Institute of Coastal Oceanography and Tides

Report on the Wash barrage desk study

A proposal to build a barrier in the Wash has initiated a study of the associated effects on the tidal regime by means of a hydrodynamical numerical model. Interest is centred on possible changes in tidal amplitudes which might necessitate some strengthening of coastal defences along the Norfolk and Lincolnshire coasts.

In view of the limited time and resources available it was decided that a numerical model based on the linearised equations of motion of the sea should be used. The non-linear terms in the equations of motion may be neglected if $\zeta \ll h$, where ζ denotes elevation above the mean surface and h depth. Non-linear effects are thus more important in shallow water. Linear solutions, however, are less complicated and should give an adequate indication of barrier effects.

The numerical model

The numerical model developed by Flather (Ph.D. Thesis - to be published) was chosen for the investigation. The model is general in the sense that any sea area and depth distribution may be represented.

The differential equations of motion and continuity are replaced by finite difference approximations which are to be solved for ζ , u and v at a discrete set of points in the sea area (the grid) and at a discrete set of times $t = n\Delta t$, where u and v are components of the vertically integrated current and Δt the timestep. The difference equations are such that ζ, u, v at time $(n+1)\Delta t$ are deduced from ζ , u, v at time $n\Delta t$, so that, given ζ , u, v at appropriate grid points at time $t = 0$, their values at subsequent times $t = \Delta t$, $2\Delta t$, $3\Delta t$, etc. may be found by repeated solution of the difference equations.

The finite-difference grid used for the Wash region is shown in fig. 1, with the representation of the land boundary and barrier locations. In choosing the grid it is necessary to compromise in such a way that the grid-spacing gives sufficient resolution to allow an adequate representation of the land boundaries and barrier locations in the Wash, whilst ensuring that the seaward boundaries are at a sufficient distance for the assumption that conditions there remain unaffected by the introduction of the barrier to be valid, and that the number of grid points remains within reasonable limits.

Along the coastal boundary a condition of zero normal flow is applied; on the seaward boundary tidal elevation is specified as a function of time. The M_2 constituent only was considered.

Data required for the model program consists of

i) various parameters such as friction and coriolis appropriate to the sea area, dimensions of the array of grid points, grid spacing, timestep, etc.;

ii) an array of labels defining the shape of the sea area;

iii) the array of depths below mean sea level shown in table 1 (provided by Binnie and Partners and assumed to be unaffected by the presence of the barriers);

iv) the tidal constants for the M_2 constituent at all points on the seaward boundary (obtained from charts);

v) arrays of zero initial values of ζ , u, v.

Three runs were carried out for the cases

1. no barrier;

2. barrier C;

3. barrier B.

The procedure for each case was to run the model program, starting from zero initial conditions, until the periodic regime was established, when a second program was used to find amplitude and phase of the constituent at each grid point. In addition the arrays ζ , u and v were printed out every 10 timesteps (1862 seconds) over the final period.

Grid points used for comparison and referred to in the text are shown on fig. 2.

Run 1) :- No barrier.

The periodic regime is established when elevations at the same stage in the tidal cycle are equal. It can be seen from fig. 3, in which elevations at the time of high water at Greenwich and 1/4 period later are plotted for each of three grid points and for five tidal cycles, that this occurs after about 720 timesteps which is 3 periods of M_2.

Tables 2 and 3 show a comparison between amplitudes and phases taken from chart and model; table 2 refers to points in the centre of the sea area, table 3 to points along the coast. In general, the model reproduces the situation, as deduced from the chart, less accurately in shallow water, as would be expected. An extreme case is point 424 at which the effective depth is 1/4 metre. It does, however, provide an adequate basis for comparison with subsequent runs in the context of the present study.

Runs 2) & 3) :- Barriers C and B.

The changes in amplitude obtained from the model on the introduction of these barriers are shown in figs. 4a and 4b, which refer to points along the coast north and south of the Wash respectively. It should be noted that the horizontal scale on these figures does not represent distance.

It can be seen that C produces an increase in amplitude of order 2% and B produces a decrease of order $3\frac{1}{2}$% in the vicinity of the respective barriers.

Both C and B produce decreases in phase of the constituent of order 8° and 11° respectively, which represents time shifts of 16 mins. and 22 mins. respectively in the tidal cycles.

