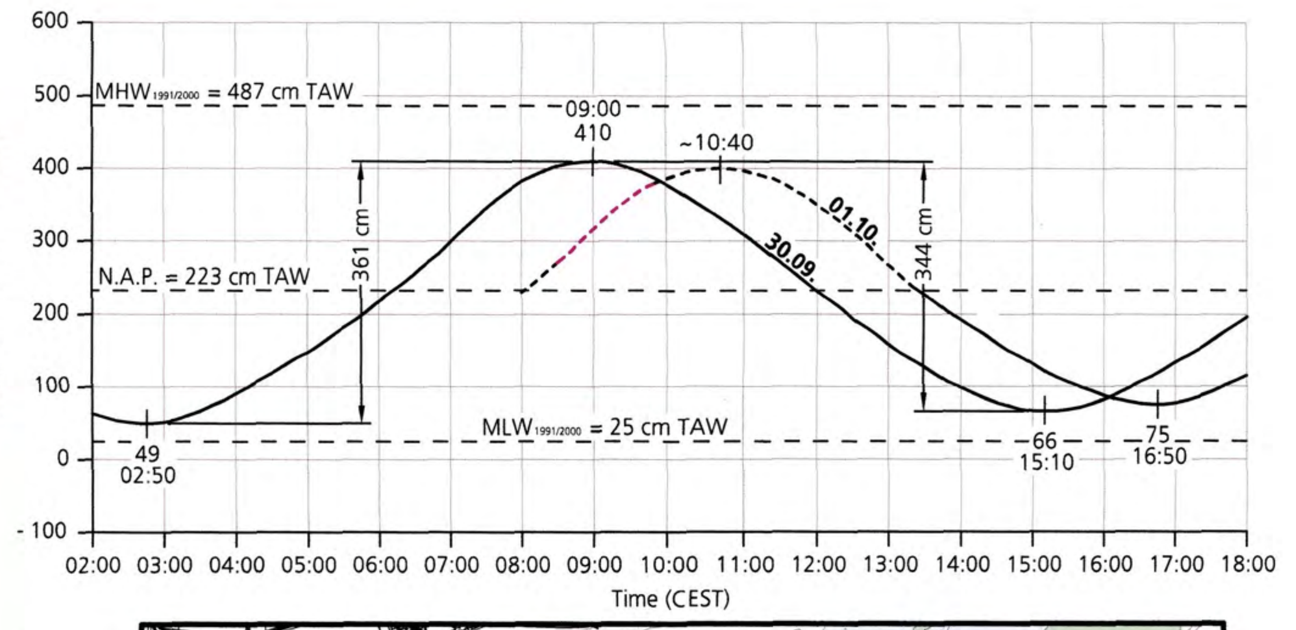
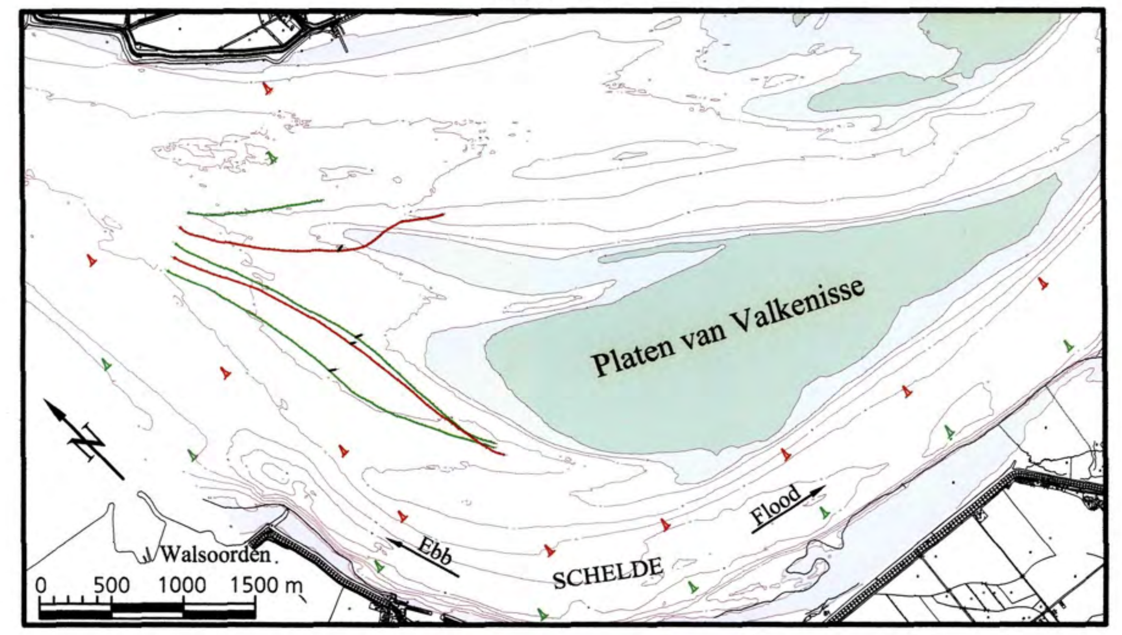
ANNEX
17

Current Measurements: 29.09.2002

Chart Datum: N.A.P. [m]







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September / October 2002

IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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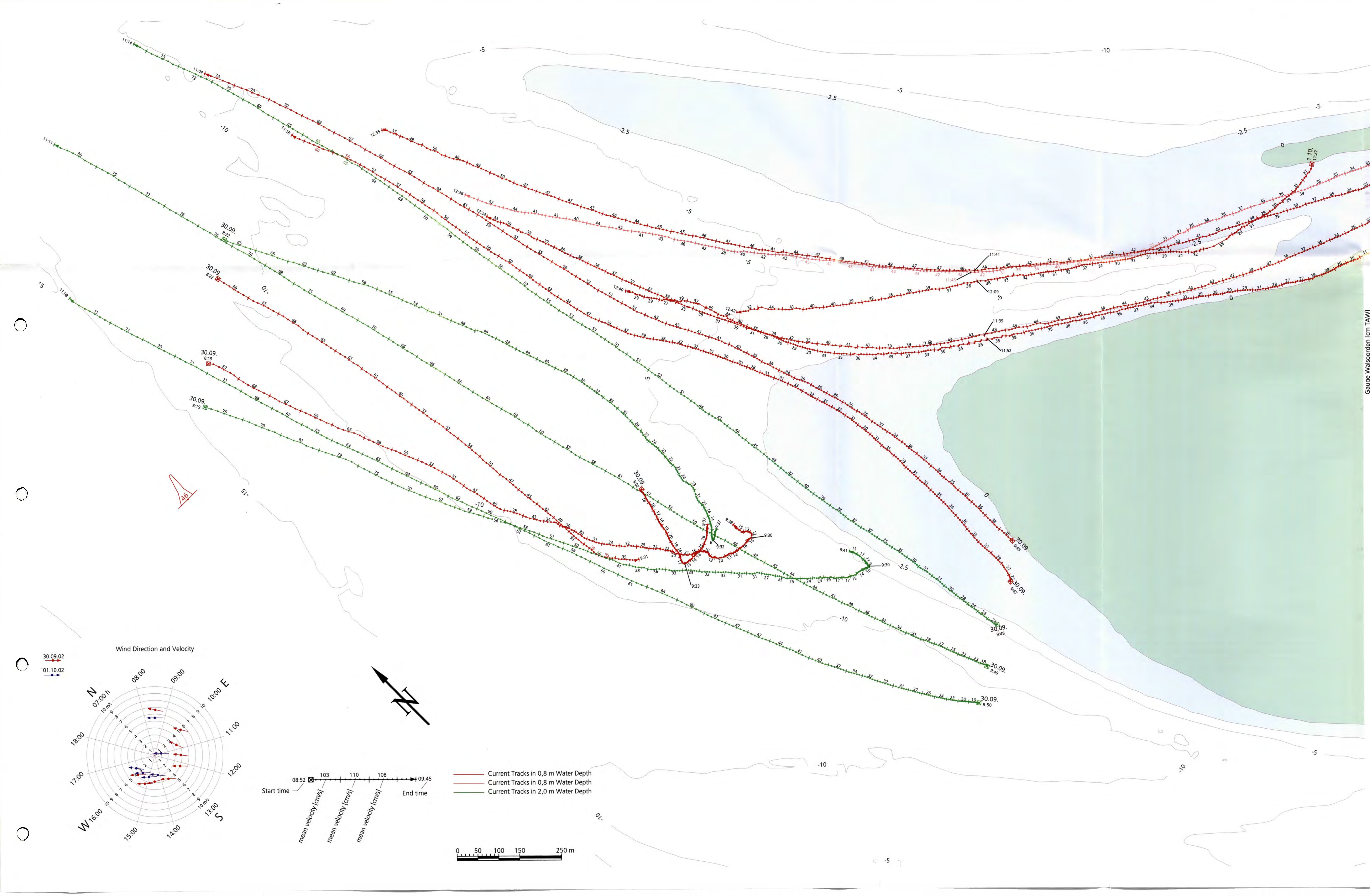
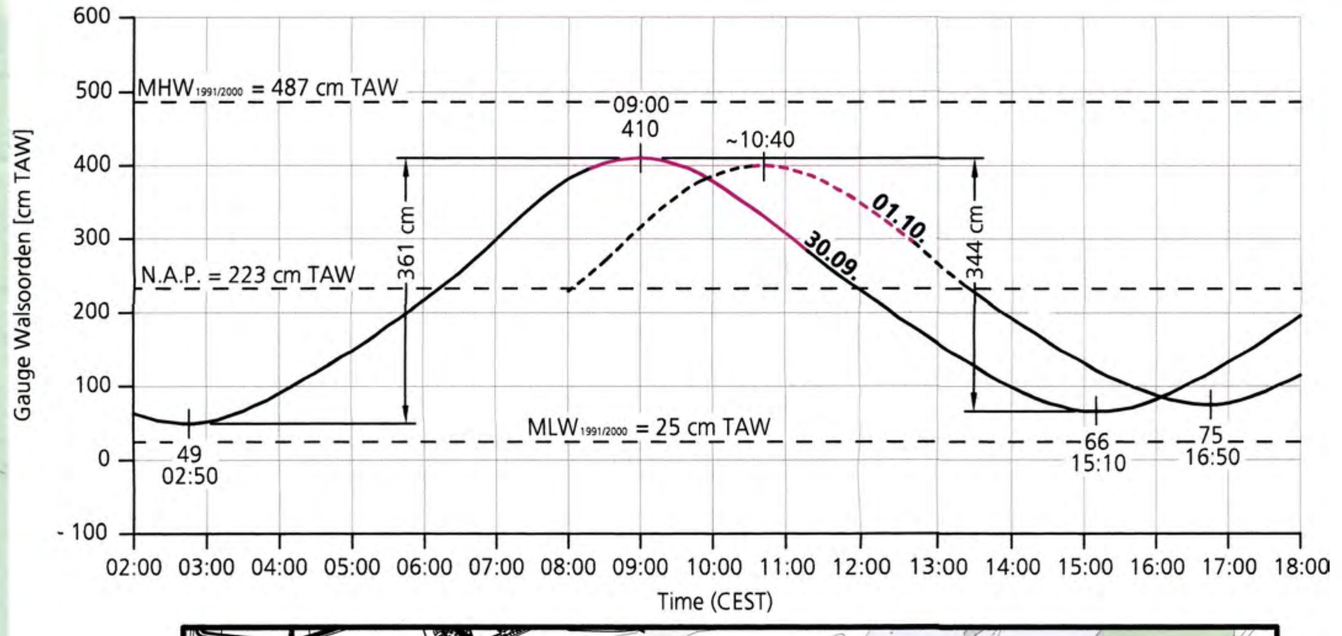
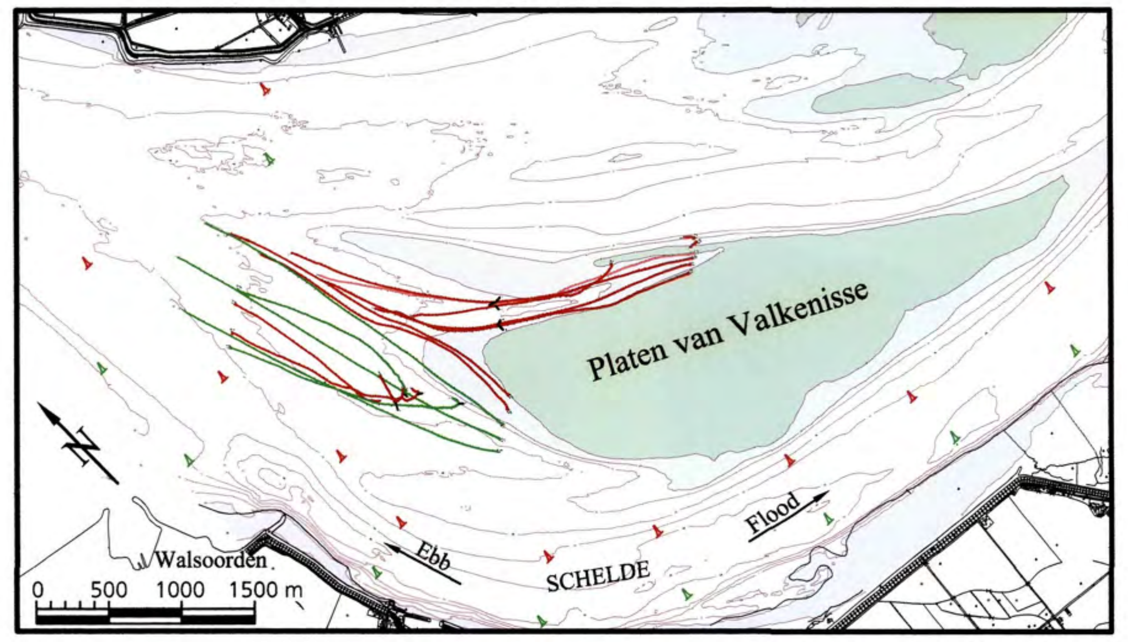
ANNEX 18

Current Measurements: 01.10.2002

Chart Datum: N.A.P. [m]







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IWA
Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

in association with:

