Ministerie van de Vlaamse Gemeenschap
Departement Leefmilieu en Infrastructuur
Administratie Waterwegen en Zeewezen
Afdeling Waterwegen Kust - Hydrografie
Hydrografie
OOSTENDE

rapport 42 bis

MULTIBEAM ECHOSOUNDER TECHNOLOGY

ANALYSIS OF SANDWAVE MIGRATION WITH MULTIBEAM ECHOSOUNDING RECORDINGS.

53551

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INTRODUCTION

For hydrographic purposes, swath-sounding systems become more and more important,because these systems enhance the efficiency of bathymetric surveys, when compared to conventional methods (single track measurements).

So far, side scan sonar was a big help in increasing the awareness of the degree of inadequacy of the single track sounding surveys. However, side scan has never quite become a real bathymetric equipment for a number of reasons: first, it is difficult to relate side scan to a depth survey and further, it is selective in what it shows, depending on the scan aspect to a feature or target. Therefore side scan sonar is to consider only as a diagnostic tool for a qualitative evaluation of sea bottom features.

Already *in 1976* a paper of Cloet (*Ref.1*) revealed that, in bathymetric surveys, residual depth errors occur as a function of the line spacing, i.e. the distance between 2 sounding lines. These depth errors could be in excess of 1 metre, where the line spacing was 60 metres or more (formula $E = 0,4 + 0,01 * L$ with: E = error and L = line spacing).

After 1976, a lot of experiments were done in the Netherlands and in the United Kingdom (UK); these findings supported the contents of the paper, mentionned above.

A paper of 1993 (*Ref.2*) confirmed the findings of Cloet: on the basis of this experience, it was felt imperative that, in a sandwave area, line-spacing needed to be reduced to at least 50 metres, which was a considerable increase in the workload of the hydrographic service.

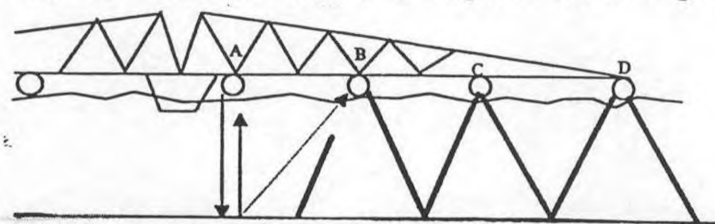
1.SWATH-SOUNDING SYSTEMS IN GENERAL

Three types of systems can be identified:

- **multiple echosounders**;
- **interferometers with a sidescan sonar**: *phase* and distance measurement;
- **fan shaped multi-beam swath echo sounder** - principle of *amplitude* measurement.

(1) Multiple Echo Sounders

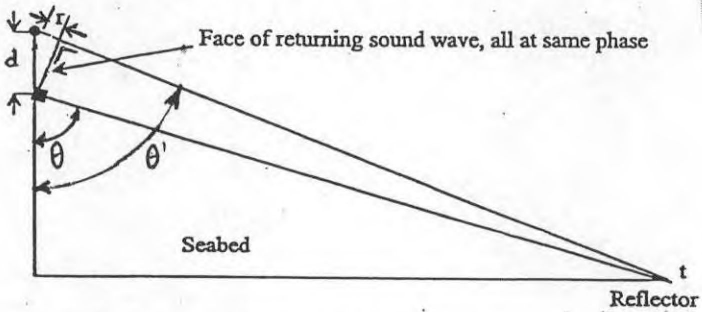
This type of system requires a very stable platform and is only suitable for sheltered waters, such as rivers/harbours.
Disadvantages: -difficult to manipulate in busy waterways;
-low operating speeds;
-swath width is limited to a maximum of 50 m;
-number of echo sounders, that can be used at the same time, is limited by the depth. See Figure below.



(2) Interferometers - Principle of phase measurement

Here *two* different systems are to distinguish:

(a) **The Bathyscan System.**
This system, used till now as a towfish configuration, combines time or distance (with a sidescan sonar) and angle measurements (with different interferometers)
Principle of *1 single interferometer*:
The interferometric sounder transmits a beam, similar to a sidescan sonar, but, besides the recording of the signal amplitude, it measures the phase difference between 2 signals from the same reflector on the sea bottom, using a pair of vertically-displaced transducers. See also Figure below.



Knowing *d*, or the transducer separation,
and *Φ*, the phase difference, measured by interferometry,
then *r* may be deduced.
From this, the angle, subtended by a reflector t on the seabed, can be calculated:

$$\theta' \approx \theta = bg\cos r/d$$

This calculation is independent of range and depth; the number of individual sample comparisons made is limited by the ability to resolve phase-difference.
In practice, very many samples are obtainable, every transmission cycle. Furthermore, since the sampling is not affected by range, resolution is maintained across the full swath. Systems, employing single interferometres, are limited in their swath by ambiguities, generated when the phase difference exceeds 360°.
Additional transducers enables these ambiguities to be removed and are incorporated in Bathyscan; on this manner *several interferometers* are used. See also the Annex A.

(b) EM-950 or EM-1000 System of SIMRAD
Here 60 beams are sent to the seabed in a honey-combe structure.
Primarily for the outer beams the interferometric principle is used, because here beamforming is smaller and also the maximum swath width is bigger (7.4 * depth).
The determination of time for one of the outer bundles can be illustrated on on a phase difference versus time diagram, shown in AnnexB
The phase difference of 2 adjacent tranducers are represented in the diagram and the zero phase difference (crossing with the x-axis) is to take into account, because this signal from the reflector on the bottom is coming from precisely the direction in which the transducer is pointing to the seabed.
The time, the transmit pulse is underway, is therefore determined at this moment as well, which, depending on the sound velocity, is a gauge of the measured depth.
The accuracy for determining the beam's angle is considered to be something around 0.02°.

(3) Multi-beam Echo Sounders - Principle of amplitude measurement

Here the necessary time and direction measurements of the different transducer-elements are carried out by the so called "amplitude measurements".
The time of one measurement corresponds with the peak of the amplitude of the bottom echo and the direction corresponds with the position of the transducer-element, where this echo is measured, as illustrated in AnnexB.
The use of multiple beams enables wider swaths to be covered, but, as interferometres in the centre beams are unsuccessfull, it is the only mean to measure under the survey vessel (angles of phase differences are there to small to be measured).
Because the outer receive beams spread more than the inner ones, they have a lower resolution.
The last statement is the reason why the EM-950 or the EM-1000 of SIMRAD uses primarily multi-beam for the inner beams and the principle of phase-measurements for the outer beams.
The Bathyscan does NOT uses multibeam at all; the drawback is that no measurements are available under the survey vessel...
A comparison between BATHYSCAN and EM 950 is given in Table 1.

2.The EM 950 ON BOARD THE MS " TER STREEP"

In order to fullfill an EC- contract on the "Assessment of volumetric and morphologic trends on the Middelkerke-Bank area" or "Chronosequential multi-beam echo-sounding by vessel", the "Afdeling Waterwegen Kust-Hydrografie" has chosen, from the very start, for a swath echo sounding system, based on the principle of acoustic interferometry.

After a close examination we found 3 firms on the market, which theoretically were able to manufacture such an interferometric sounding device, i.e. Marconi Underwater Systems (UK), Simrad Subsea A/S (Norway) and Submetrix Ltd (UK).

So far, some systems were manufactured in a towfish configuration, but it was our intention from the beginning to install the transducer array on the available moon pool trolley of our hydrographic survey vessel ms "Ter Streep"; by doing this, the array is more protected against a possible loss. Also on this manner, its position is better known and less attitude sensors are needed in order to cope with the movements of the ship.

On 17/05/1994, we were able to order the SIMRAD 950-system, that has been choosen and proposed to our Ministry before.

The installation of the system took place in the period from the 12th of September till the 3th of October 1994.

The harbour and acceptance tests happened from the 10th to the 12th of October 1994.

After the elimination of the classical so called "child deseases", the system was subject to a thorough quality controll as well.