Conclusion

The presence of a barrier seems unlikely to produce substantial changes in the tidal regime in the area of the Wash. It should be stressed, however, that the model used is linear and contains many other assumptions. The conclusion reached would need to be confirmed in due course by a considerably longer, more sophisticated and more expensive study.

Tidal amplitudes in the case of barrier C, which represents the most feasible location on economic grounds, are practically unaffected. A more seaward location may produce a slight decrease in amplitude in the immediate neighbourhood of the barrier.

The region in which the largest increase in tidal amplitude might result is along the south-eastern coast of the Wash and the north coast of Norfolk.

Acknowledgements

I am indebted to members of the staff of the Institute of Coastal Oceanography and Tides for their assistance. My thanks are due in particular to Dr. M. Laska for his helpful advice and for the excellent diagrams and to Dr. J.R. Rossiter, Director of the Institute, for his valued guidance throughout the project.

Bidston Observatory,
11th December, 1969.

R.A. Flather.

													5	10	30	44	39	58	61	70	67
												0	16	25	49	47	53	56	61	65	63
												6	19	29	49	49	51	54	60	56	50
											0	8	23	38	51	51	53	52	54	50	39
										5	0	12	23	40	46	46	49	47	48	50	41
										7	9	14	27	36	40	44	50	50	39	39	49
									0	5	10	21	21	31	33	38	45	49	43	46	54
									4	10	12	18	20	25	33	32	39	41	41	52	54
								0	8	14	16	34	34	47	28	30	28	36	38	41	52
				0	4	0	0	7	12	12	23	18	21	20	27	28	28	30	34	41	43
				0	5	10	10	20	25	19	25	14	18	16	19	21	28	28	34	38	34
				0	1	12	12	10	8	12	19	18	17	13	19	17	23	46	29	28	36
				0	0	0	4	6	10	12	15	21	22	21	19	19	23	19	23	30	30
								5	10	18	20	25	15	21	21	19	45	25	28	38	27
									10	18	23	21	21	21	21	25	37	27	37	28	23
									4	18	19	21	19	19	28	24	37	25	28	28	23
										8	23	27	25	23	28	27	27	21	28	23	23
										8	18	27	34	30	21	34	21	21	23	21	21
										8	10	24	36	30	16	17	19	19	19	19	23
										13	21	19	25	32	21	19	19	23	21	25	25
									2	14	26	21	23	38	38	19	28	19	23	27	28
								0	8	17	21	23	27	41	38	21	25	28	30	25	28
					0	0	3	11	19	19	23	23	27	45	36	27	32	39	30	28	28
0	0	0	0	0	8	12	23	28	25	21	32	28	33	38	37	37	31	33	31	31	29
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2	14	23	21	25	32	30	34	36	39	39	46	43	40	35	35	35	35	29	26	27	26
0	21	36	34	24	30	33	43	38	41	40	46	42	40	35	31	27	27	24	25	29	26
9	39	46	32	28	34	39	39	51	37	42	38	38	40	40	27	26	24	24	27	29	26
3	41	23	32	41	43	52	49	41	37	40	37	35	33	33	33	27	33	23	26	29	27
0	32	39	47	47	49	40	39	39	38	44	35	31	33	37	33	29	22	27	26	27	28
[illegible]	41	41	45	41	47	40	41	39	38	38	38	33	33	38	31	22	29	29	27	28	29
0	34	36	36	39	36	36	39	38	41	39	32	33	31	27	20	27	27	28	28	29	30

Table 1.
Depths used in model, measured in metres below mean sea level.

Table 2. Comparison of amplitudes and phases obtained from chart and model within the sea area.

POINT NUMBER	DEPTH h METRES	AMPLITUDES IN CMS.		$H_c - H_M$ CMS.	PHASES IN DEGREES		$g_c - g_M$ DEGREES
		CHART H_c	MODEL H_M		CHART g_c	MODEL g_M	
634	51·0	157	154·9	2·1	128	127·5	0·5
567	38·75	158	157·3	0·7	140	137·8	2·2
500	30·5	157	156·2	0·8	150	149·9	0·1
434	18·0	149	136·3	12·7	164	164·1	-0·1
368	22·25	130	115·1	14·9	180	175·8	4·2
302	24·25	90	88·0	2·0	203	185·6	17·4
236	38·75	65	53·6	11·4	231	201·2	29·8
170	37·5	40	28·0	12·0	265	216·3	48·7
104	33·25	23	3·5	19·5	310	249·5	60·5
101	41·0	35	17·8	17·2	328	323·7	4·3
98	41·75	52	40·2	11·8	333	332·4	0·6
95	34·0	71	65·3	5·7	333	334·1	-1·1
92	37·0	97	95·4	1·6	334	337·0	-3·0

Table 3. Comparison of amplitudes and phases obtained from chart and model along the coast.