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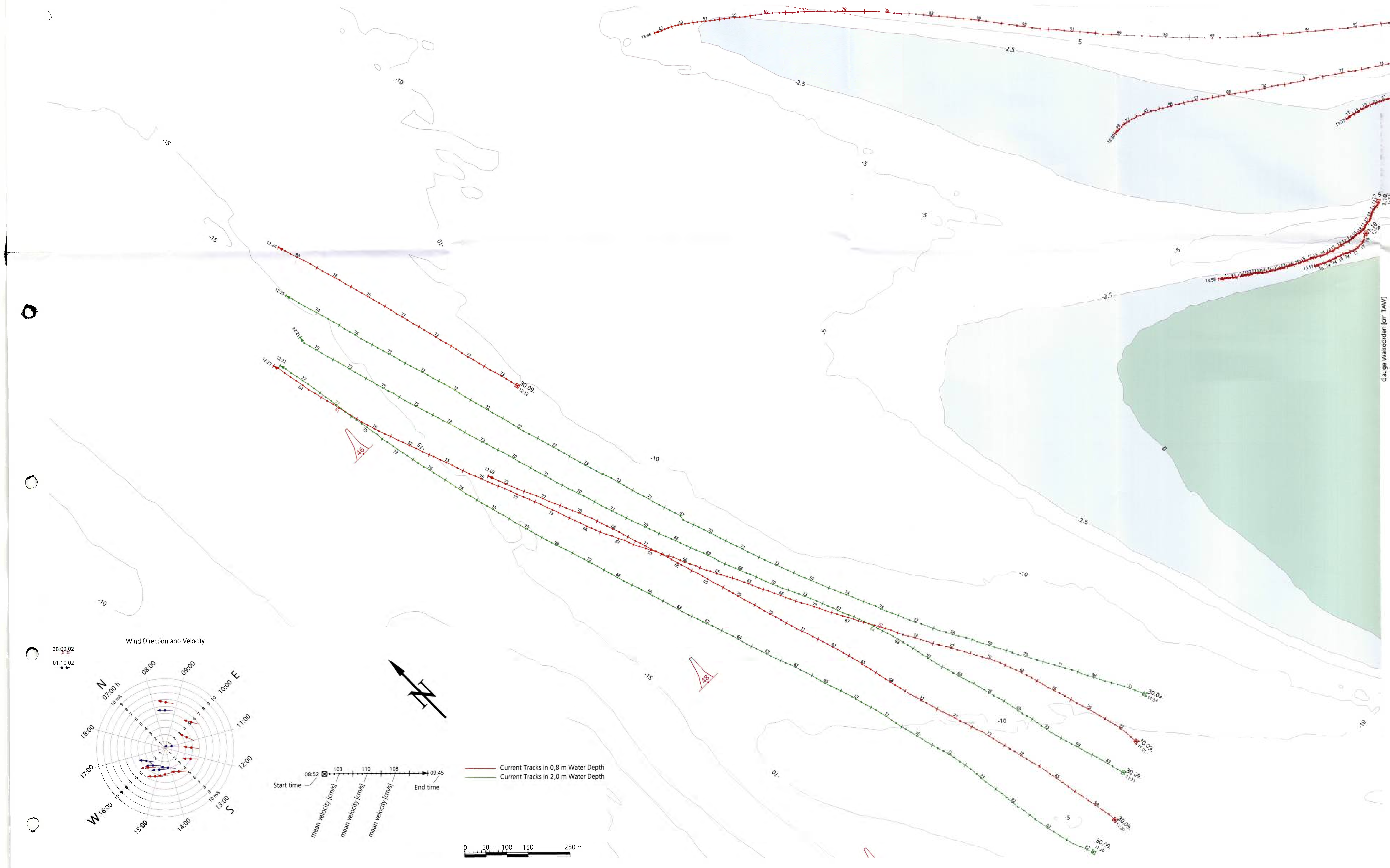
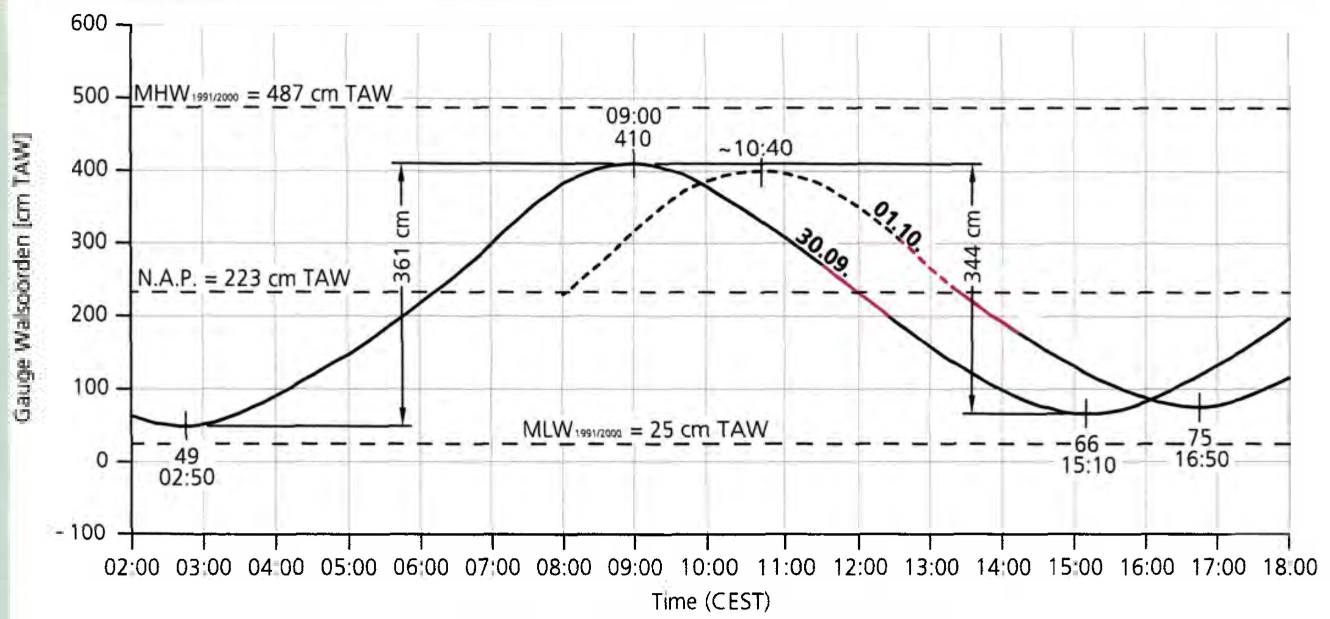
ANNEX

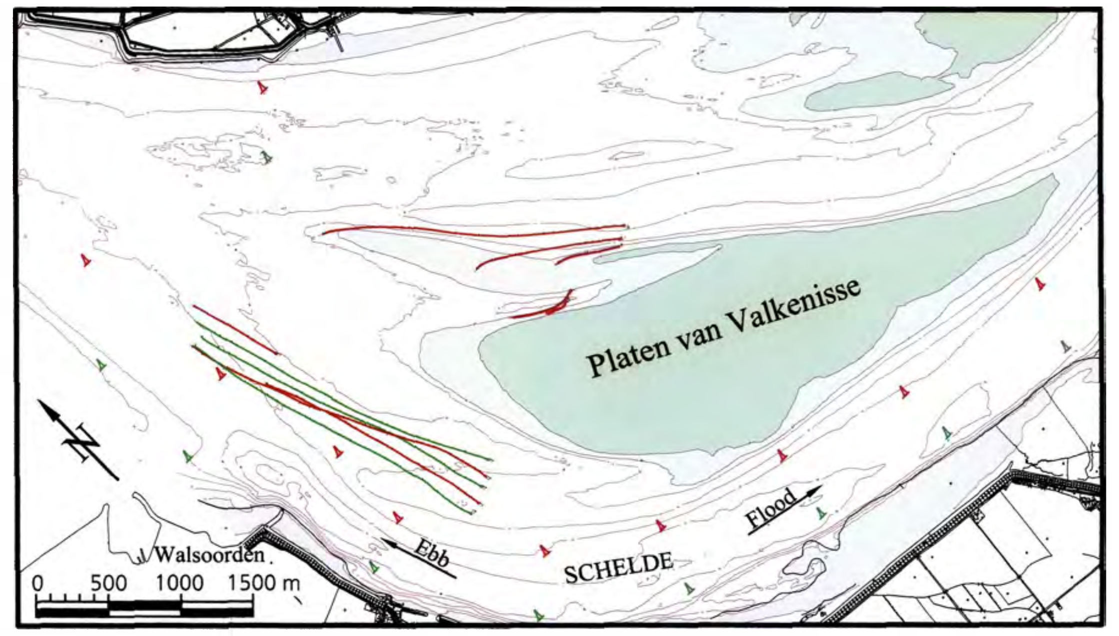
19

Current Measurements: 30.09. and 01.10.2002

Chart Datum: N.A.P. [m]







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Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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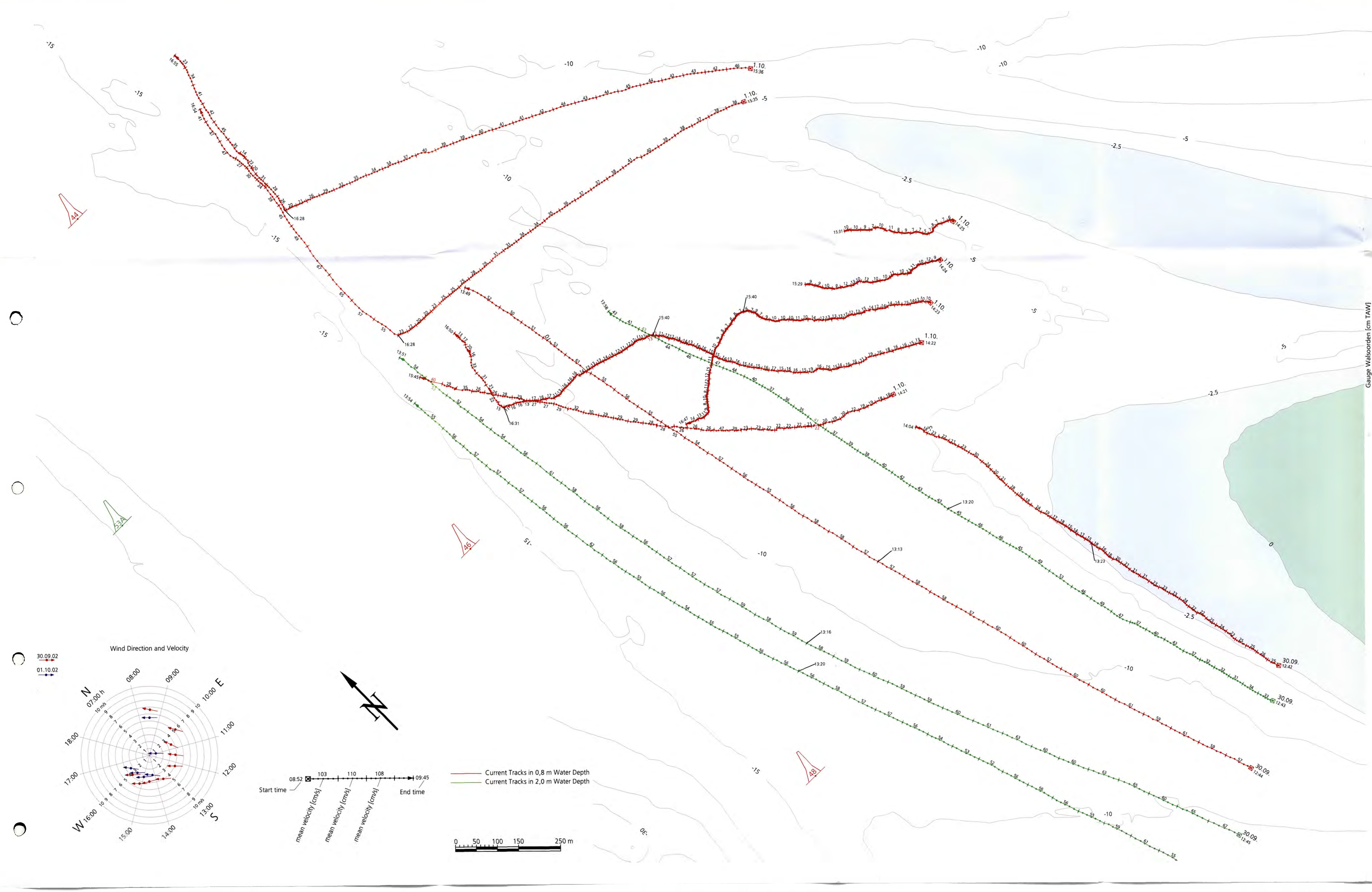
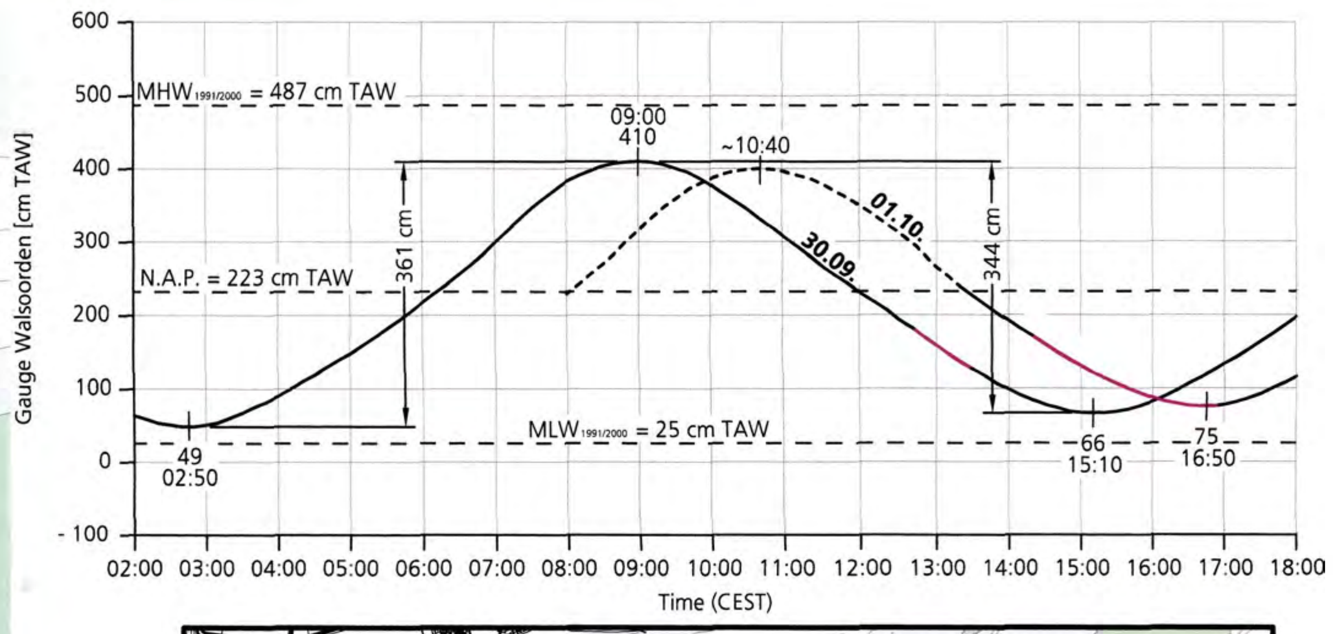
Current Measurements: **30.09. and 01.10.2002**

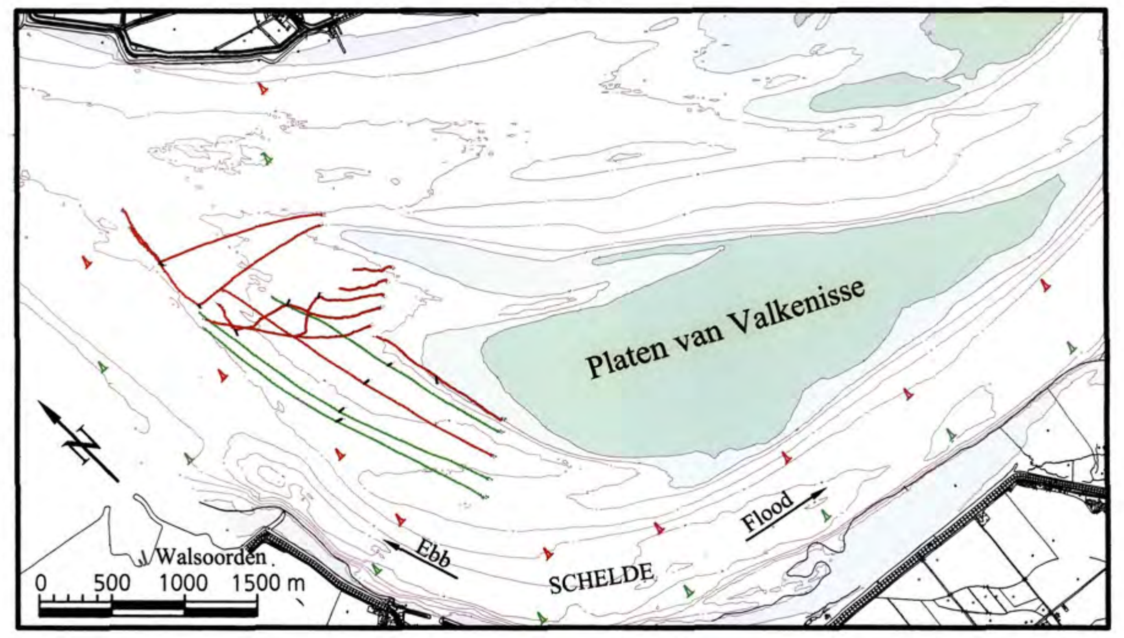
Chart Datum: N.A.P. [m]

ANNEX

20







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IWA
Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

in association with:

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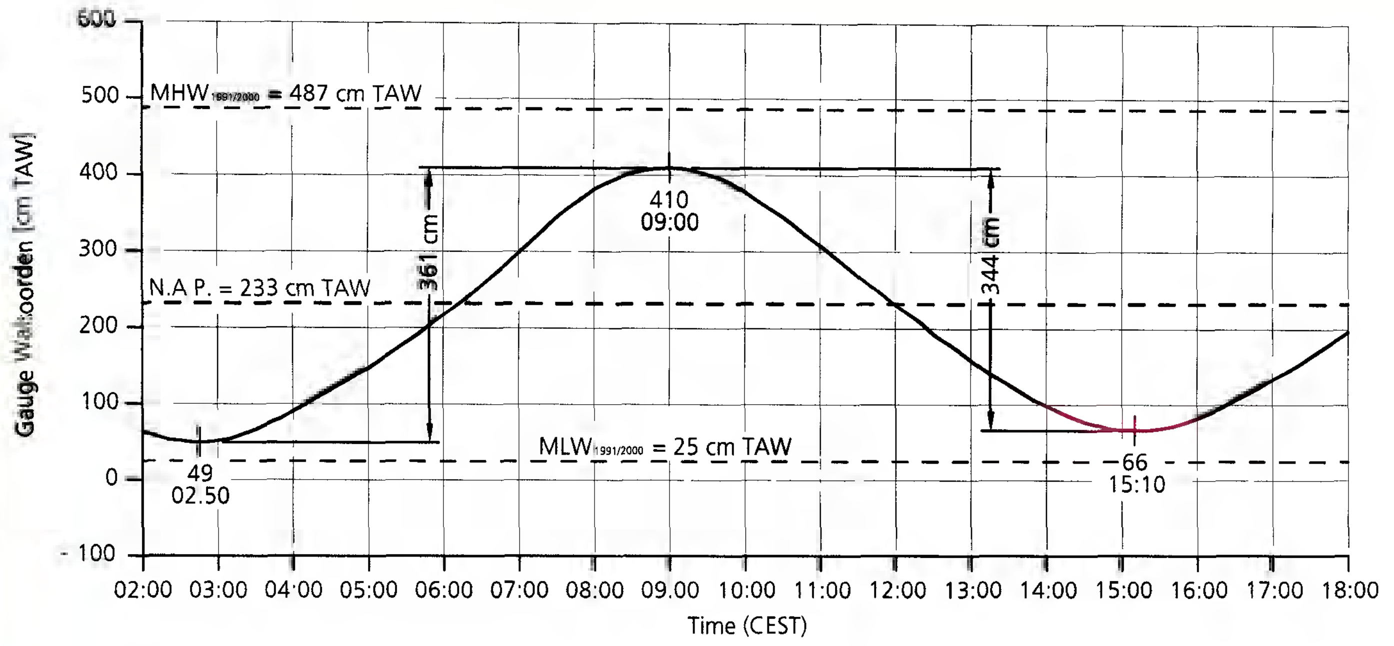
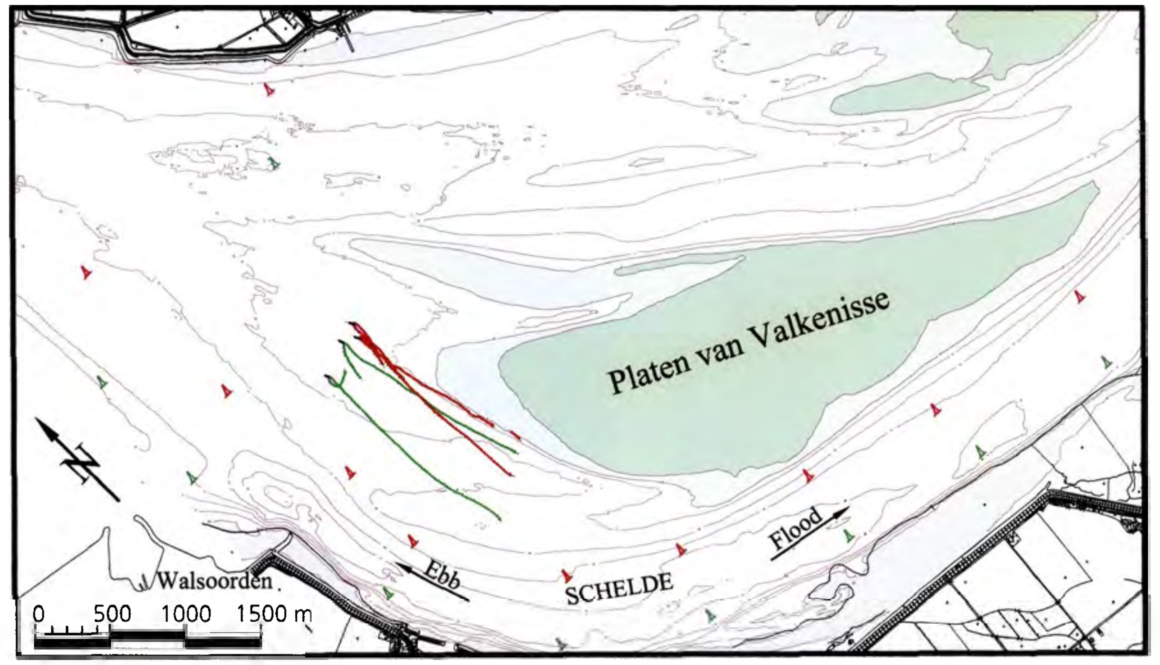
ANNEX

21

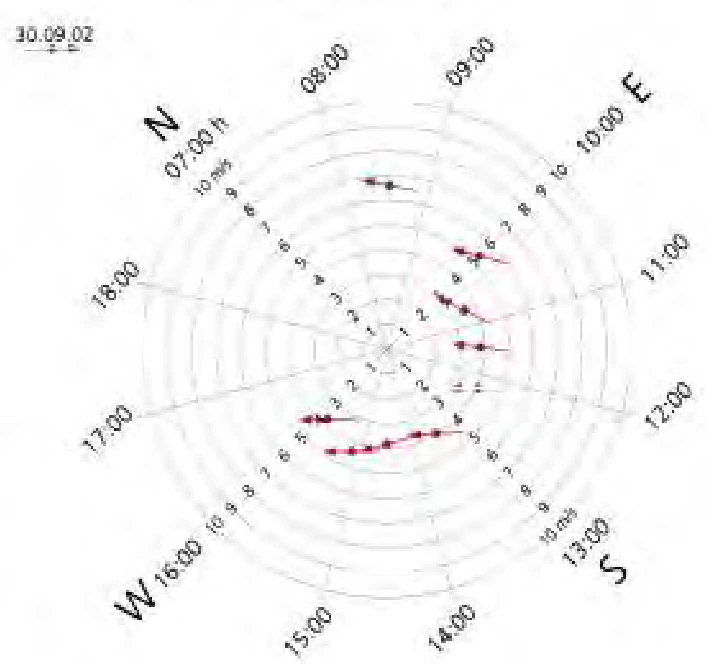
Current Measurements: 30.09. and 01.10.2002

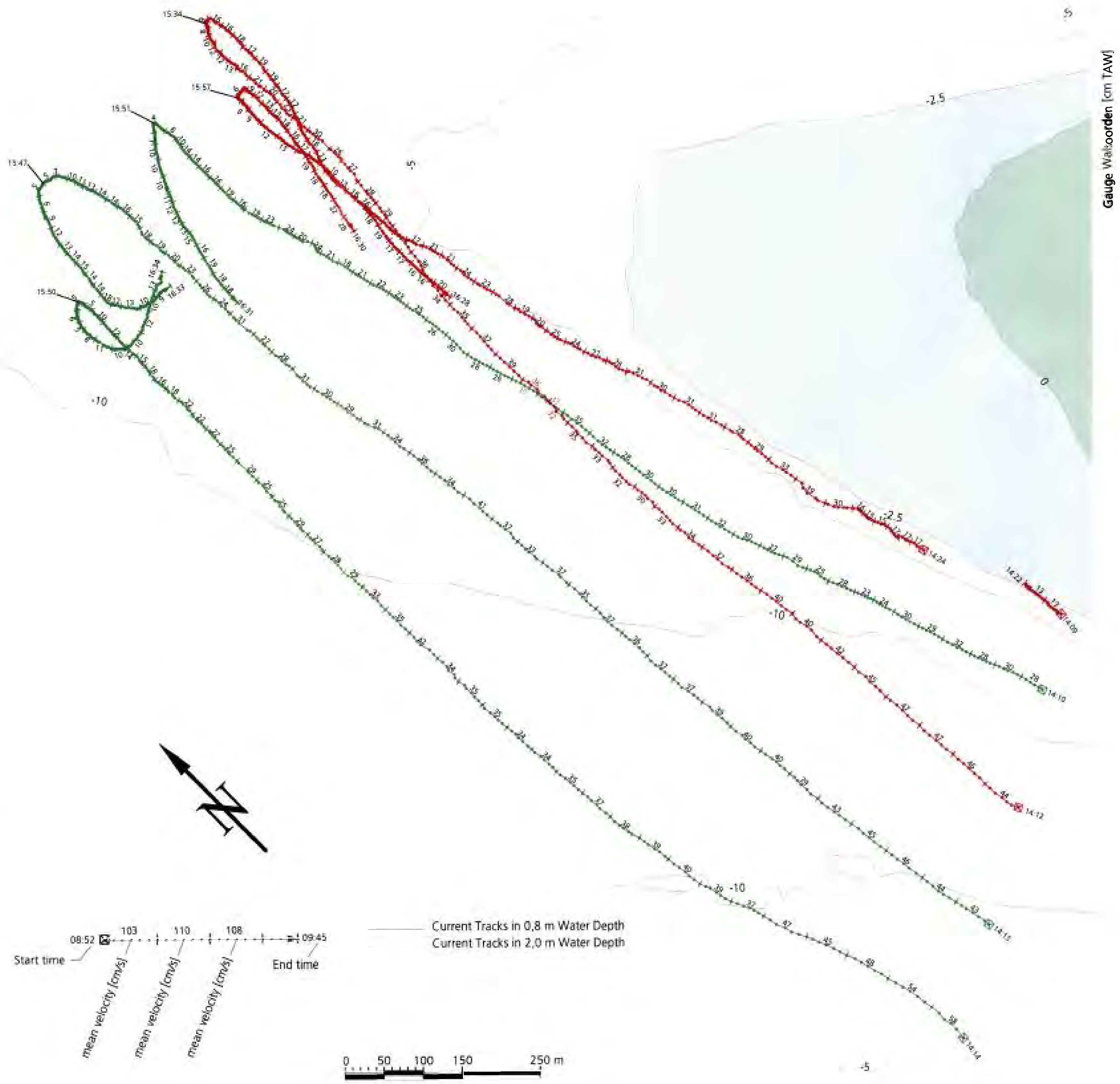
Chart Datum: N.A.P. [m]





Wind Direction and Velocity





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IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel. 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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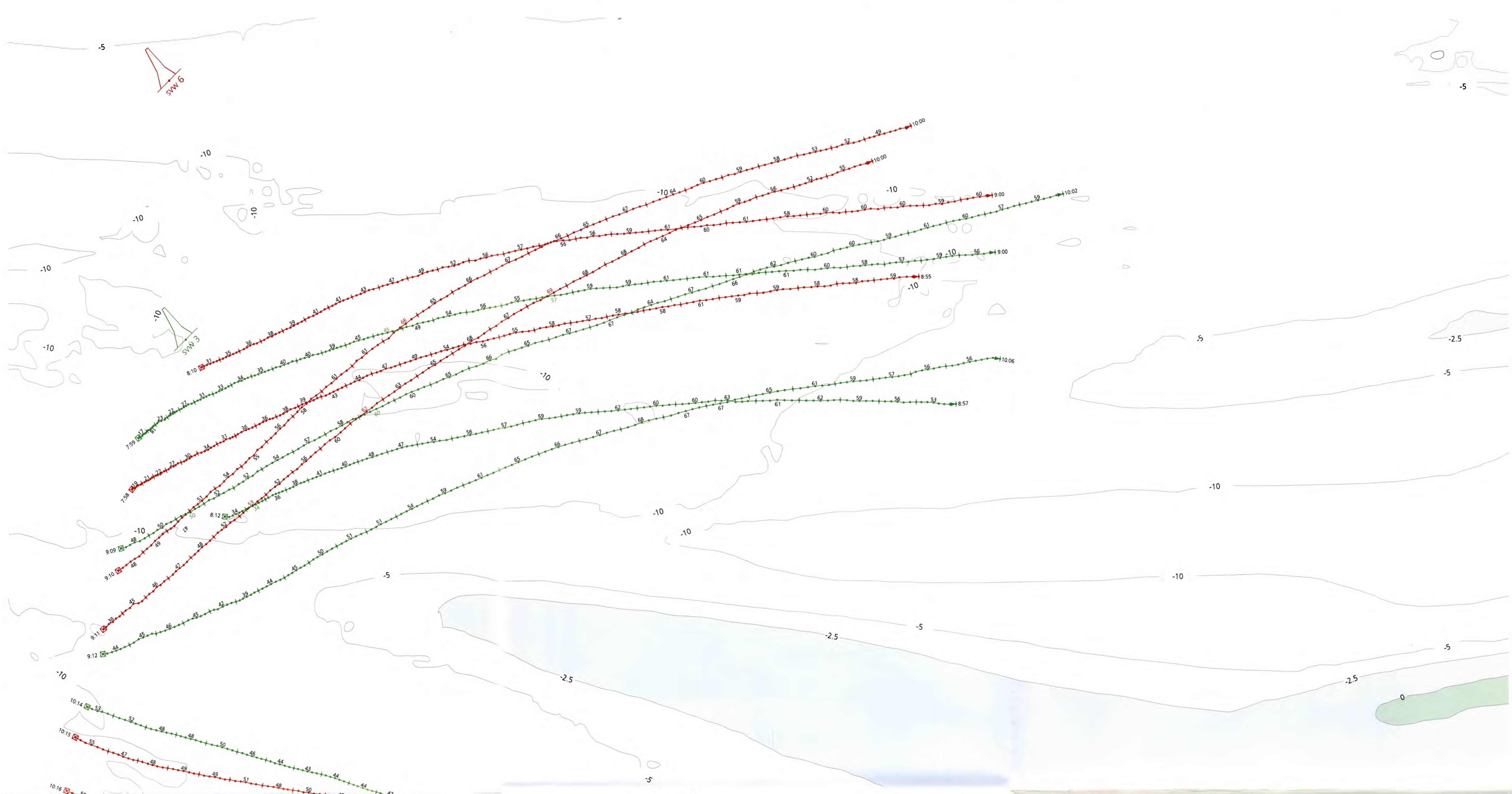
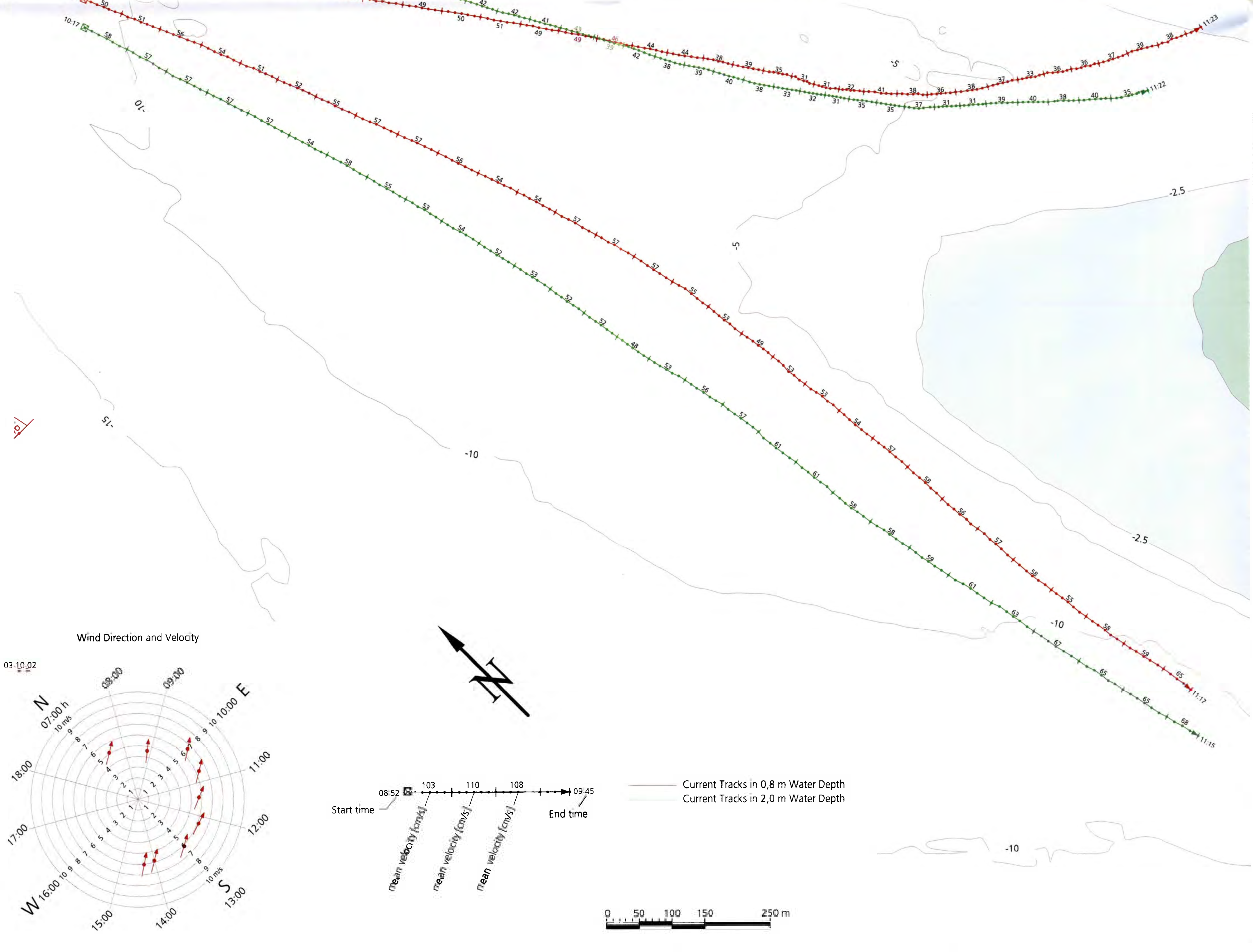
ANNEX