The *main system specifications* are:

Transducer: Size: 400 x 900 mm
Weight: 130/95 (in air/water)
Shape: Cylinder segment
Number of staves: 128
Transmission: Total peak power: 4,5 kW
Frequency: 95 kHz
Pulse length: 0,2 msec
Source level: 225 dB
Max.ping rate: 4 pulses/sec(240 soundings per sec)
Reception: TVG: digitally controlled
A/D conversion: 12-bit quadrature sampling
Range resolution: 15 cm
Depth resolution: 2 cm
Beamforming: Equidistant or equi-angle spacing of soundings
Number of soundings: 120 over 2 pings
Normal operation for shallow water:
Sounding spacing: 6,3 % of depth for EDBS- or equidistant mode
1°,25 for the shallow or equi-angle mode
Sector covered: 150°
Max.swath width: 7,4 x depth
Water depth: 3 - 200 m.

Other EDBS modes for deeper waters and embankment modes for measuring along and up the slopes of embankments are also possible.
See ***Annex 1*** with 2 pictures of this vessel, where, on the figure below, the centre-well is indicated, and where the transducer, mounted on a carriage, can move up- and downwards.

The *Annex 2* shows the *System Configuration* with the **system units**:

(1) The **main system units** of the EM 950 are:

-Transducer array
-Transceiver
-Bottom Detector Unit
-Operator Unit with colour display

The last 3 Units are hold in a *Electronics Cabinet.*

The *Transducer array* is formed as a 160° segment of a cylinder, with a radius of 45 cm and a length of 47 cm.

The *Transceiver* contains power amplifiers, preamplifiers, digital signal processors, interfaces and control processor.

The signals processors are used for:

-beamforming
-frequency filtering
-roll compensation
-determination of amplitude and phase in each beam
-transmission of data to the Bottom Detector Unit.

The *Bottom Detection Unit* controls the tranceiver circuitry in the Electronics Cabinet and sets all the system parameters.

The *Operator Unit with colour display* runs the operator interface via a 14" colour graphic monitor with integrated joystick and connects the EM 950 to all external units.

(2) The so called **system options** of the EM 950 are:

(a) Real time processing:

Data are transferred by Ethernet to a SUN workstation, running a Unix operating system.

Two systems are running on this workstation:

-*MERMAID* or data recording software: loggs all the data in a digital form for archiving and postprocessing;
-*MERLIN*: visualisation software, ,available from the end of 1993, provides 2-dimensional and 3-dimensional real time presentations of both bathymetric data and sonar image data.

(b) Postprocessing:

Normally bathymetric data processing is handled by the NEPTUNE II software system of SIMRAD, but, as our office already used CARIS for electronic charting, it seemed more handy to use *CARIS HIPS* (Hydrographic Information Processing System):

HIPS is a powerful software system, which has been designed specially to process very large quantities of sounding data, especially swath systems. This system is generic - that is, it can be supplied to any swath sounding system.

HIPS has 2 major components:

(i) The Hydrographic Data Cleaning Software (HDCS): first it retrieves previously logged survey data and further it processes the data globally: that means it can correct for blunders, tide, draught, sound velocity, heave, roll, pitch, etc., so that the corrected data are clean;

(ii) The cleaned soundings are then processed and displayed via the Data Visualisation software.

(3) The **external units** are:

-*Sound velocity profiling probe*
-*Positioning system DGPS* of Aquanav
-Ship's course *Gyro*
-*Vertical Reference Unit Hippy 150 with an analog B-filter*, providing the heave, roll and pitch measurements.

As the last Unit is installed in the middle of the survey vessel, the horizontal offset (15,11 m) and pitch's angle is needed for a further compensation of the heave measurements.

Ship's roll is compensated by the 4 outer transducers by switching on or off transducers, as a function of the roll angle; as the angular displacement of 1 beam equals 1,25°, full compensation for roll is possible to a maximum roll of +/- 5°degr.

3.THE FIELD PROGRAM FOR STARFISH

The field program for the EC-kontract STARFISH on the Middelkerke Bank, as determined in cooperation with the other Starfish partners, is as shown in the ***Annex 3***.

In the 2 concerned areas R2 and R4, while using the multibeam system, the different tracks of the survey vessel are spaced by 40 or 50 m from each other, depending on the depths nearby.

The 2 areas do not belong to the shallowest parts of the bank: by means of the chronosequential multi-beam echo-sounding we will examine how stable sandwaves are, as the time is passing by.

During the summer and autumn period of 1995 we surveyed also the whole of the Middelkerke Bank with our single-beam and with our multibeam system at the same time.

4.THE MEASUREMENTS WITH THE EM 950

After the elimination of the classical "child diseases", the system was subject to a thorough quality control.

Anticipating in spring 1994 on a possible late installment of the device on board the ms "Ter Streep", we decided to take up the chronosequential multi-beam echo-sounding on the Middelkerke Bank for the first time on the 20 and the 21th of april 1994.

This could only be done by our Dutch colleagues of the Rijkswaterstaat-Meetdienst Zeeland in Flushing, because on 19/01/1994 a similar system (the Simrad EM 1000) became operational on board the "Wijdvliet", being one of the Dutch survey launches.

As our own equipment was also NOT operational for a mid-year survey of the same areas, the Rijkswaterstaat has been requested once more to carry out the second survey in 1994.

Only at the end of October 1994 the SIMRAD EM 950 became operational on board the ms "Ter Streep", so that, from that period on, we were able to take over the task of surveying the chosen areas.

The ***Annex 4*** provides us with the dates of all the chronosequential measurements (R2 and R4) and with the dates of the other bathymetric measurements of the bank as a whole.

Concerning the tidal reduction of the bathymetric data, I want to refer to Ref.4, where our M2 tidal reduction method has been explained.

5. THE RESULTS - CONCLUSIONS.

The aim of the chronosequential multi-beam echo-sounding on the Middelkerke Bank is to monitor 5 sandwaves in the R2-area and 2 bigger sandwaves in the R4-area.
The R2-area is the shallowest one, with minimum depths between 70 and 80 dm on the crests. On the other hand, the R4-area, situated in the northern part of the bank, is deeper, showing depths between 130 and 140 dm on top of the crests.
In all, we are able to present here the 9 detailed charts, on a scale of 1/2000, for each zone, where we can notice the shapes of several underwater sand dunes and channels in between the crests.
The most relevant charts for the R2-area are these, where we can see some movements in the configuration of the crests (red contour lines of 9 m) and the channels (green and blue lines of 10 and 11 m).
As we do not see a significant change in the first 4 charts, we can take ***Annex 5*** as representative of this situation; afterwards there is a shift to the east of nearly 20 m in the ***Annex 6*** *(March 1995)*; gradually this shift goes back to the early situation, as we can see for instance in the ***Annexes 7 and 8***; in the last one the earlier situation is completely restored.

For the R4-area also 3 colours have been used: the red lines of 14 m contour the 2 crests of the sand dunes, while the green and the blue lines represent the 15 m and the 16 m.

Here we do not see any significant change in the bathymetry of the area: the first chart (***Annex 9***) and the last chart in the row (***Annex 10***) can be taken as representing this stable situation.

We think the occurence of oscillations, such as we see in the area R2, has to deal with:
(1) the storminess of the winter period in 1995 was:

1 to 2 January	24+20 hours, NNW, Bft.7 to 9
12 January	8 hours, NNW to N, Bft.8 to 9
26 January	10 hours, N to NW, Bft.8 to 9
28 February	6 hours, WSW, Bft.7 to 8
06 March	12 hours, WNW, Bft.8
18 March	24 hours, WSW, Bft.8 to 10
20 March	10 hours, NW, Bft.7
27 March	12 hours, WSW, Bft.8 to 9
29 March	15 hours, N, 7 to 10
18 April	8 hours, WSW, 7 to 8

(2) the type of the tide, occuring during the storminess: on the 20th of March, there was a strong spring tide;
(3) the depths on the crests:
depths on the crests are significantly lower in the R2-area, so that there the waves (orbital movements) touch more the bottom than in the R4-area.