POINT	DEPTH	AMPLITUDES IN CMS.		$H_c - H_M$	PHASES IN DEGREES		$g_c - g_M$
NUMBER	h METRES	CHART H_c	MODEL H_M	CMS.	CHART g_c	MODEL g_M	DEGREES
607	5·0	195	183·9	11·1	145	134·2	10·8
562	7·75	210	187·7	22·3	150	144·4	5·6
517	9·0	212	186·1	25·9	157	155·1	1·9
494	6·75	215	188·1	26·9	162	162·5	-0·5
471	9·25	220	191·5	28·5	167	170·2	-3·2
468	2·25	242	207·7	34·3	177	193·0	-16·0
424	0·25	245	44·8	200·2	183	271·0	-88·0
427	8·0	214	187·3	26·7	172	174·9	-2·9
406	7·75	197	172·7	24·3	174	174·5	-0·5
385	14·0	181	155·1	25·9	179	175·9	3·1
364	19·5	162	142·6	19·4	185	178·5	6·5
298	11·0	120	118·0	2·0	208	191·6	16·4
254	18·5	88	83·6	4·4	230	206·7	23·3
209	15·75	67	52·5	14·5	256	239·0	17·0
184	9·5	72	51·9	20·1	280	294·3	-14·3
159	6·75	93	74·0	19·0	304	318·0	-14·0