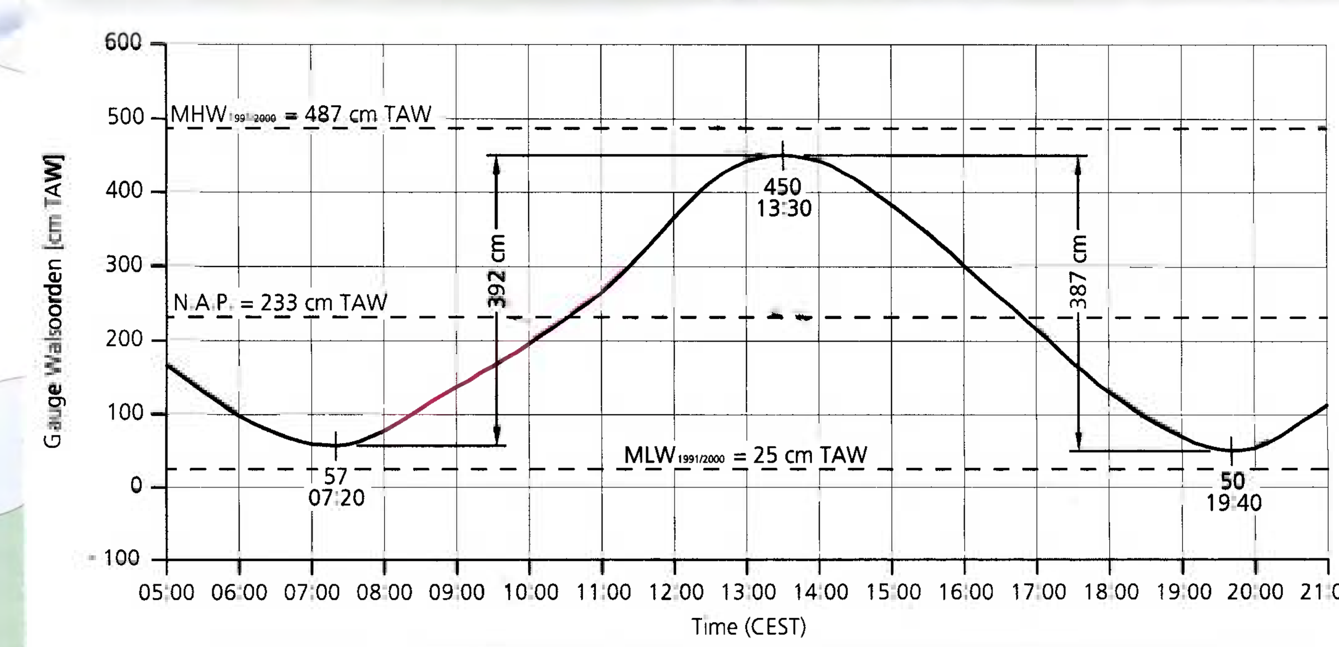
22

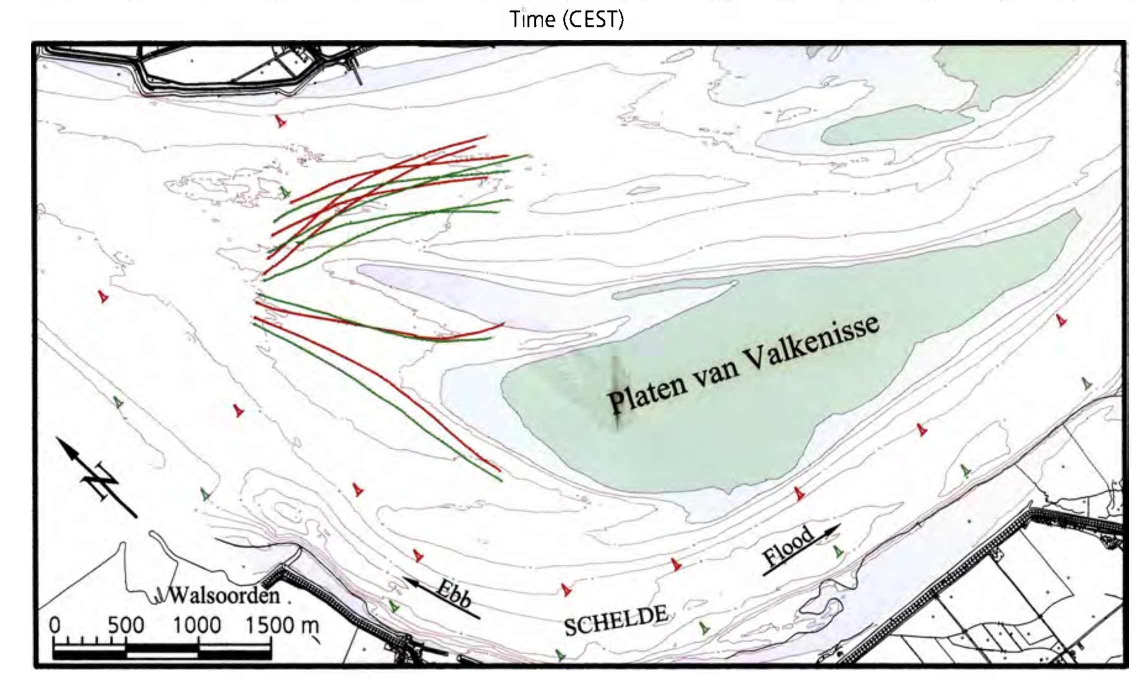
Current Measurements: 30.09.2002

Chart Datum: N.A.P [m]









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IWA Institut für Wasserbau

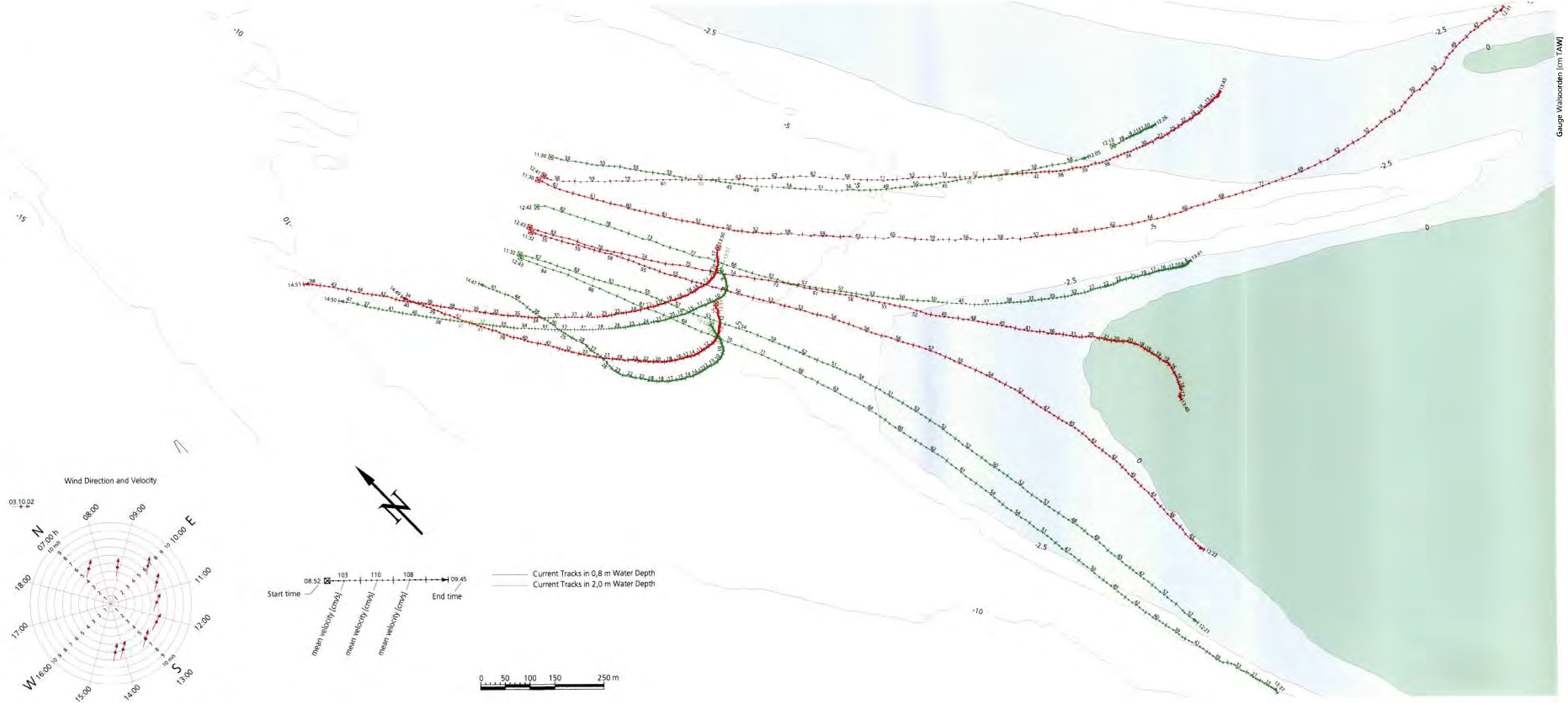
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

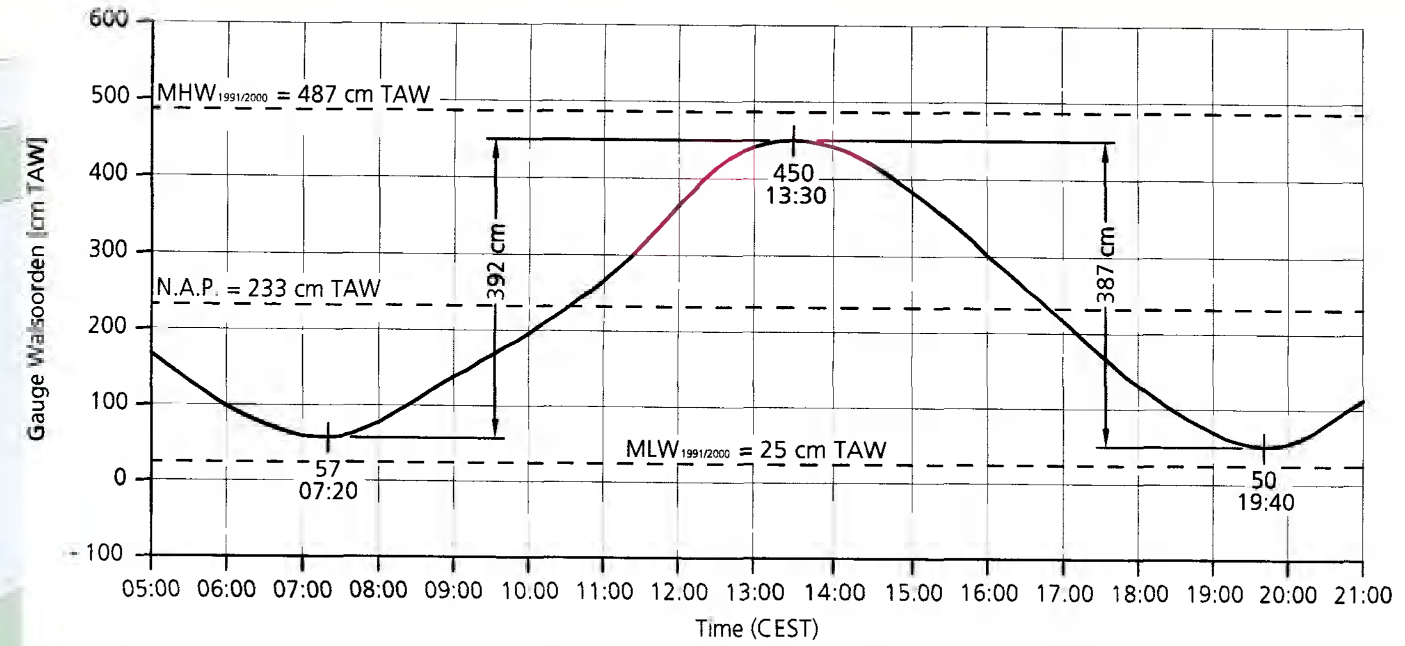
in association with:
Ministerie van Verkeer en Waterstaat
Meetinformatiedienst Zeeland

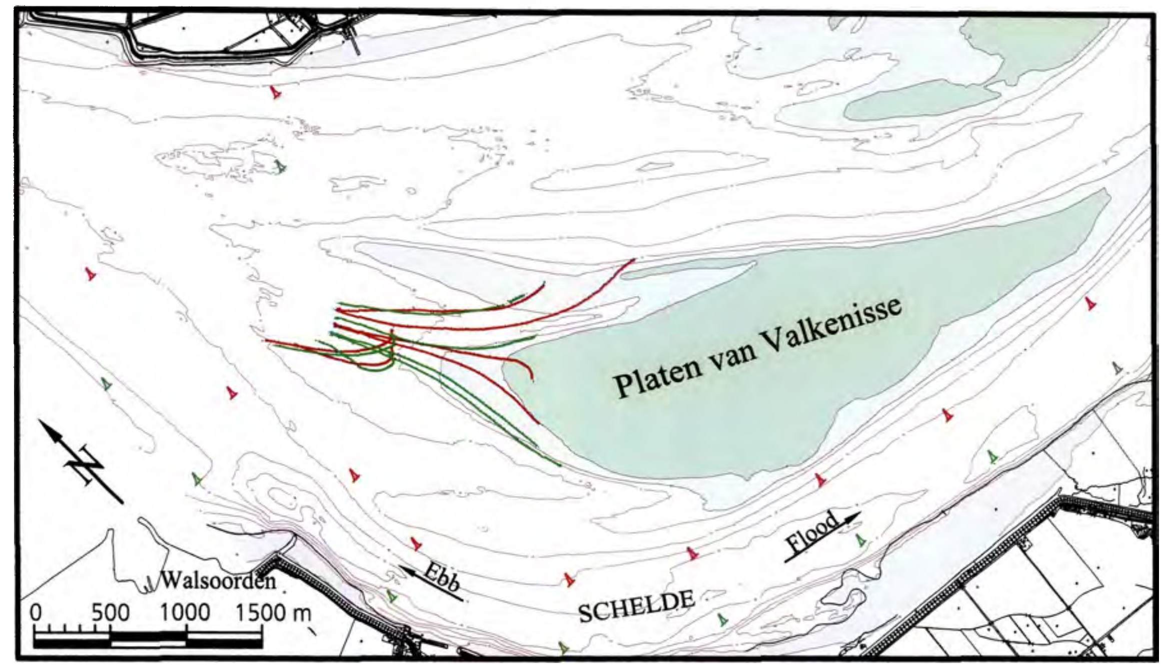
ANNEX 23

Current Measurements: **03.10.2002**

Chart Datum: N.A.P. [m]