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2. E.C.BOUWMEESTER and A.W.HEEMINK. Optimal line spacing in hydrographic survey.
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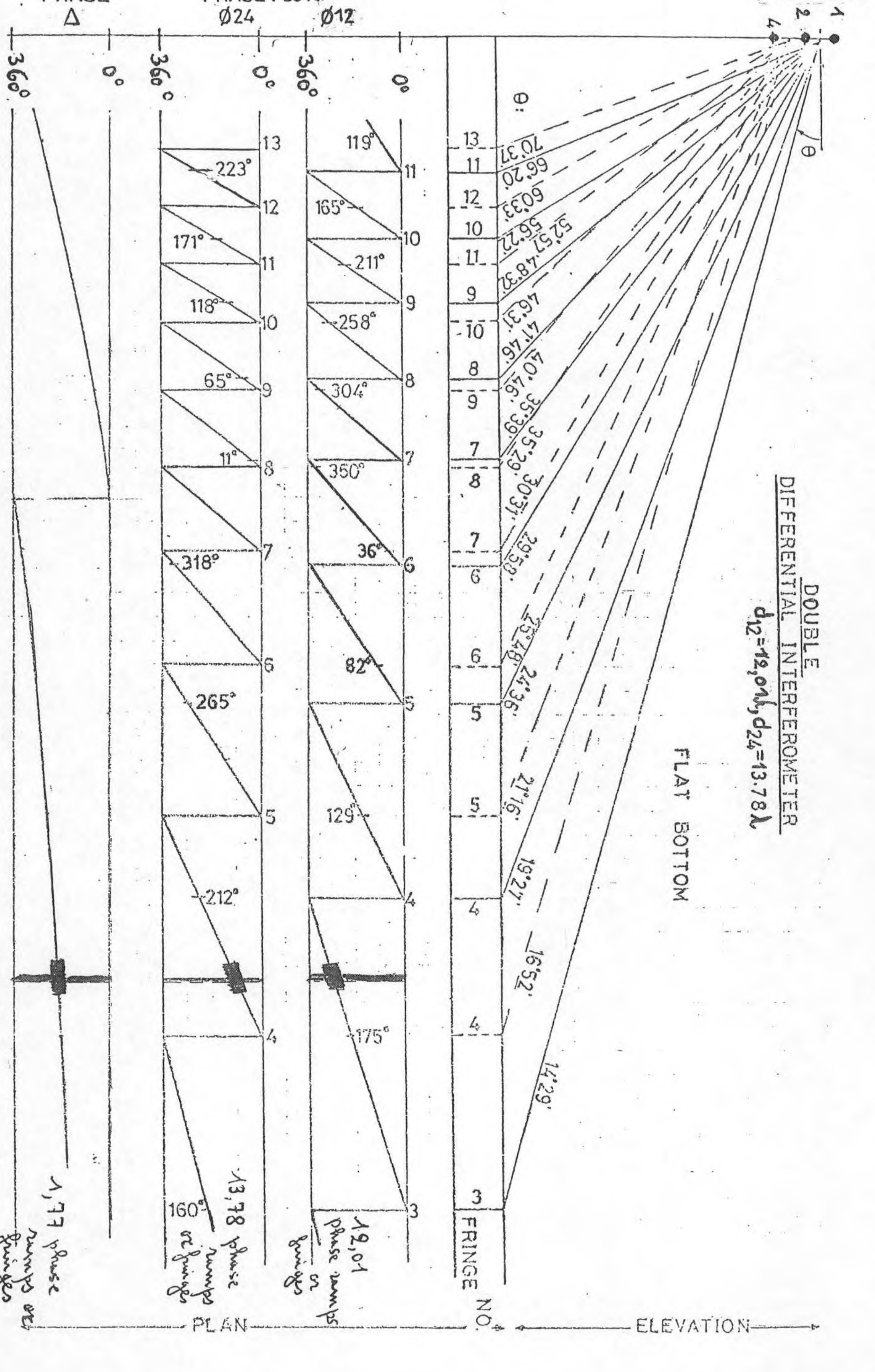
4. C.VAN CAUWENBERGHE, L.DEKKER and A.SCHUURMAN. M2 tidal reduction method for coastal zones.
Hydrographic Society-Benelux Branch Workshop over "Tidal reduction methods". Amsterdam, 19/06/1987.
Rapport No.33 of the Hydrographic Service.

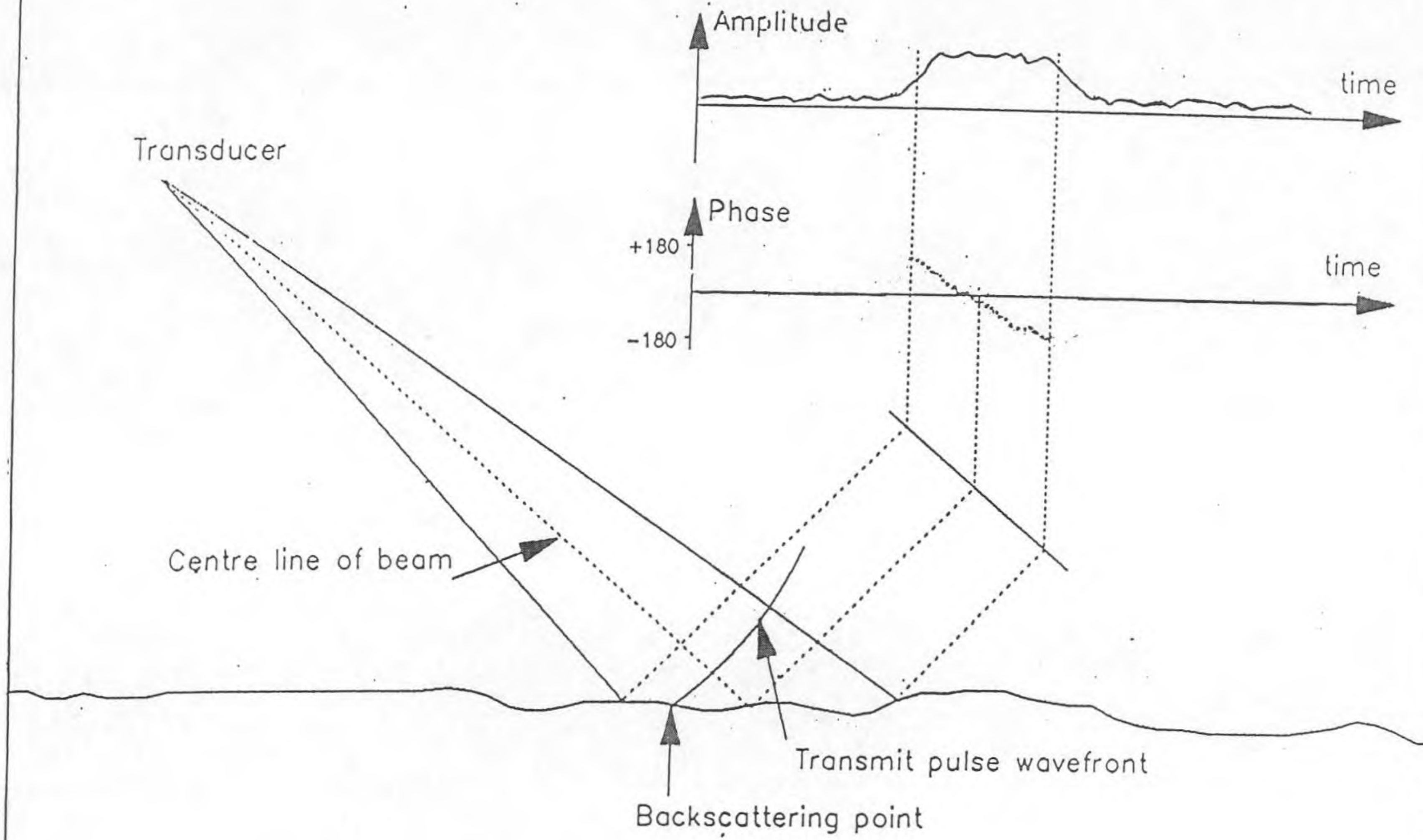
Brussels, 08/01/1996.