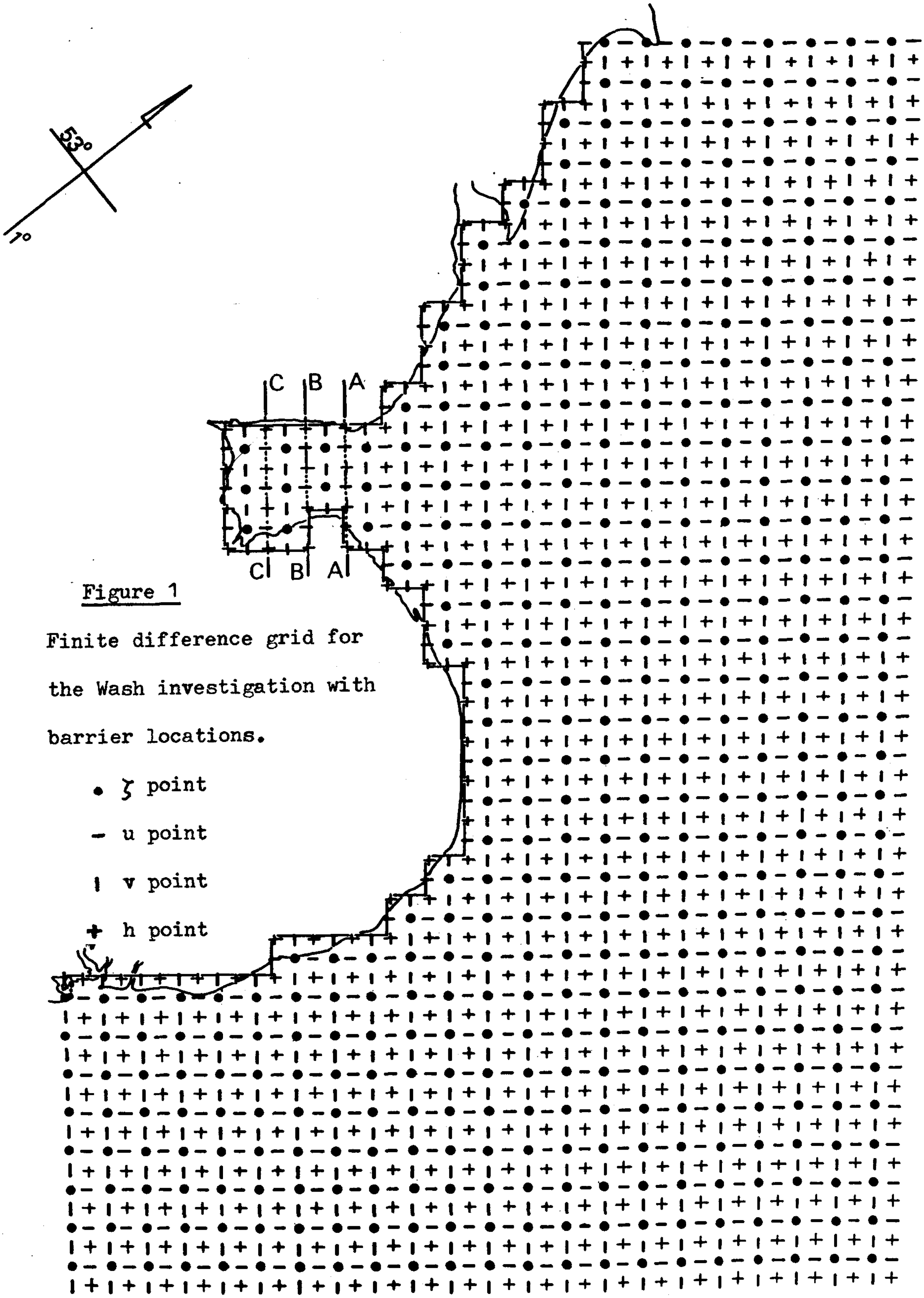

Figure 1

Finite difference grid for the Wash investigation with barrier locations.