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IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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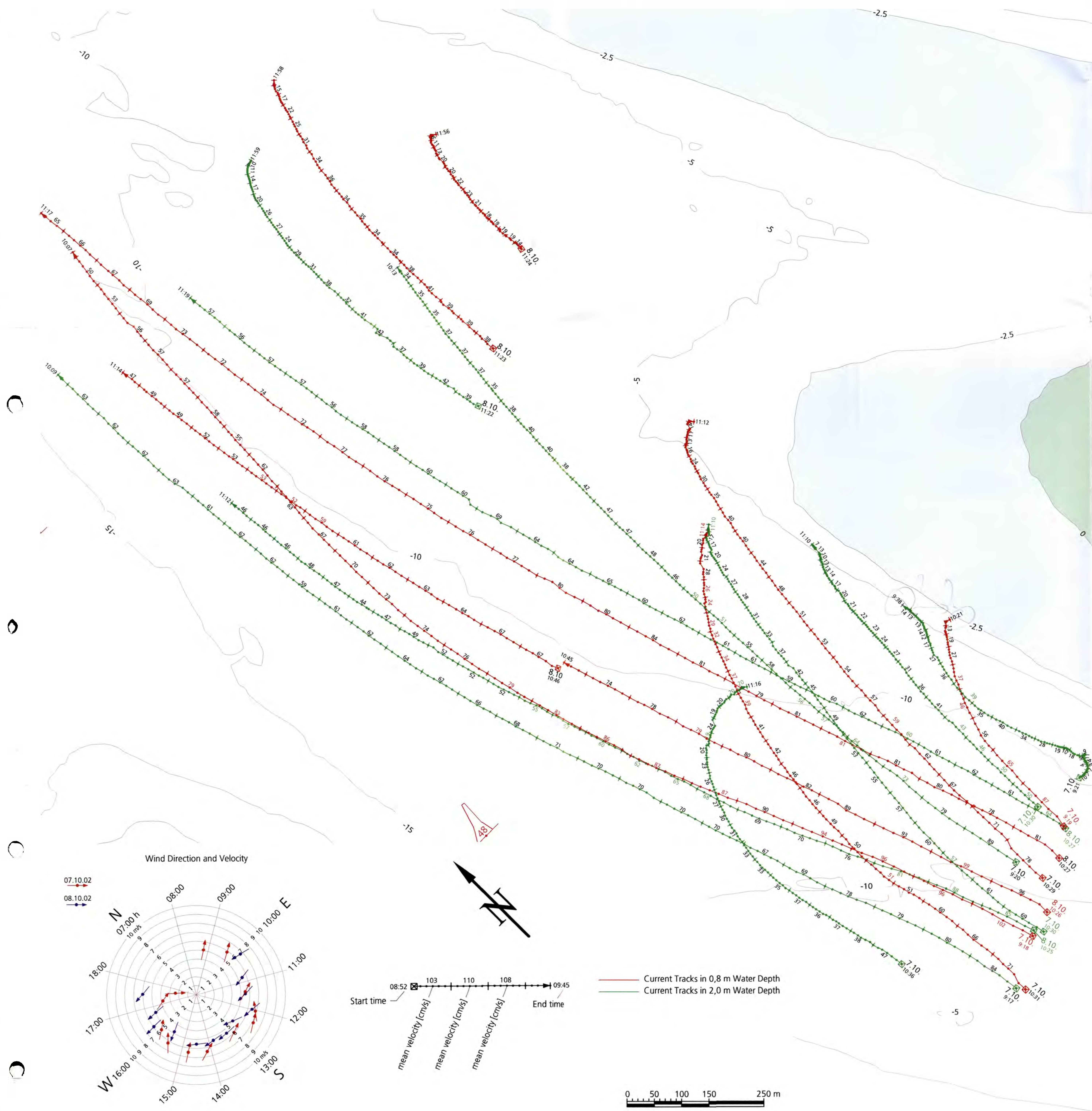
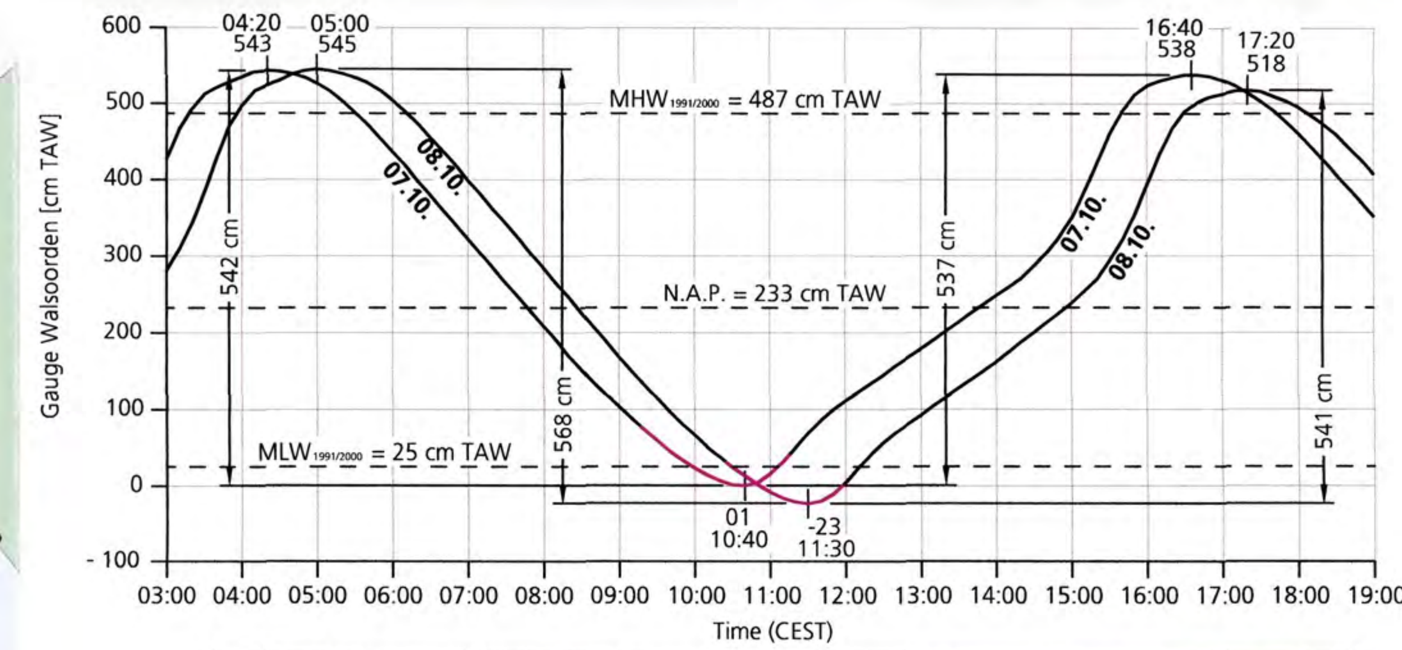
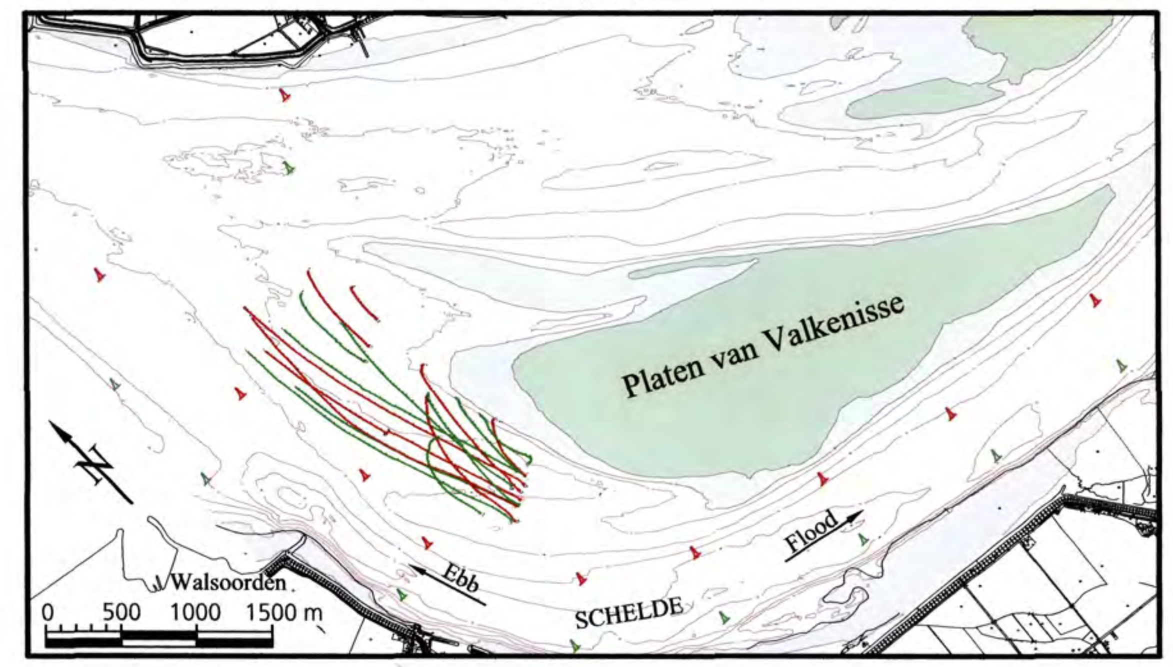
ANNEX 24

Current Measurements: 03.10.2002

Chart Datum: N.A.P. [m]







Waterbouwkundig Laboratorium en Hydrologisch Onderzoek Antwerpen	National Institute for Coastal and Marine Management / RIKZ	ProSes Projectdirectie ontwikkelingsschets Schelde-estuarium

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Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

in association with:
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ANNEX
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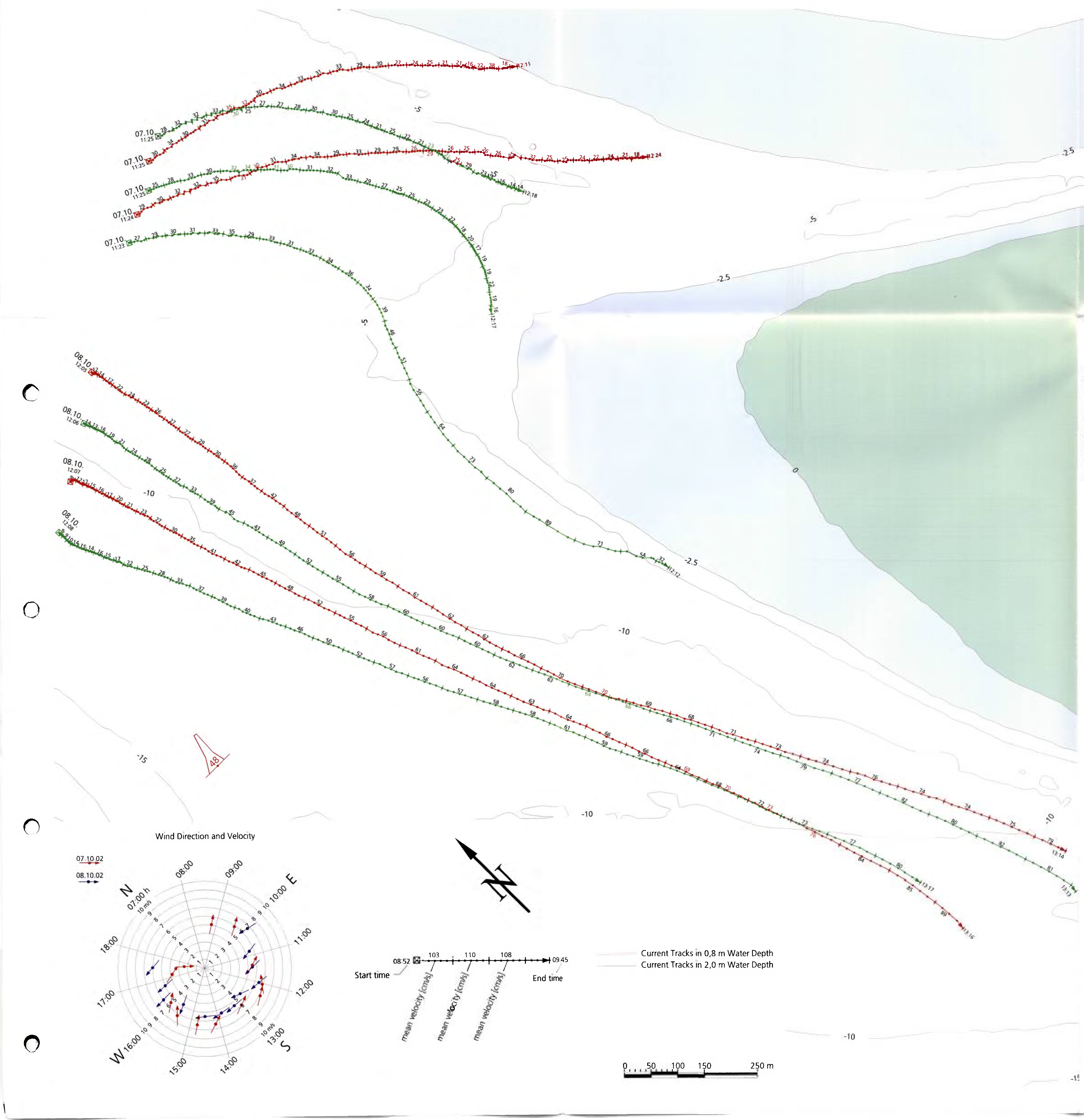
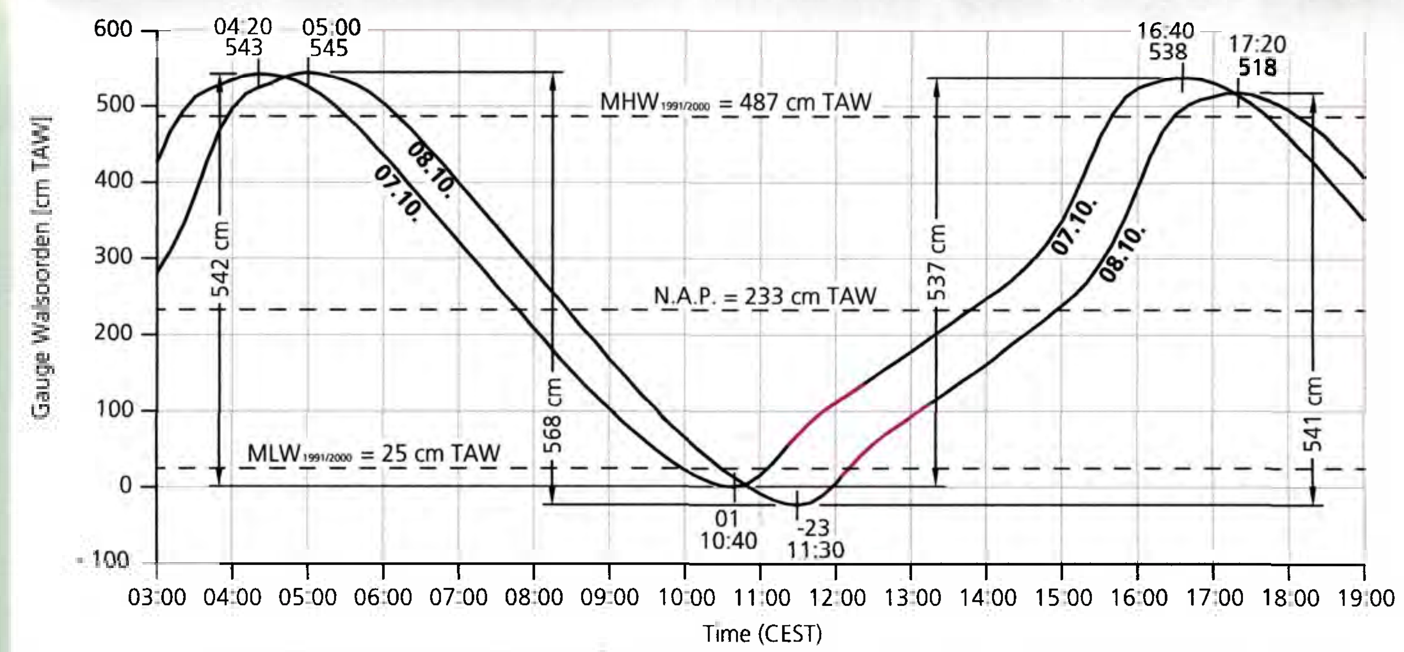
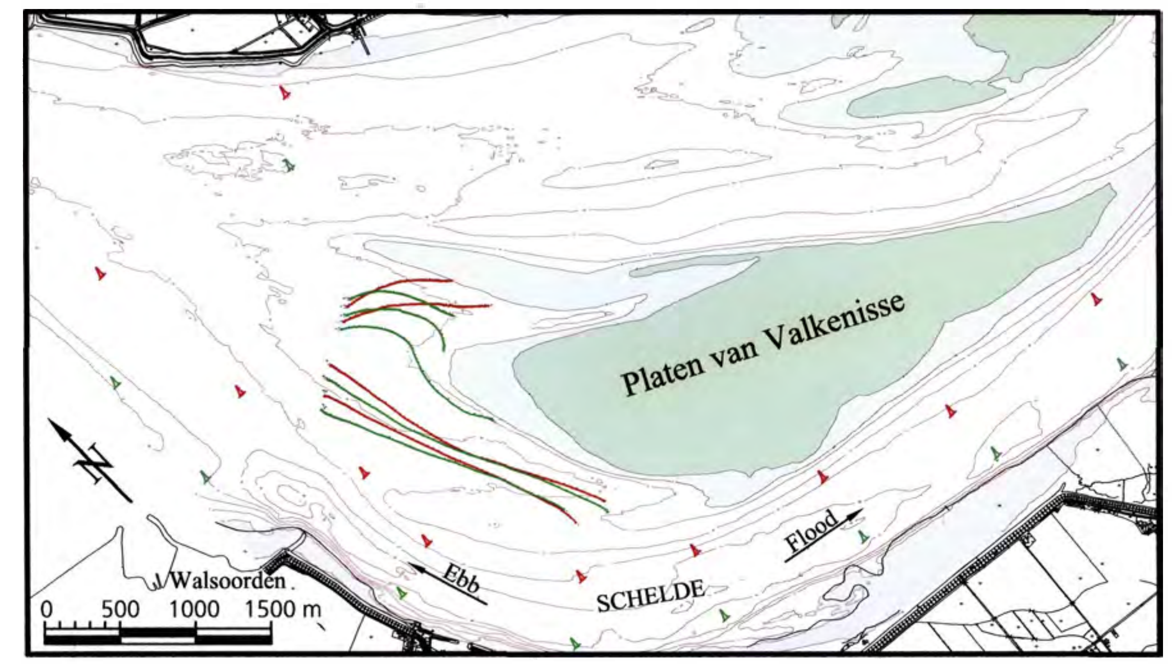
Current Measurements: **07.10. and 08.10.2002**