C.Van Cauwenberghe

Annex A



PHASE
Δ
PHASE PLOTS
Ø24
Ø12
360°
0°
θ
θ:
FRINGE NO.
DOUBLE DIFFERENTIAL INTERFEROMETER
d_{12}=12,01λ, d_{24}=13.78λ
FLAT BOTTOM
1,77 phase ramps or fringes
13,78 phase ramps or fringes
12,01 phase ramps or fringes
PLAN
ELEVATION
70°37'
66°20'
60°33'
56°22'
52°57'
48°32'
46°31'
41°46'
40°46'
35°39'
35°29'
30°31'
29°50'
25°48'
24°36'
21°16'
19°27'
16°52'
14°29'
223°
171°
118°
65°
11°
318°
265°
212°
160°
119°
165°
211°
258°
304°
350°
36°
82°
129°
175°



Interferometric Signal Processing

Same accuracy across the swath

COMPARISON OF 2 SWATH SOUNDING SYSTEMS

	BATHYSCAN	EM 950
Frequency in kHz	300 (100 also possible)	95
Wavelength in metres	0,005 m	0,0167 m
Number of transducers	1 transmitter & 4 receivers in one	128 elements (120 used) in one
Pulse duration	0,2 msec	0,2 msec
Sampling rate	1024 data per 0",2048(=1024 X 0,2 msec); filtering with moving averages to 256 data	Honeycombe structure: 4 X 60 = 240 data per 1"
Distance measurement	Principle of SSS; increments of 15 cm; for, 1500 x 0,2 / 1000 = 0,30 M = 2 x 0,15 m	Triggering of 60 transducers simultaneously
Angle measurement	Interferometric principle of R.Cloet with 3 or 4 receivers (see Annex 1 with 3 receivers)	SIMRAD Interferometric principle for the outer beams. Multibeam principle/amplitude measurement for the inner beams
Vertical angular displacement	0°,2	1°,25 X 2=2°50
Vertical angular coverage	2 x 60° = 120°	Normally EDBS: 2°,5*60=150° Other modes are also possible: Shallow and Embankment
Horizontal beam angle	1°,0	3°,0
Mean swathe depth	8 x depth	7,4 X depth
Water depth	5-70 m	3-300 m for 150°
Advantage	High resolution	Data available everywhere

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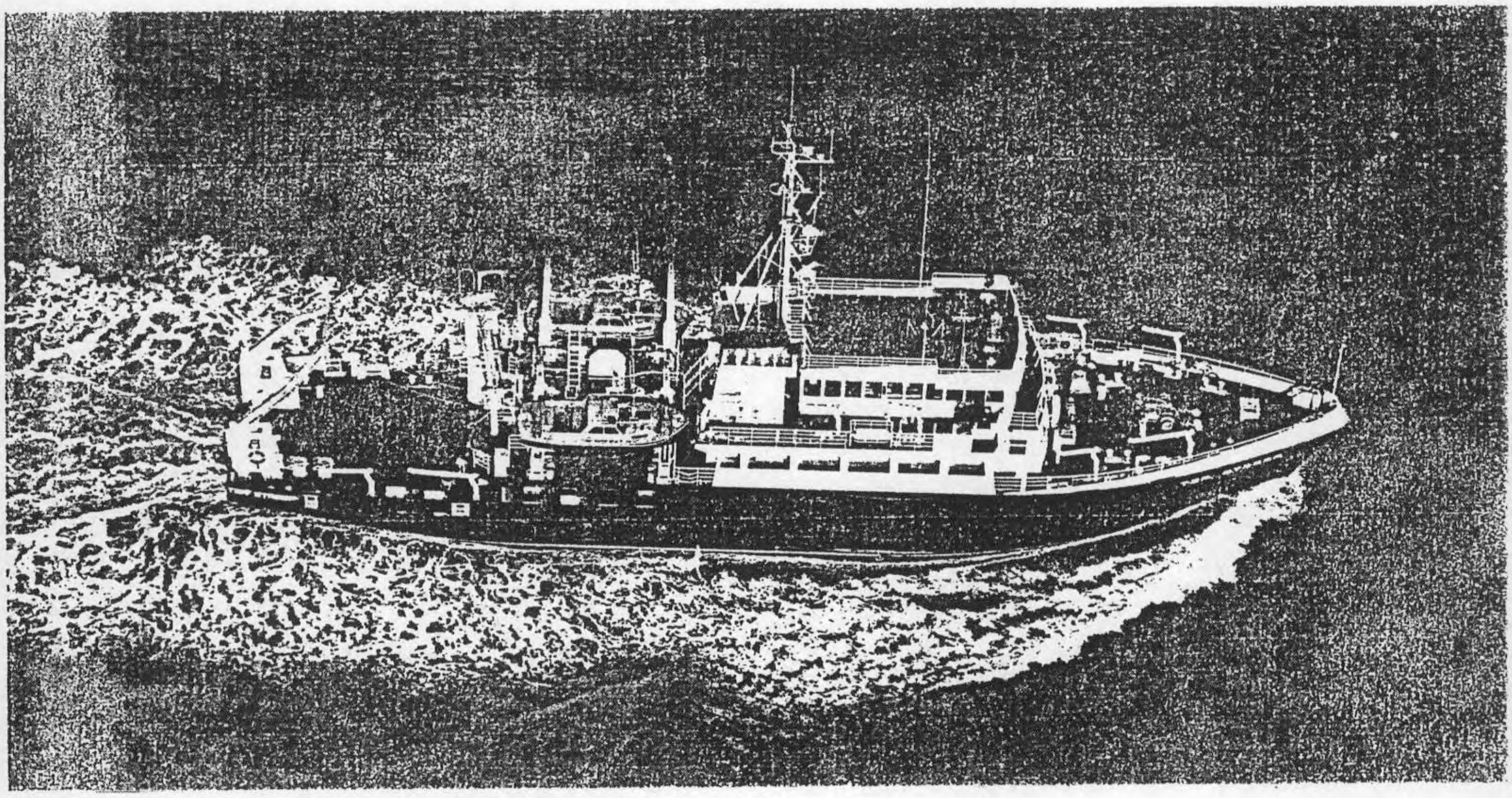
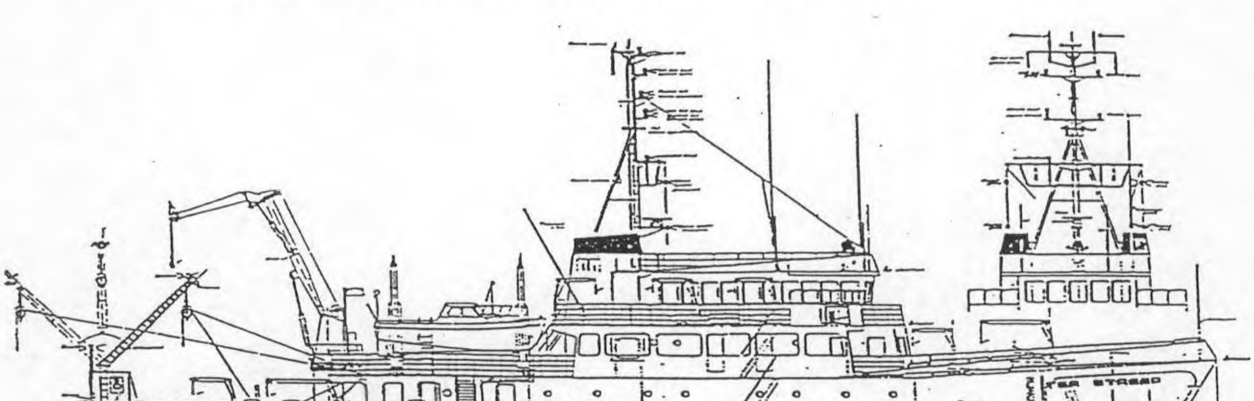
ANNEX 1