- • ζ point
- – u point
- ı v point
- + h point

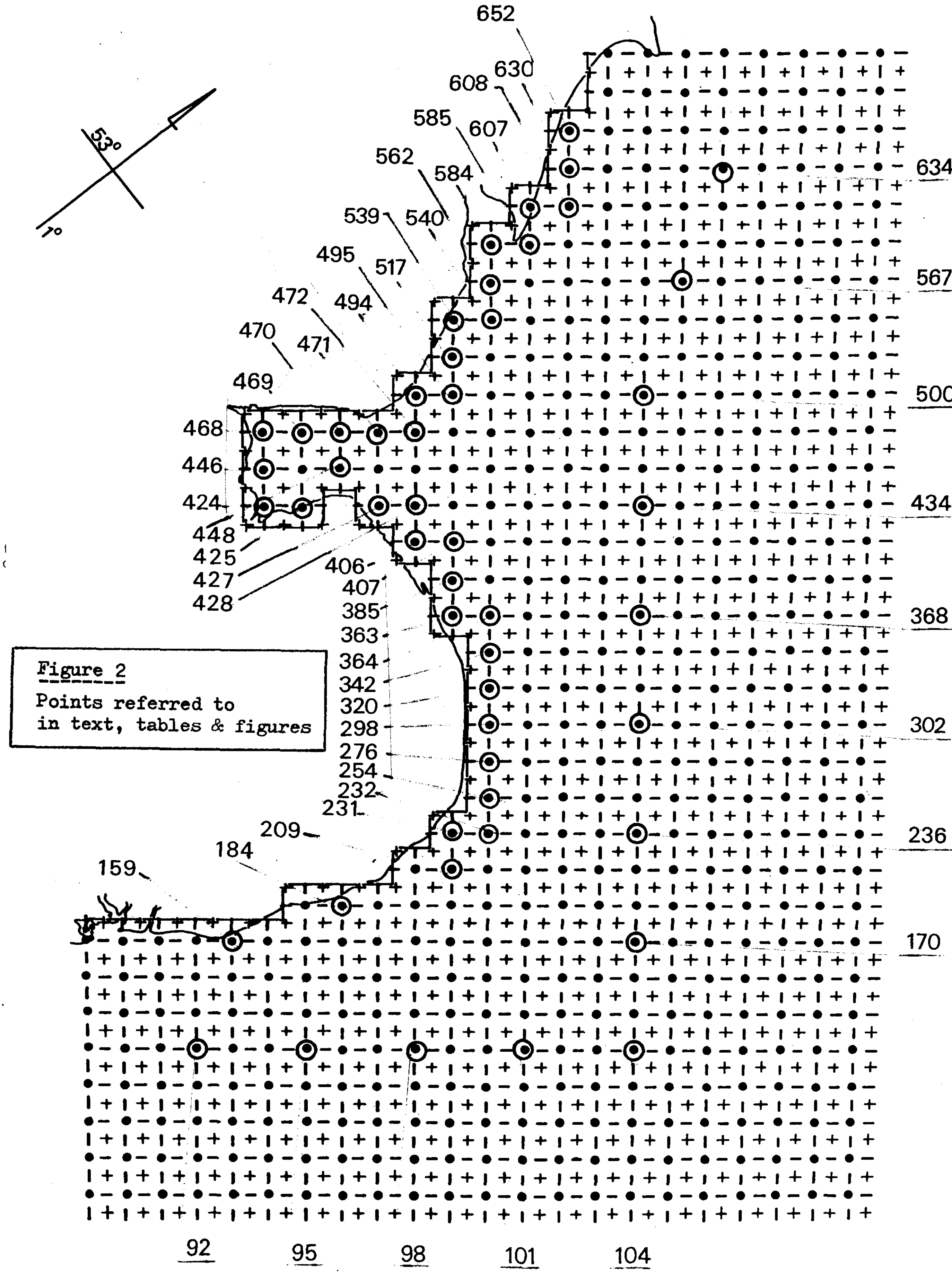

Figure 2

Points referred to in text, tables & figures

Figure 3

Development of periodic regime (points; 363, 468, 539)