Chart Datum: N.A.P. [m]







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Current Measurements in the Westerschelde September / October 2002

IWA
Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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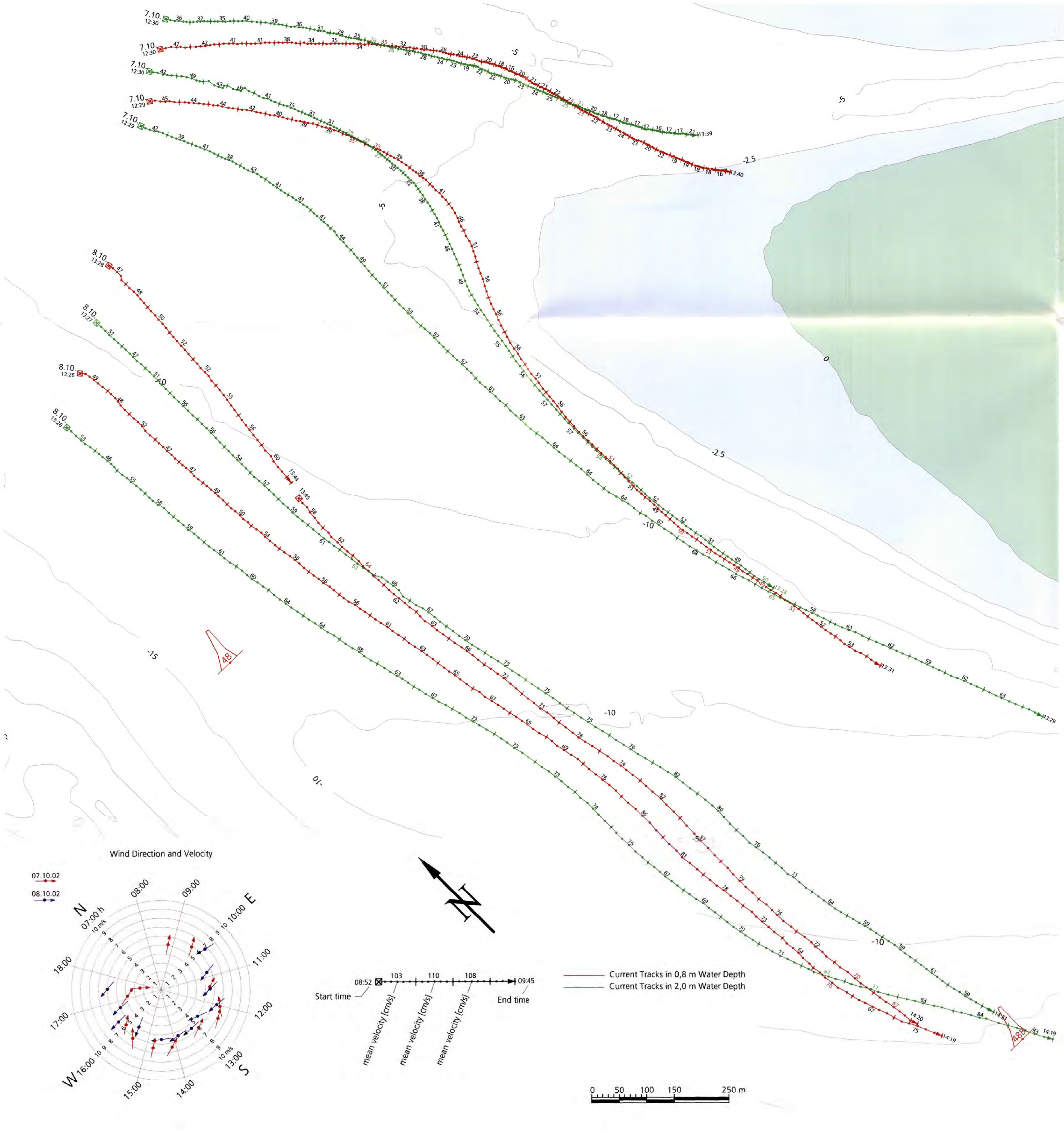
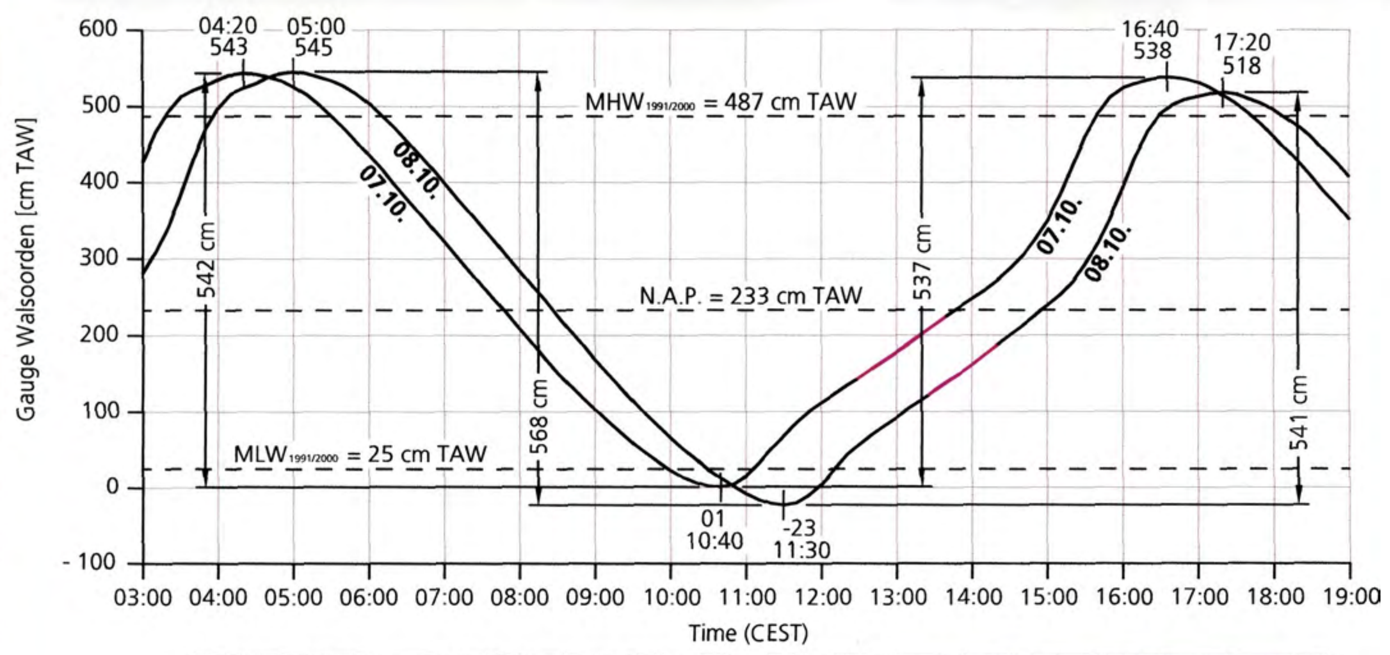
ANNEX

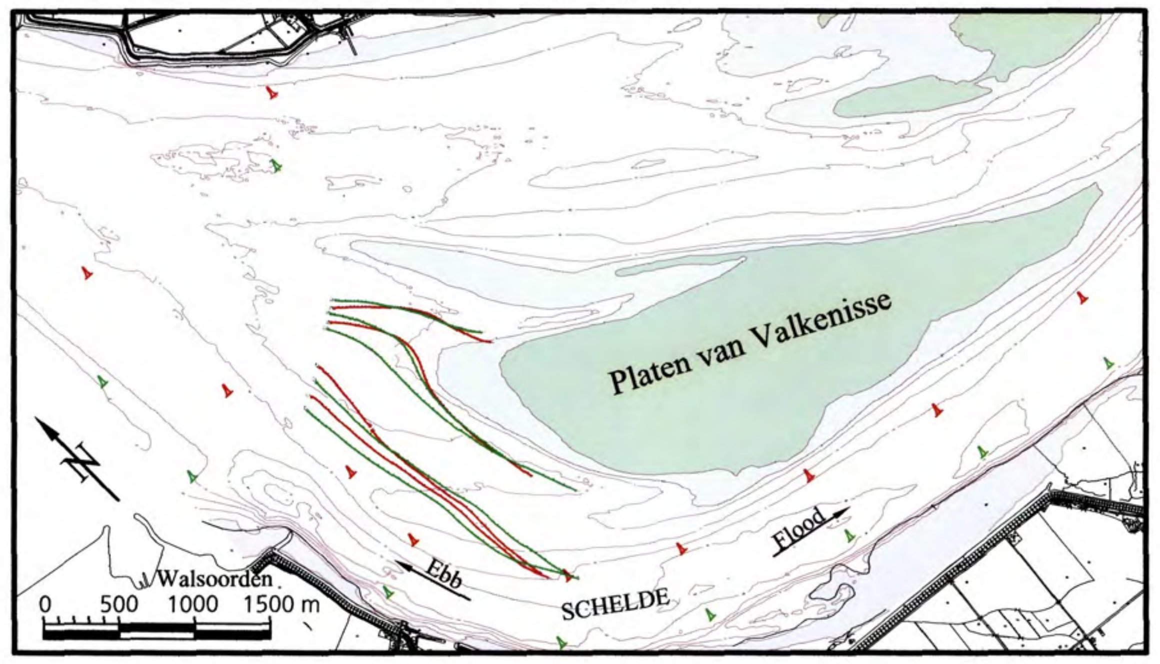
26

Current Measurements: 07.10. and 08.10.2002

Chart Datum: N.A.P. [m]