MS TER STREEP
The hydrographic survey vessel for the Belgian conshelf



Main dimensions and characteristics

Length overall	49.550 m
Length P.P.	44.900 m
Moulded breadth	9.600 m
Moulded depth	4.800 m
Draught at underside keel	3.250 m
Displacement	647 m^3
Gross tonnage	643 GRT
Net register tonnage	193 NRT



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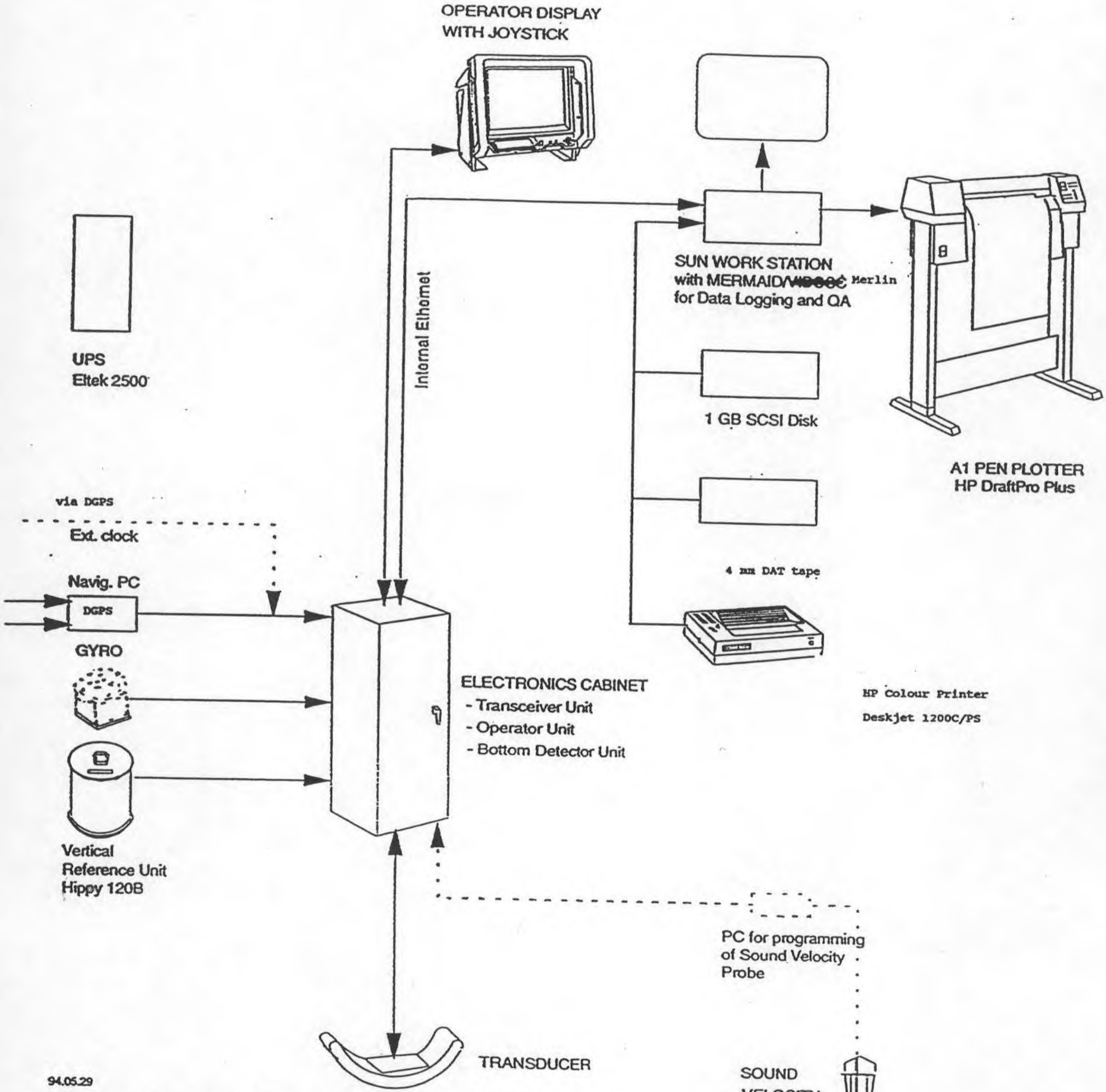
ANNEX 2

MS TER STREEP

SIMRAD EM 950 MULTIBEAM ECHOSOUNDER

System Configuration



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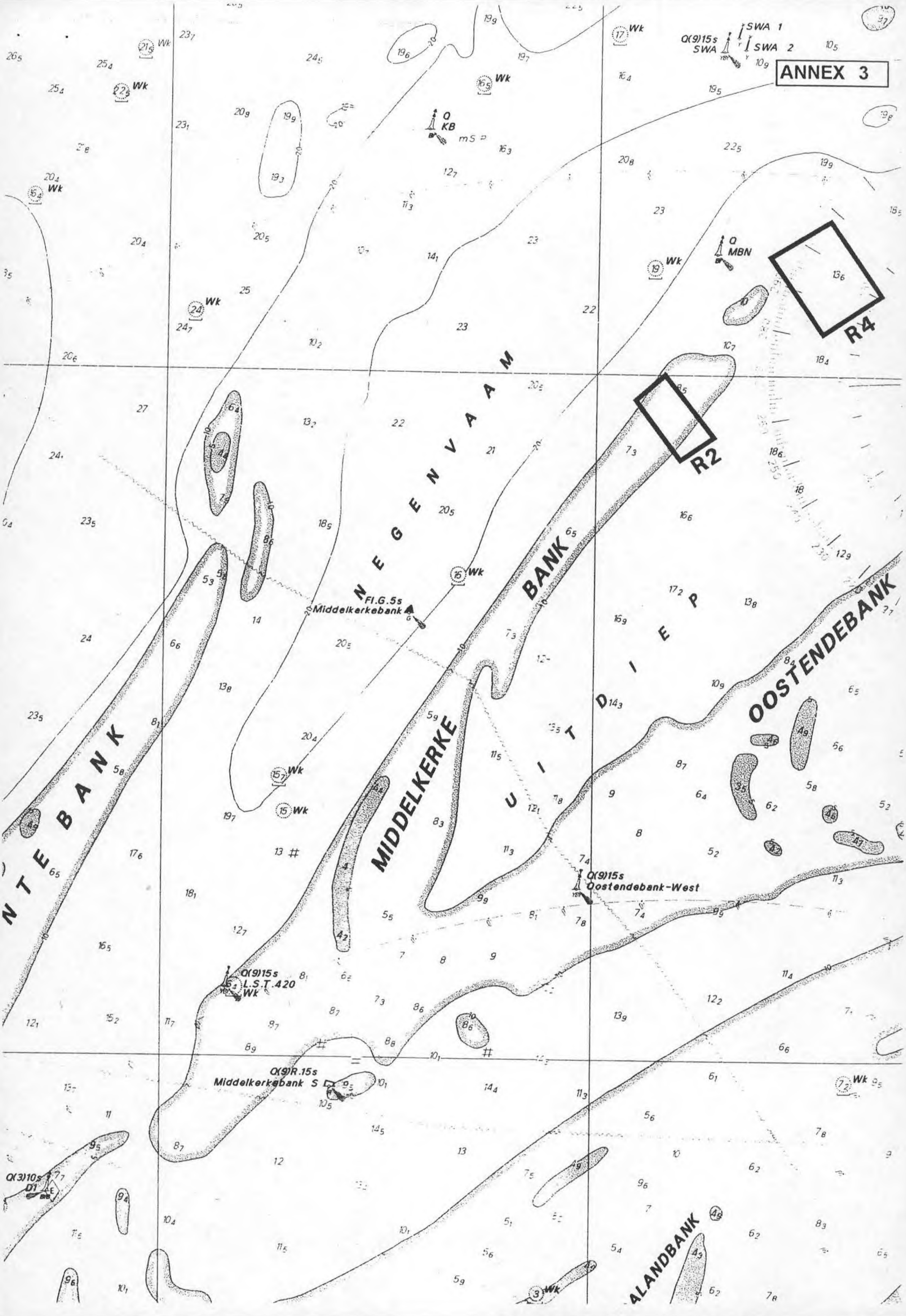
SIMRAD Mermaid: Data Logging System, operating on a UNIX workstation
Simrad Merlin : Real-time software system for capture and visualisation of the multibeam echo sounder data, also operating on a UNIX workstation