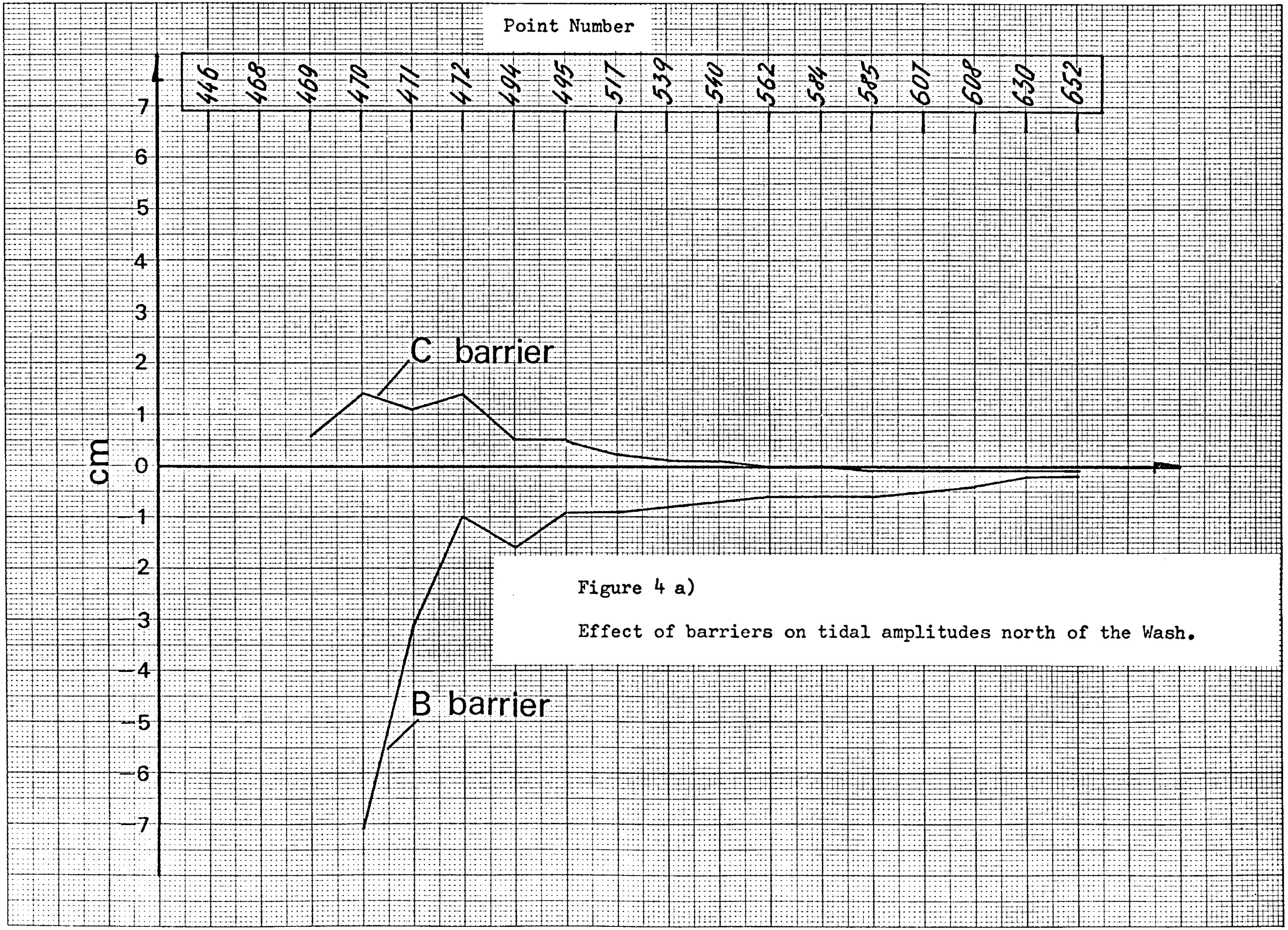

Figure 4 a)

Effect of barriers on tidal amplitudes north of the Wash.

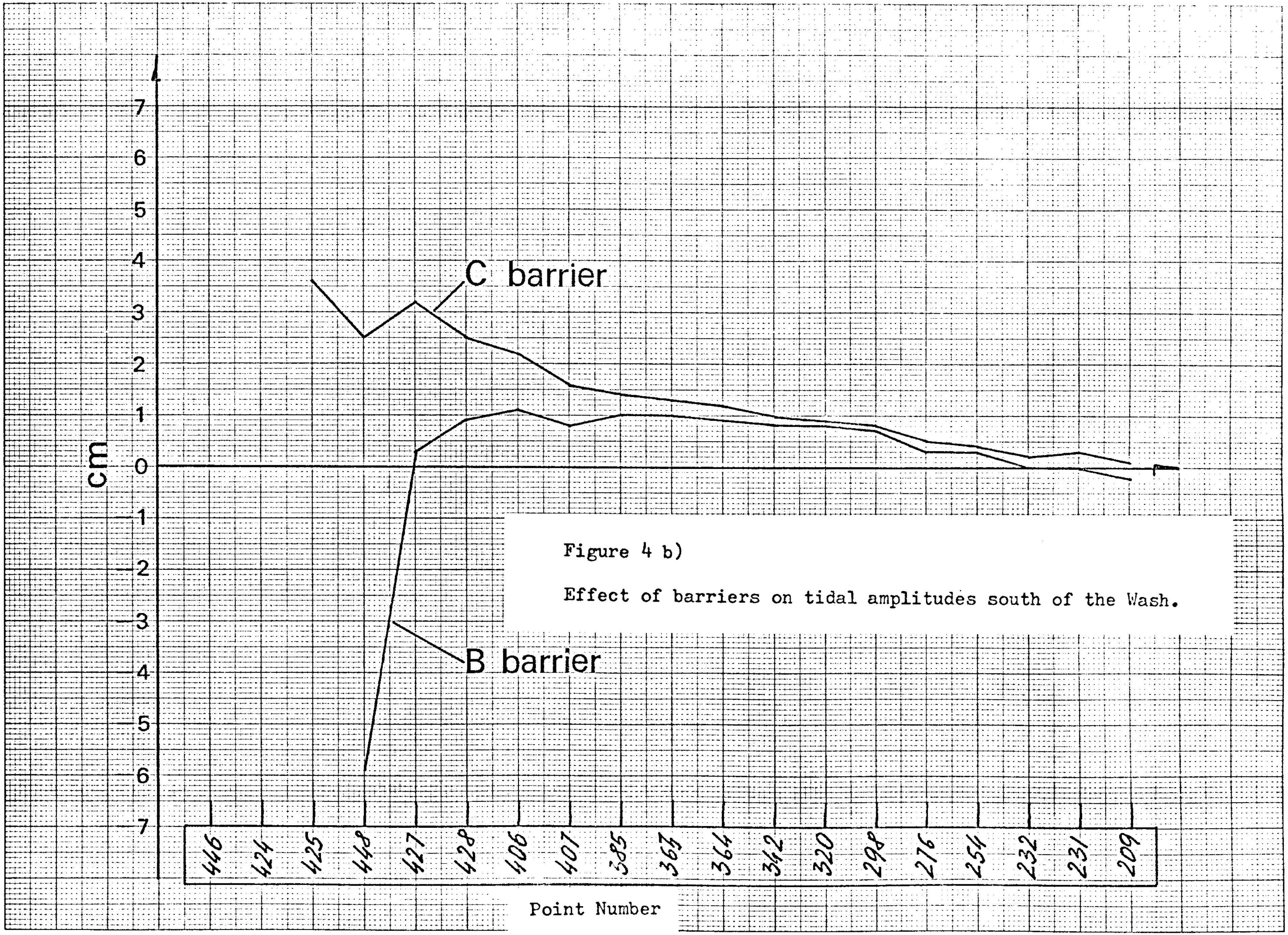

Figure 4 b)

Effect of barriers on tidal amplitudes south of the Wash.