Waterbouwkundig Laboratorium en Hydrologisch Onderzoek Antwerpen

National Institute for Coastal and Marine Management / RIKZ

ProSes Projectdirectie ontwikkelingsschets Schelde-estuarium

Current Measurements in the Westerschelde
September / October 2002

IWA Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

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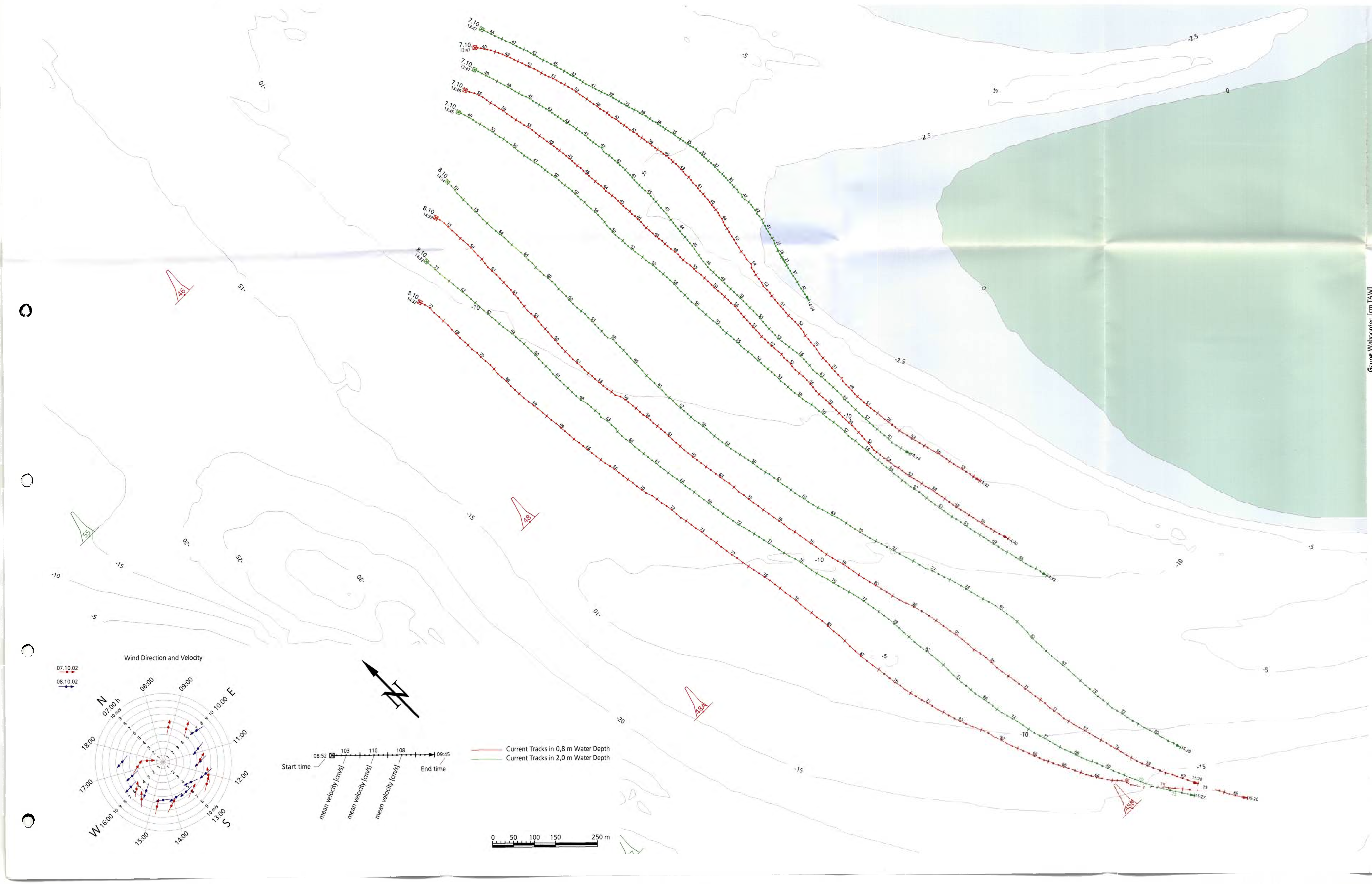
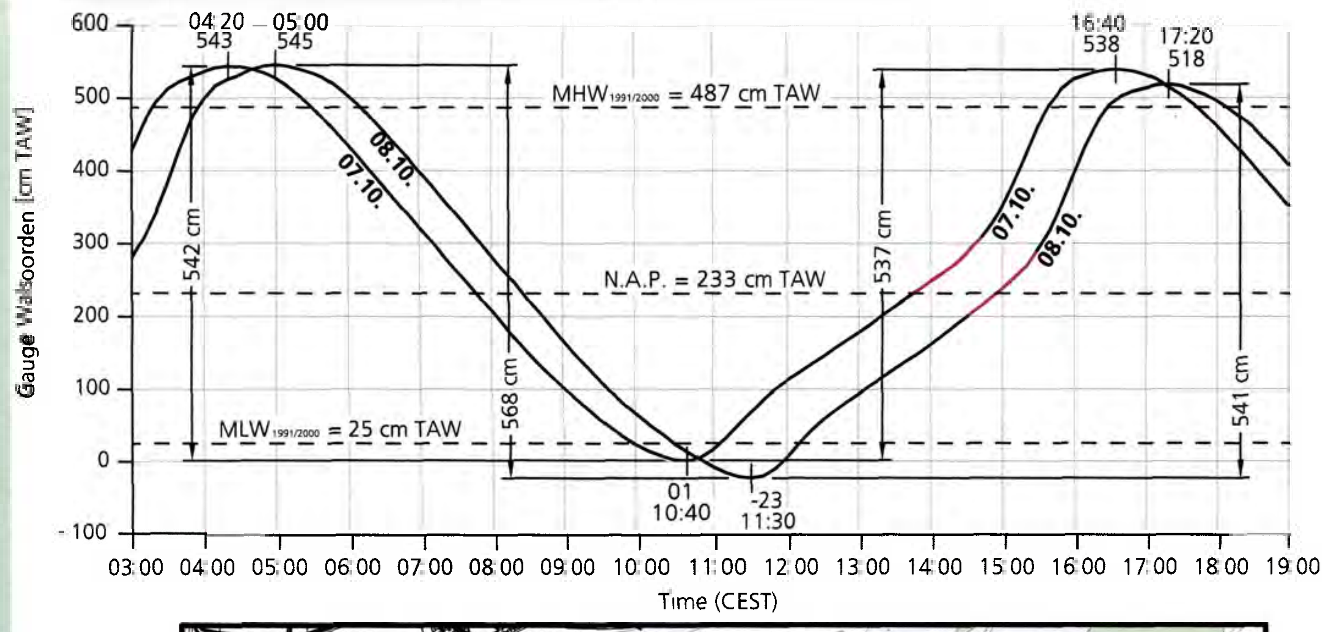
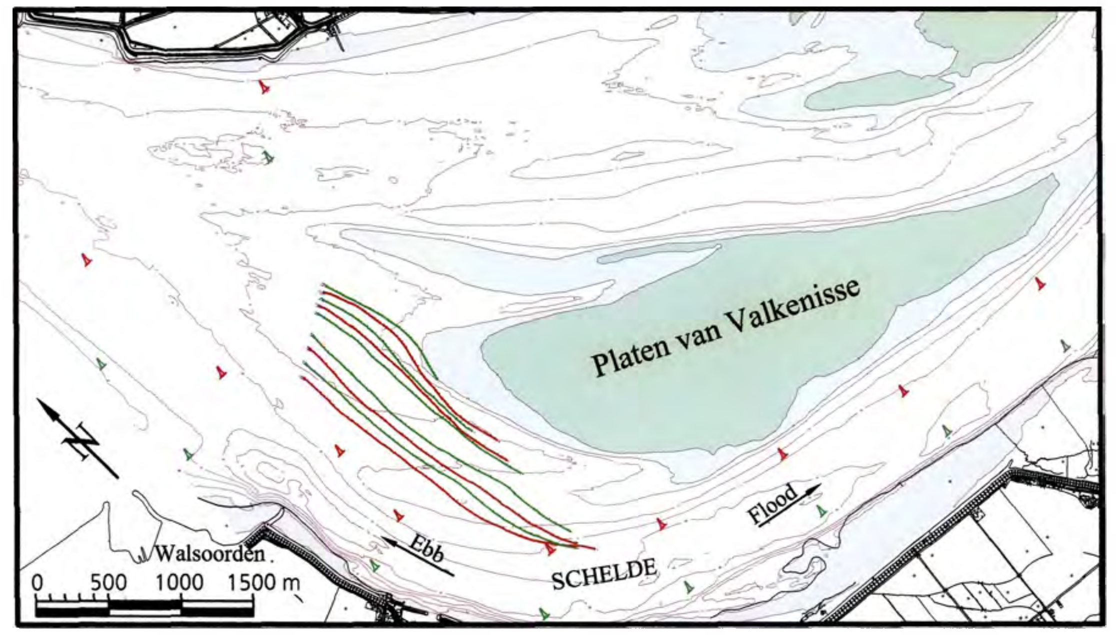
ANNEX 27

Current Measurements: 07.10. and 08.10.2002

Chart Datum: N.A.P. [m]







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Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel 0421-5905 2313
Fax 0421-5905 2382
e-mail wabau@fbb hs-bremen de

in association with

Ministerie van Verkeer en Waterstaat

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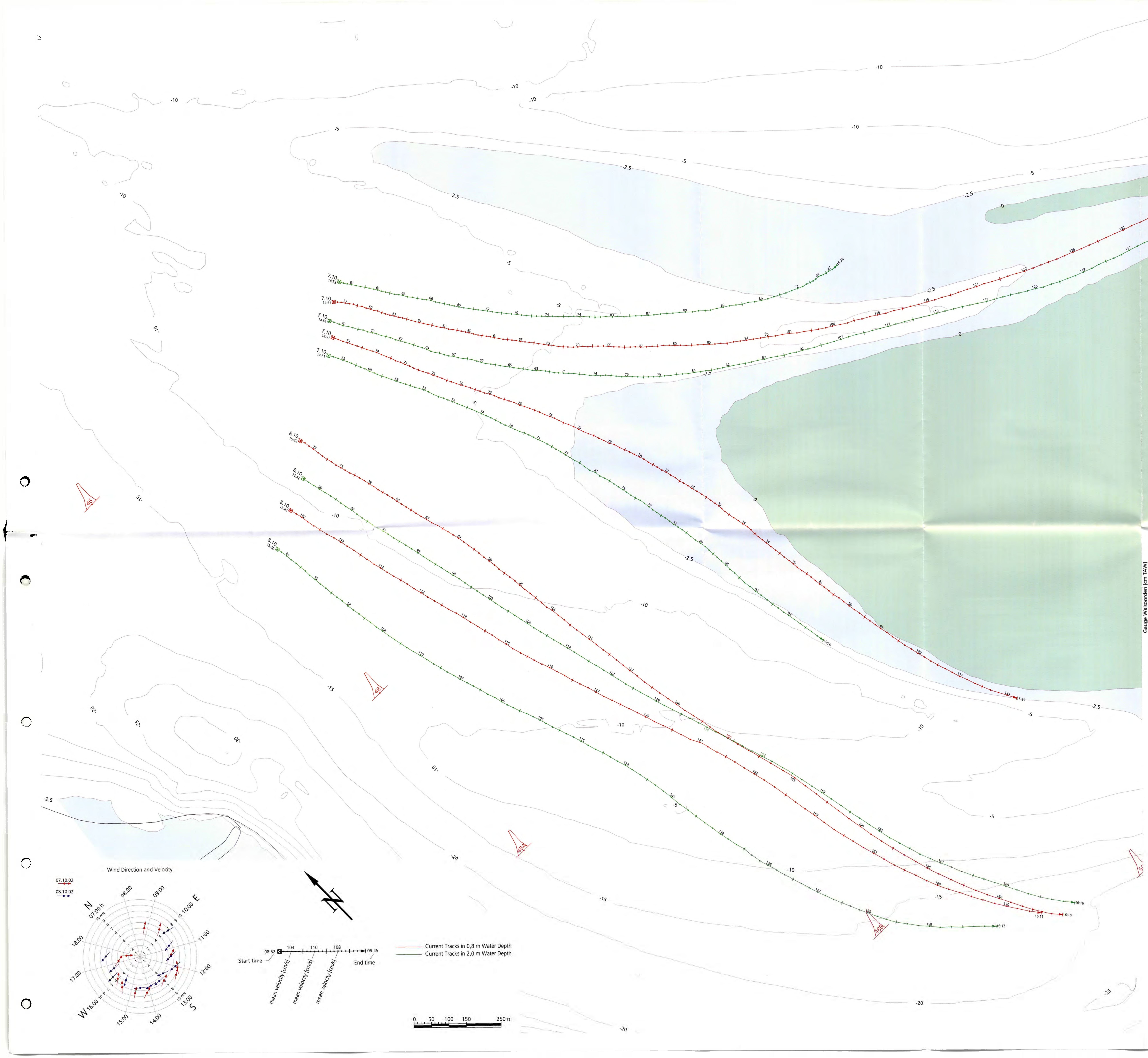
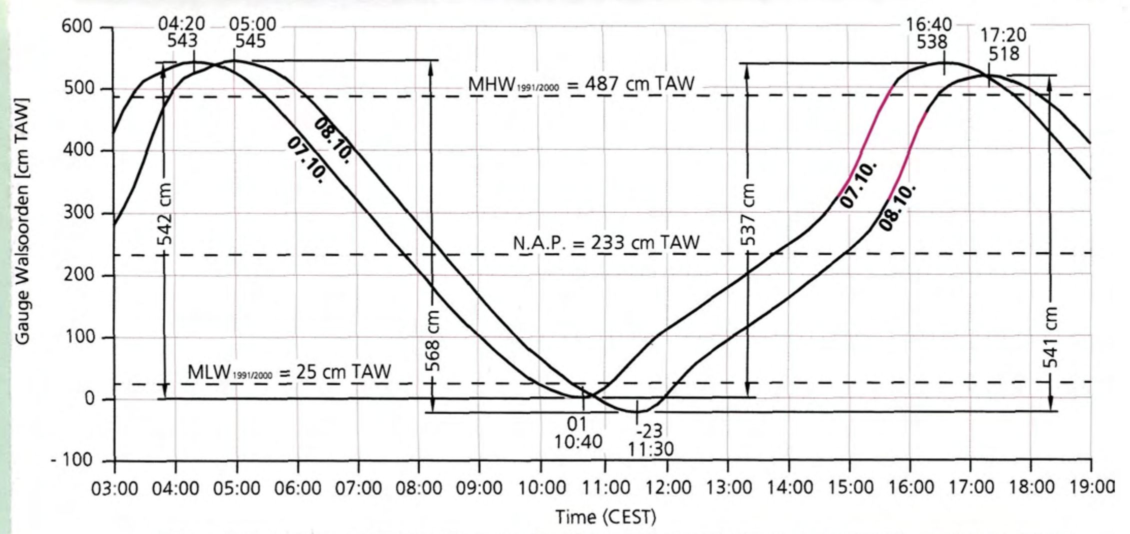
ANNEX

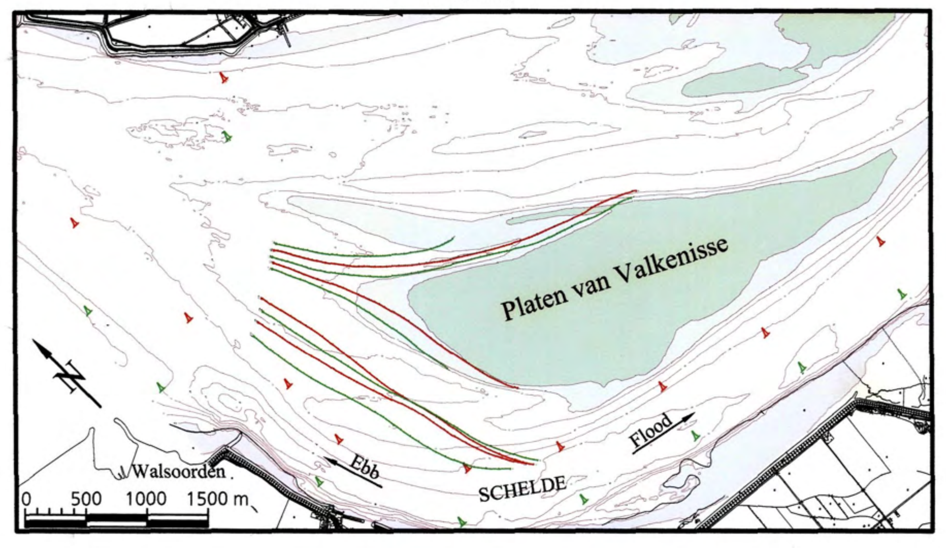
28

Current Measurements: **07.10. and 08.10.2002**

Chart Datum: N.A.P. [m]







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IWA
Institut für Wasserbau

Institut für Wasserbau
Neustadtswall 30
28199 Bremen

Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

in association with:

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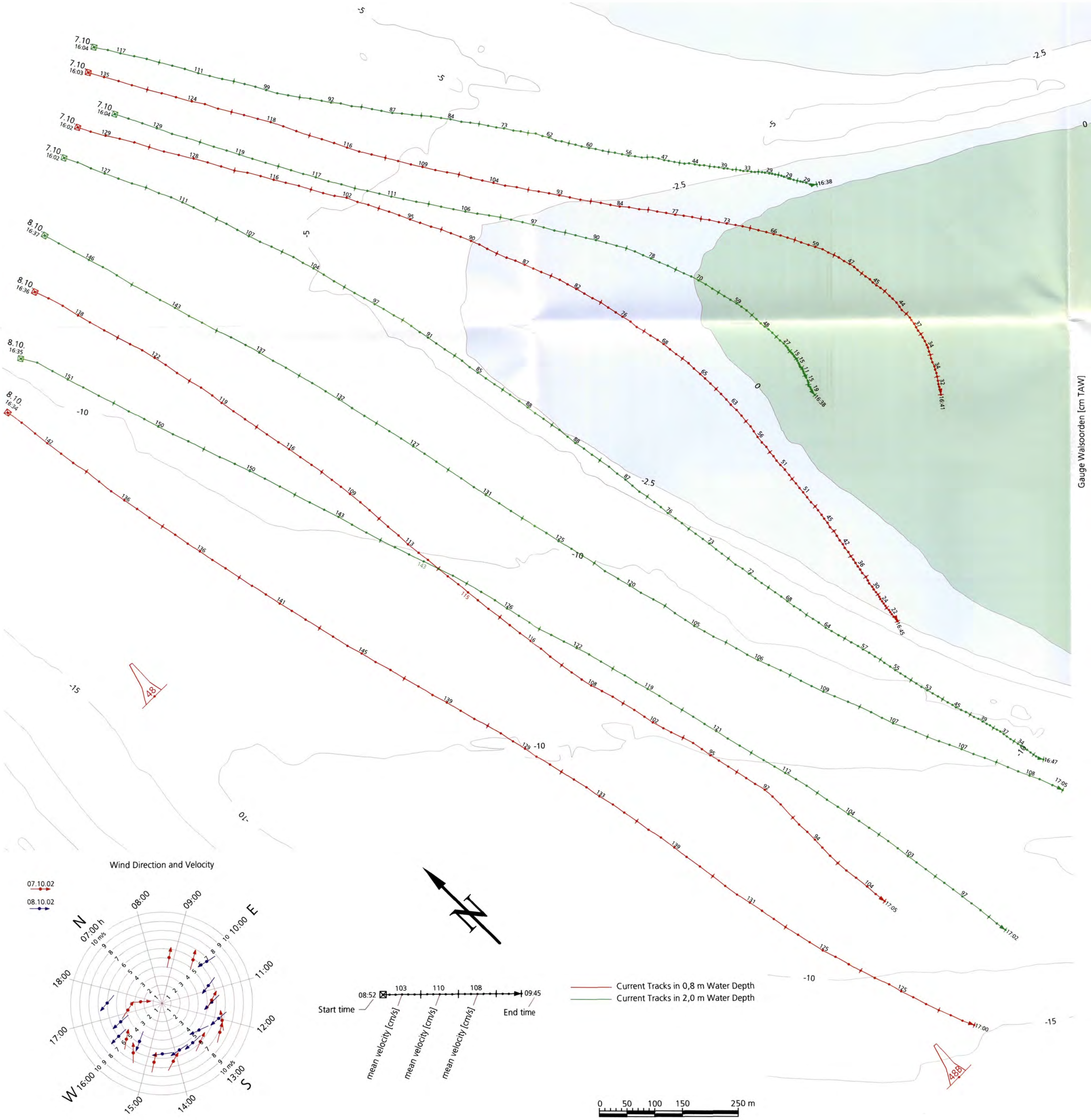
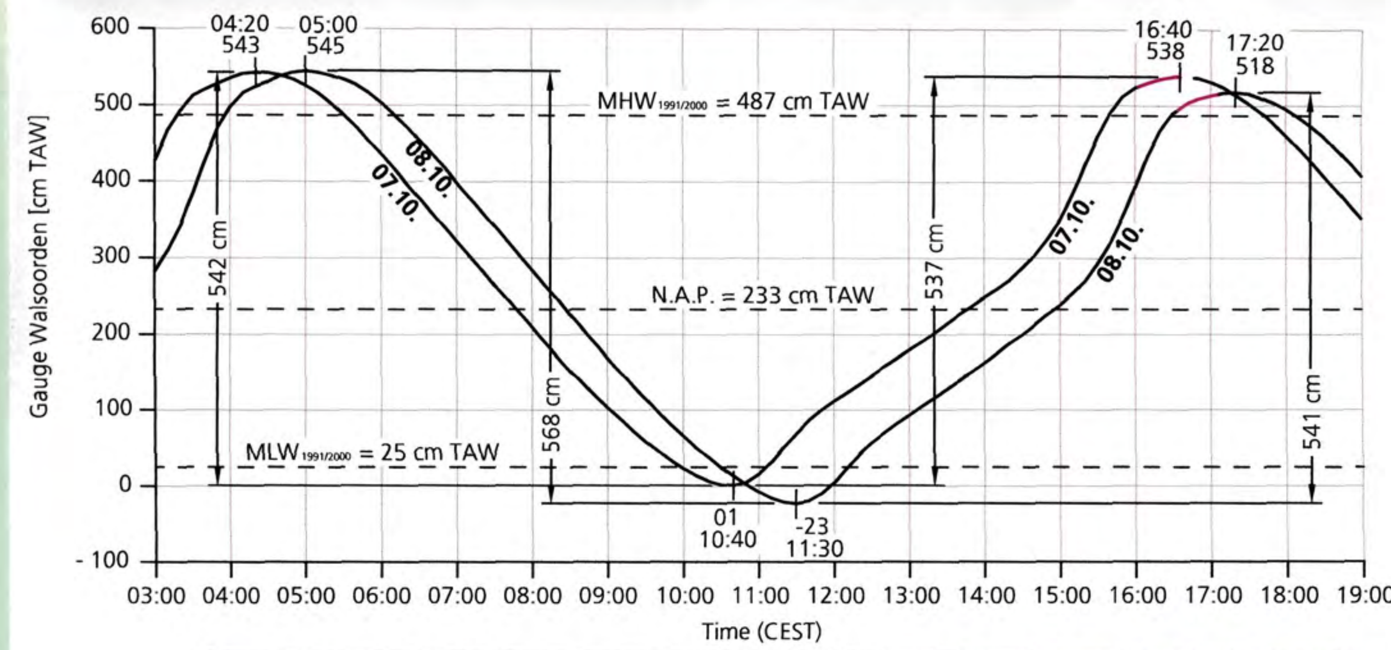
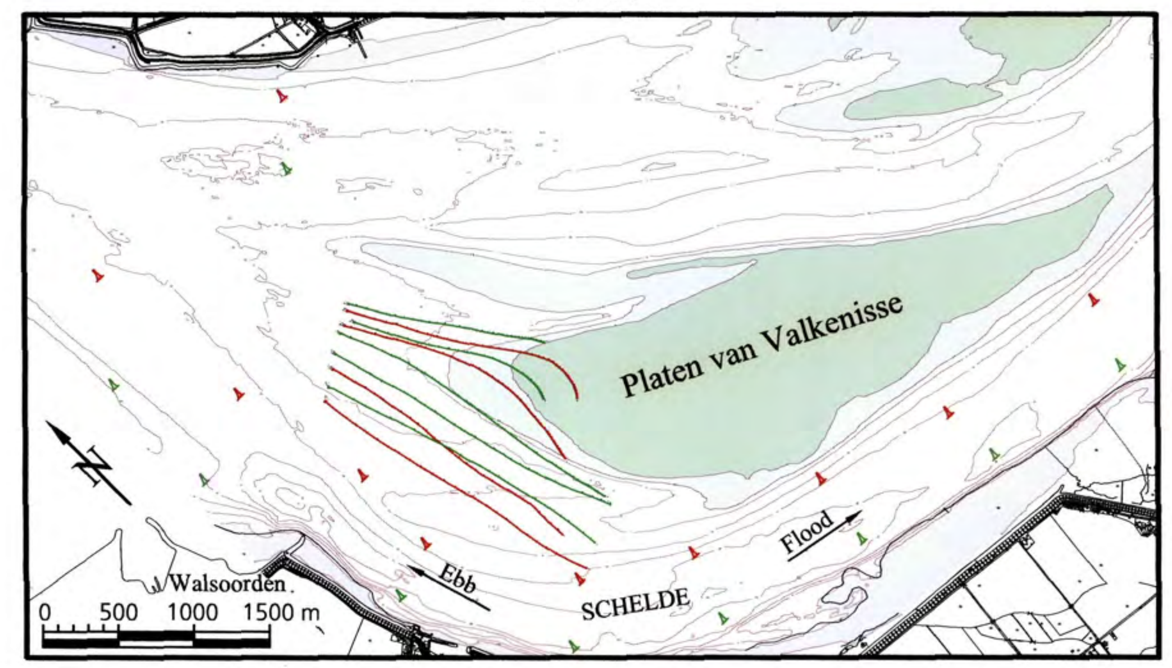
ANNEX 29

Current Measurements: **07.10. and 08.10.2002**

Chart Datum: N.A.P. [m]







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Institut für Wasserbau
Institut für Wasserbau
Neustadtswall 30
28199 Bremen
Tel: 0421-5905 2313
Fax: 0421-5905 2382
e-mail: wabau@fbb.hs-bremen.de

in association with:
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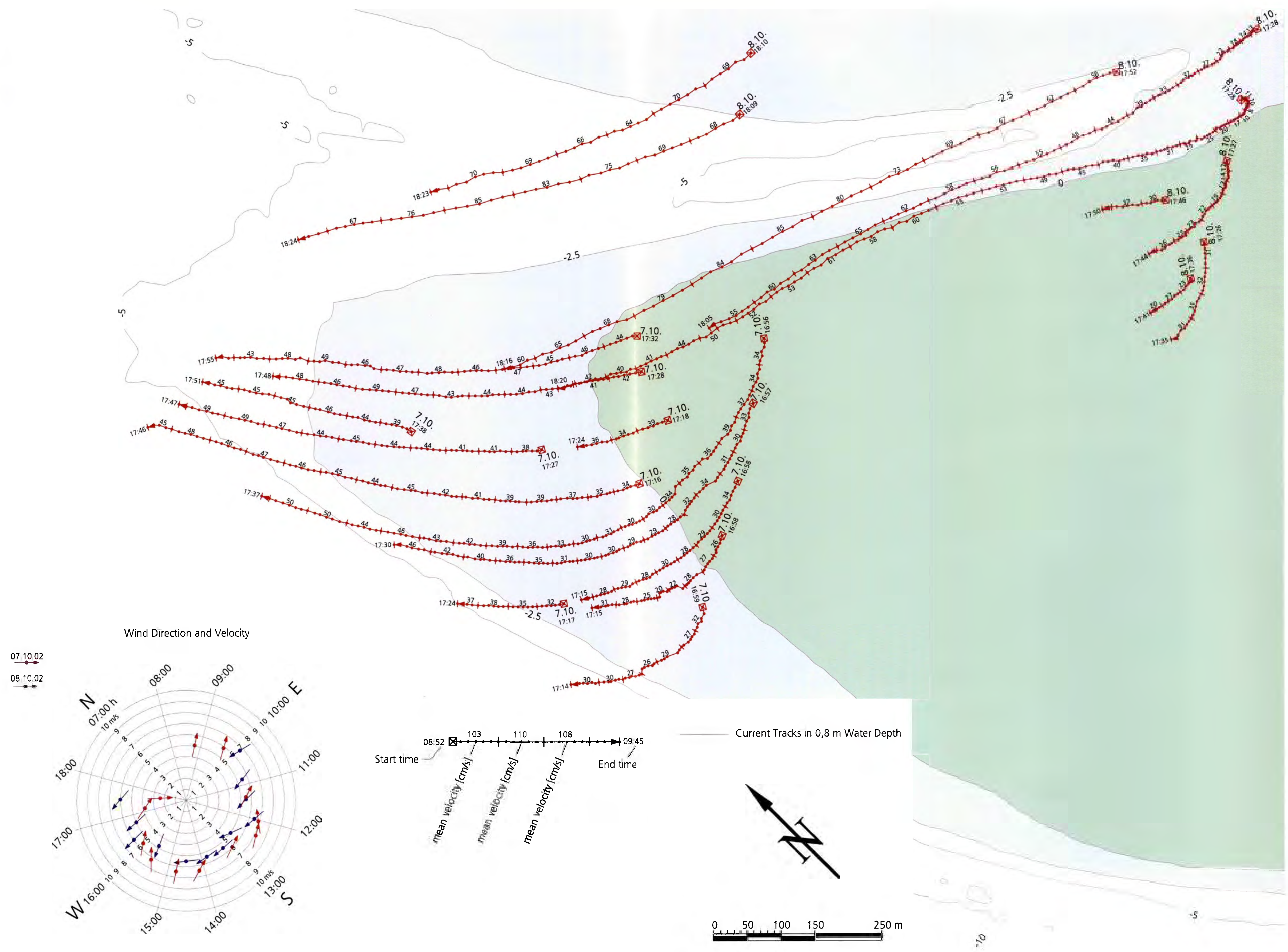
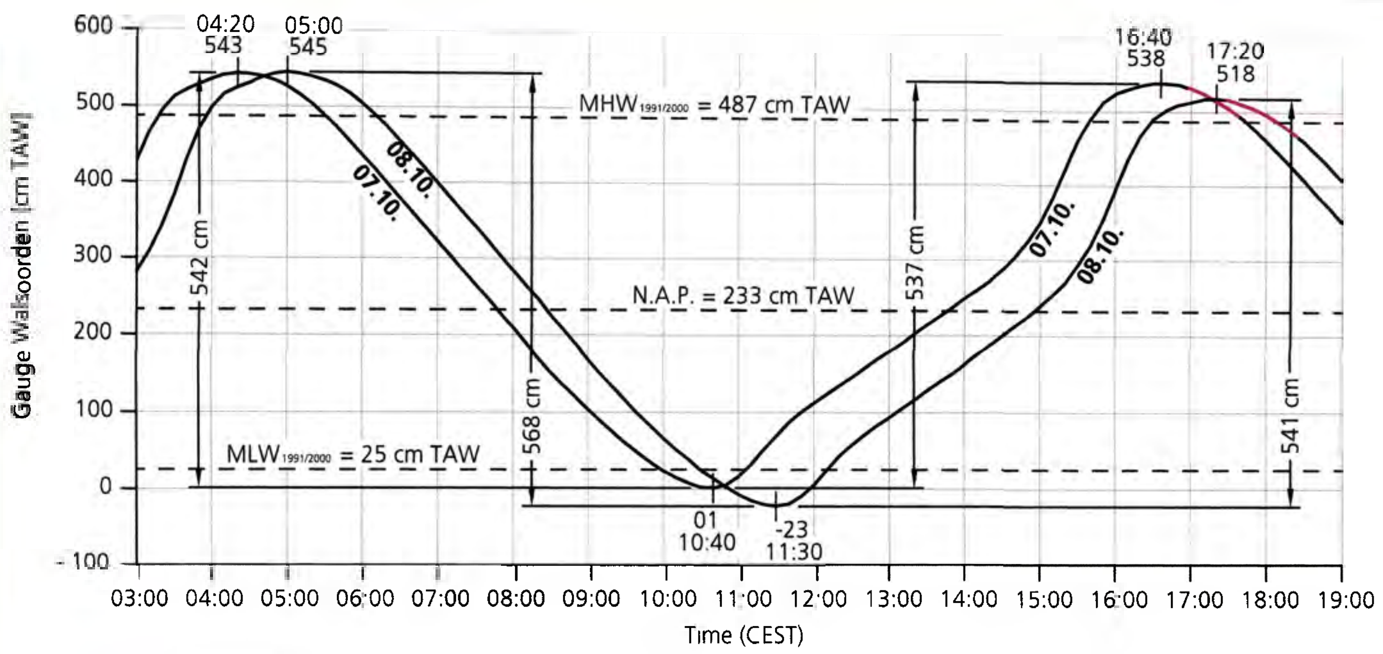
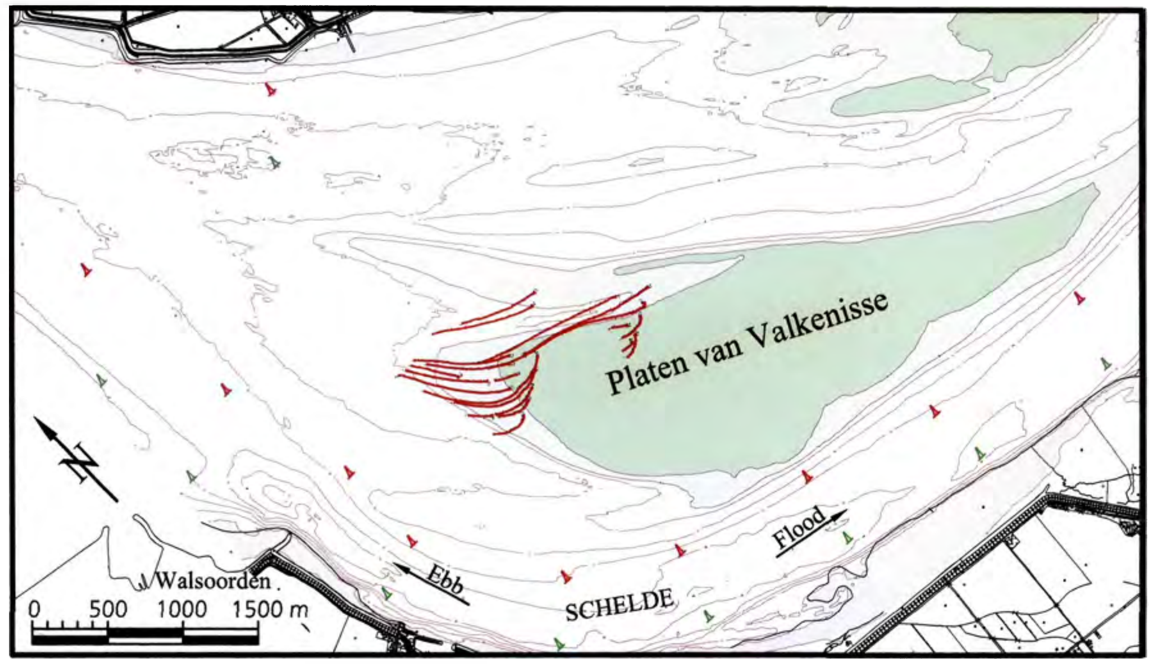
ANNEX 30

Current Measurements: 07.10. and 08.10.2002

Chart Datum: N.A.P. [m]







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ANNEX 31

Current Measurements: 07.10. and 08.10.2002

Chart Datum: N.A.P. [m]