ANNEX 3



Q(9)15s
SWA
SWA 1
SWA 2
Q
KB
Q
MBN
R4
R2
NEGENVAAM
MIDDELKERKE BANK
UITDIEP
OOSTENDEBANK
NTE BANK
Fl.G.5s
Middelkerkebank
Q(9)15s
Oostendebank-West
Q(9)15s
L.S.T.420
Wk
Q(9)R.15s
Middelkerkebank S
Q(3)10s
D1
ALANDBANK

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ANNEX 4

MS TER STREEP

DATES OF THE MEASUREMENTS

STARFISH - PROJECT: MIDDELKERKE BANK

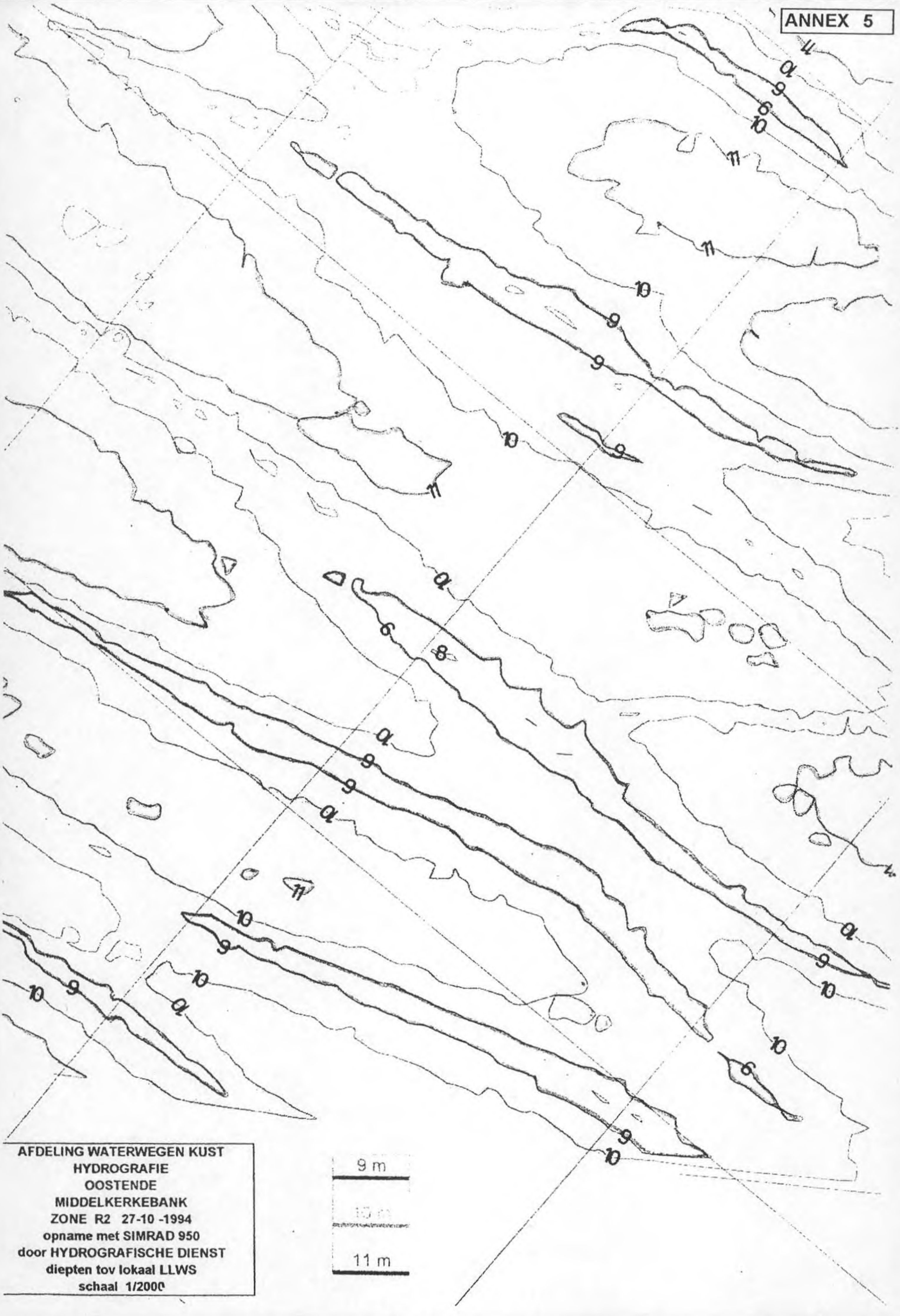
CHRONOSEQUENTIAL MULTI-BEAM SURVEYS

NUMBER OF THE SURVEY	DATES FOR R2	DATES FOR R4	WHO DID IT?
1	20/04/94	21/04/94	RWS-Meetdienst Vlissingen
2	24/08/94	24/08/94	Idem
3	27/10/94	07/11/94	Afdeling Waterwegen Kust-Hydrografie
4	16/01/95	19/01/95	Idem
5	24/03/95	23/03/95	Idem
6	02/05/95	03/05/95	Idem
7	27/06/95	21/06/95	Idem
8	22/08/95	22/08/95	Idem
9	04/10/95	03/10/95	Idem

SINGLE-BEAM AND MULTI-BEAM SURVEYS

NUMBER OF THE DAYS	DATES	WHO DID IT?
1	20/07/95	Afdeling Waterwegen Kust-Hydrografie
2	31/07/95	Idem
3	11/08/95	Idem
4	22/08/95	Idem
5	23/08/95	Idem
6	24/08/95	Idem
7	5/09/95	Idem
8	6/09/95	Idem
9	7/09/95	Idem
10	14/09/95	Idem
11	2/10/95	Idem
12	4/10/95	Idem
13	5/10/95	Idem
14	6/10/95	Idem

ANNEX 5

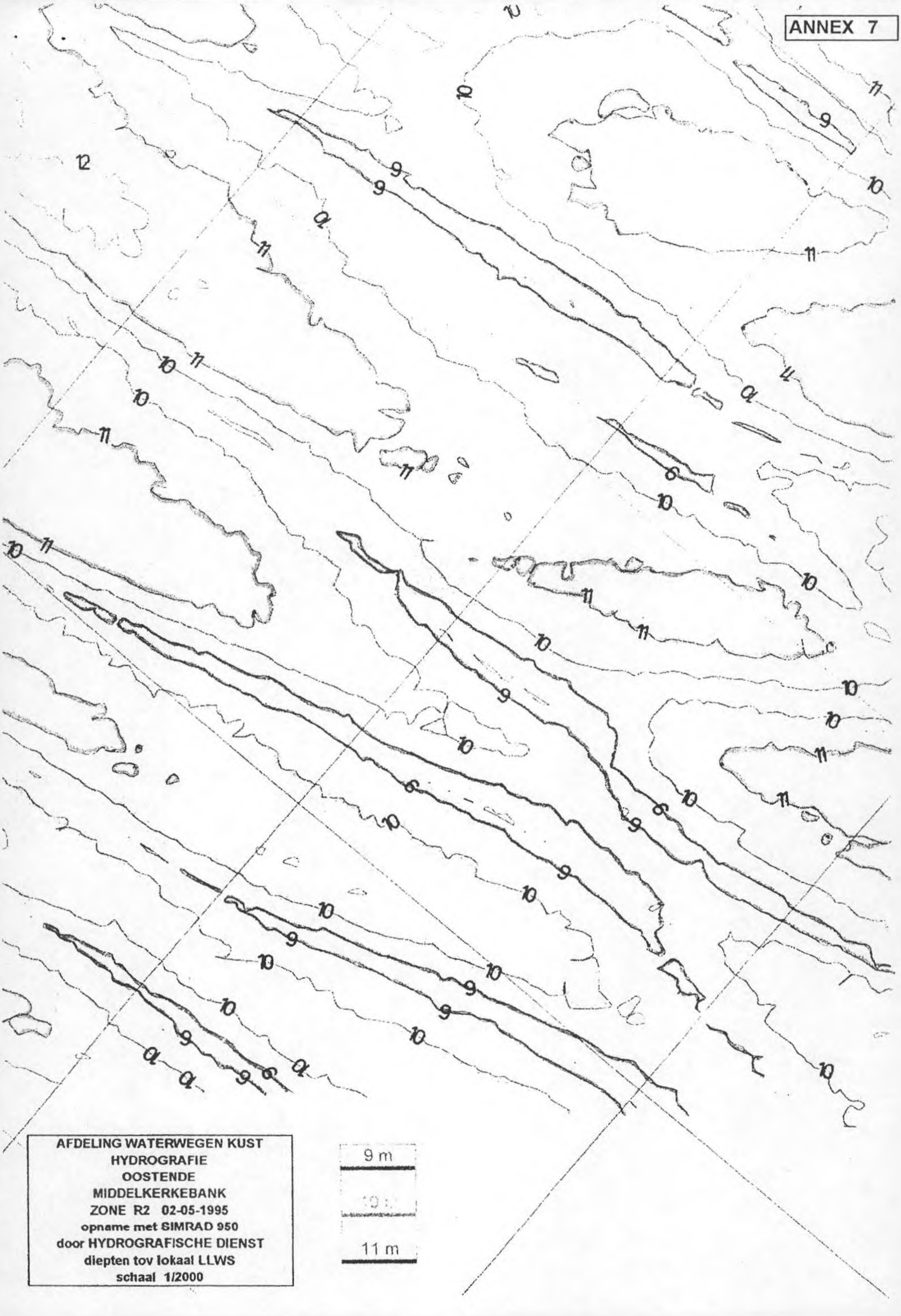


AFDELING WATERWEGEN KUST
HYDROGRAFIE
OOSTENDE
MIDDELKERKEBANK
ZONE R2 27-10 -1994
opname met SIMRAD 950
door HYDROGRAFISCHE DIENST
diepten tov lokaal LLWS
schaal 1/2000

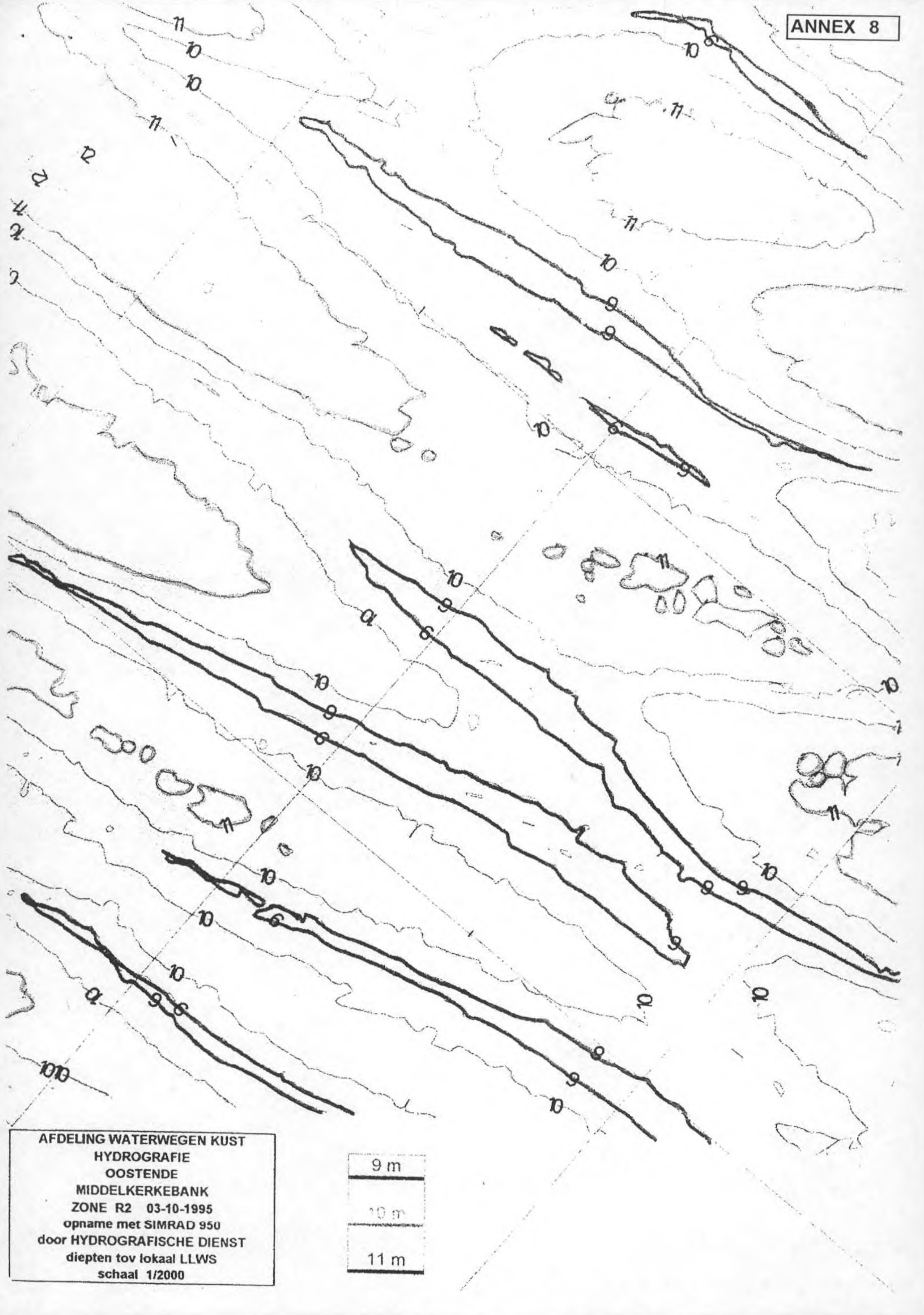
ANNEX 6

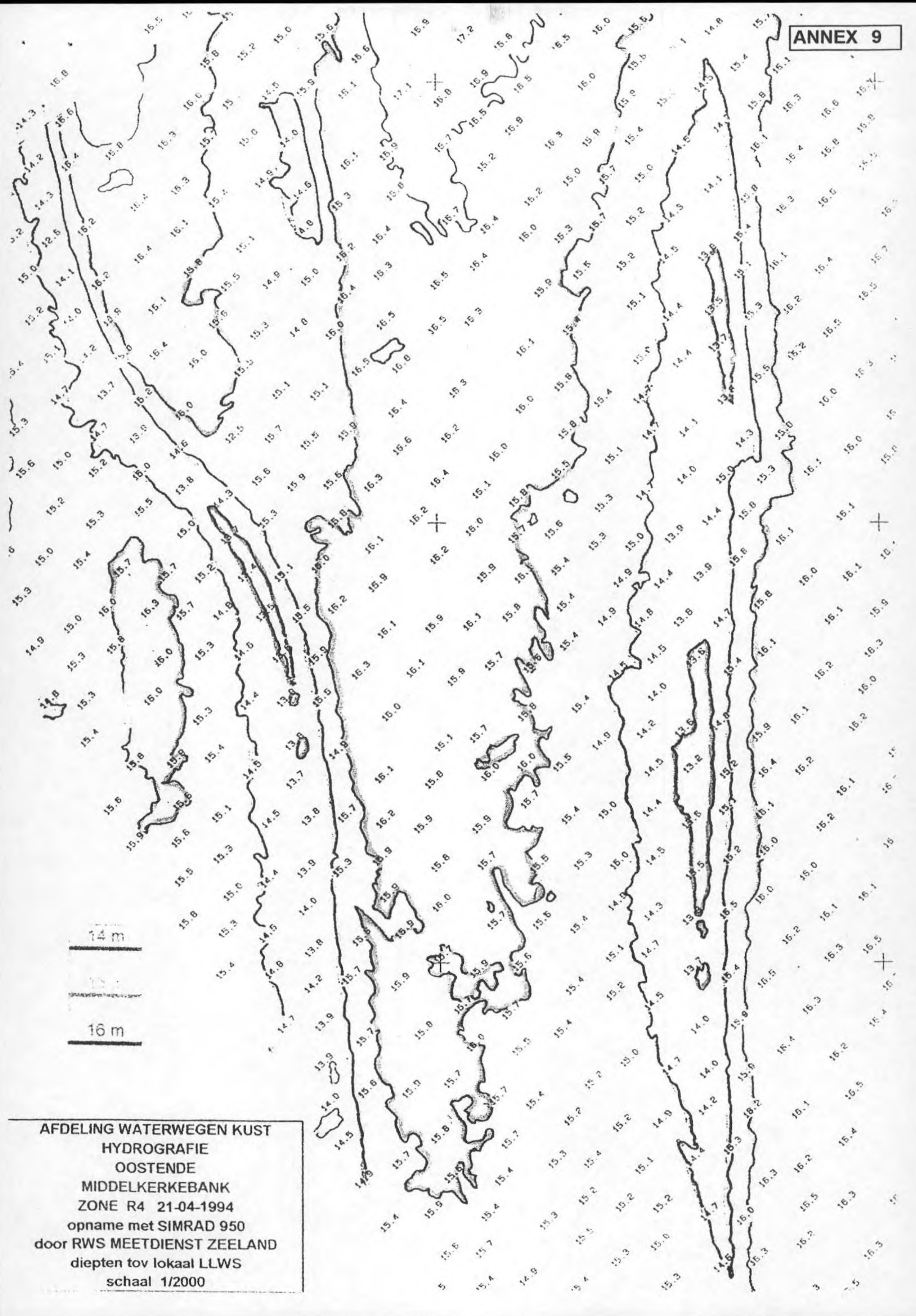
AFDELING WATERWEGEN KUST
HYDROGRAFIE
OOSTENDE
MIDDELKERKEBANK
ZONE R2 24-03-1995
opname met SIMRAD 950
door HYDROGRAFISCHE DIENST
diepten tov lokaal LLWS
schaal 1/2000

ANNEX 7

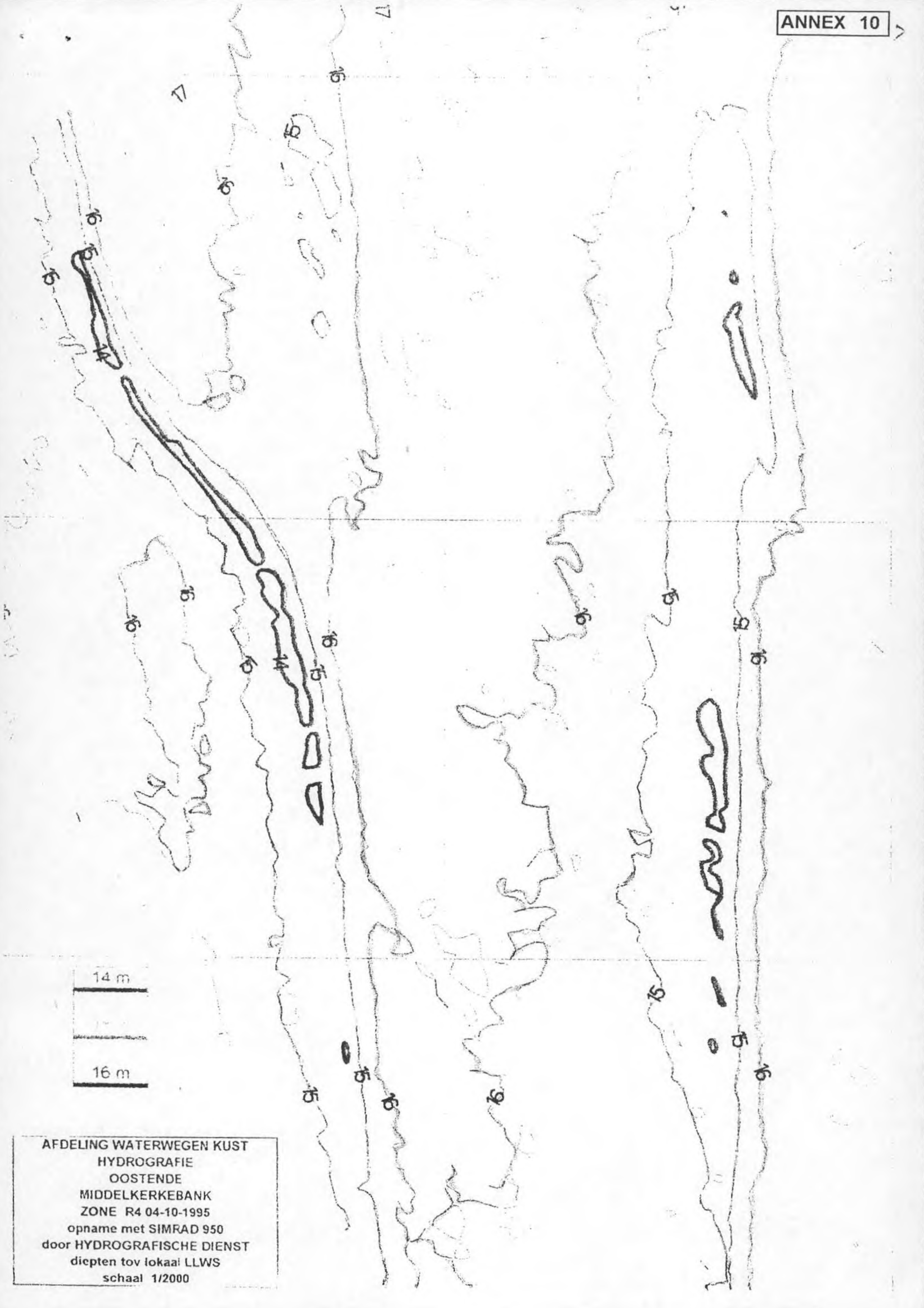

AFDELING WATERWEGEN KUST
HYDROGRAFIE
OOSTENDE
MIDDELKERKEBANK
ZONE R2 02-05-1995
opname met SIMRAD 950
door HYDROGRAFISCHE DIENST
diepten tov lokaal LLWS
schaal 1/2000
9 m
11 m

ANNEX 8


AFDELING WATERWEGEN KUST
HYDROGRAFIE
OOSTENDE
MIDDELKERKEBANK
ZONE R2 03-10-1995
opname met SIMRAD 950
door HYDROGRAFISCHE DIENST
diepten tov lokaal LLWS
schaal 1/2000
9 m
10 m
11 m


ANNEX 9
14 m
16 m
AFDELING WATERWEGEN KUST
HYDROGRAFIE
OOSTENDE
MIDDELKERKEBANK
ZONE R4 21-04-1994
opname met SIMRAD 950
door RWS MEETDIENST ZEELAND
diepten tov lokaal LLWS
schaal 1/2000

ANNEX 10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16 m
AFDELING WATERWEGEN KUST
HYDROGRAFIE
OOSTENDE
MIDDELKERKEBANK
ZONE R4 04-10-1995
opname met SIMRAD 950
door HYDROGRAFISCHE DIENST
diepten tov lokaal LLWS
schaal 1/2000