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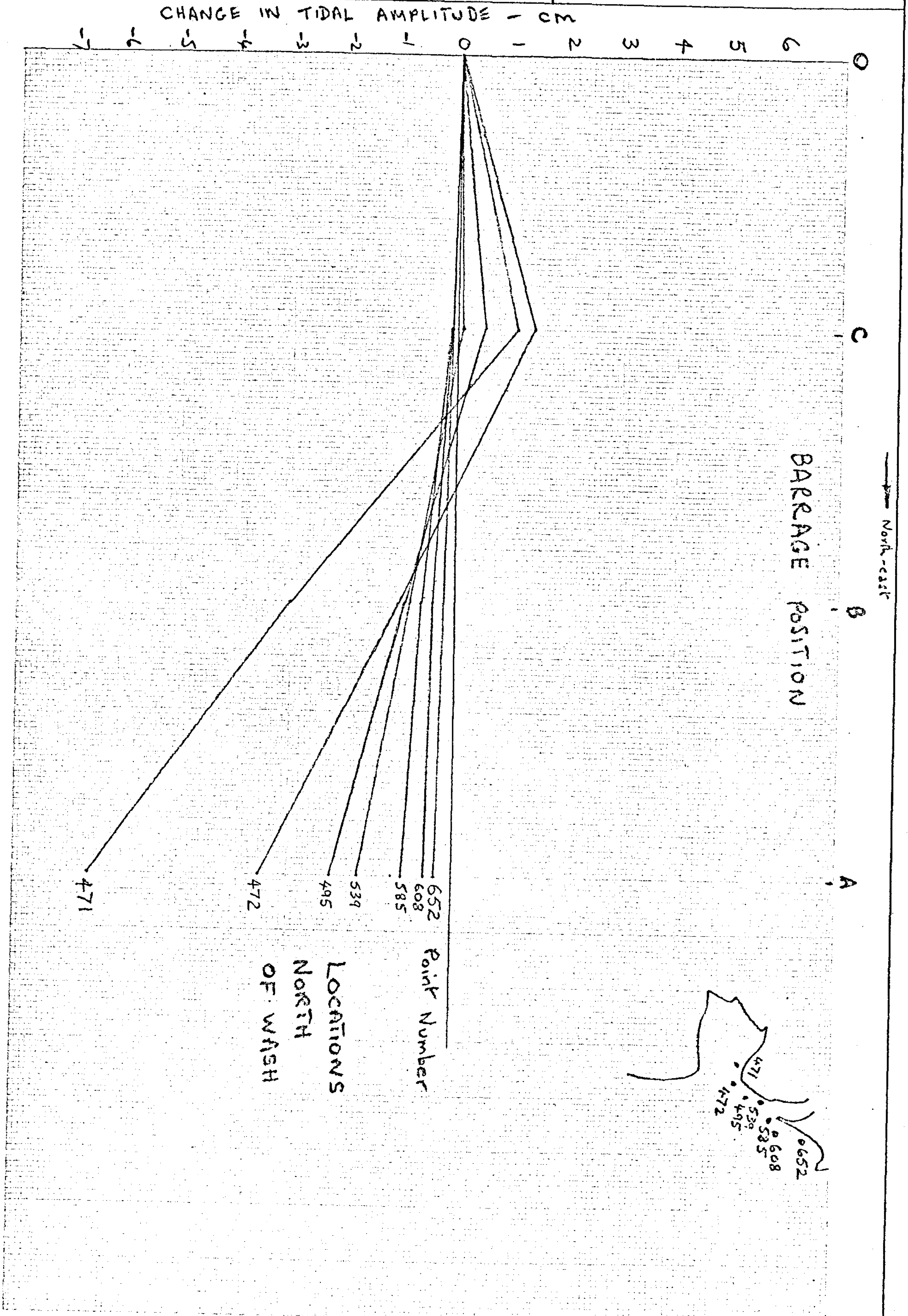
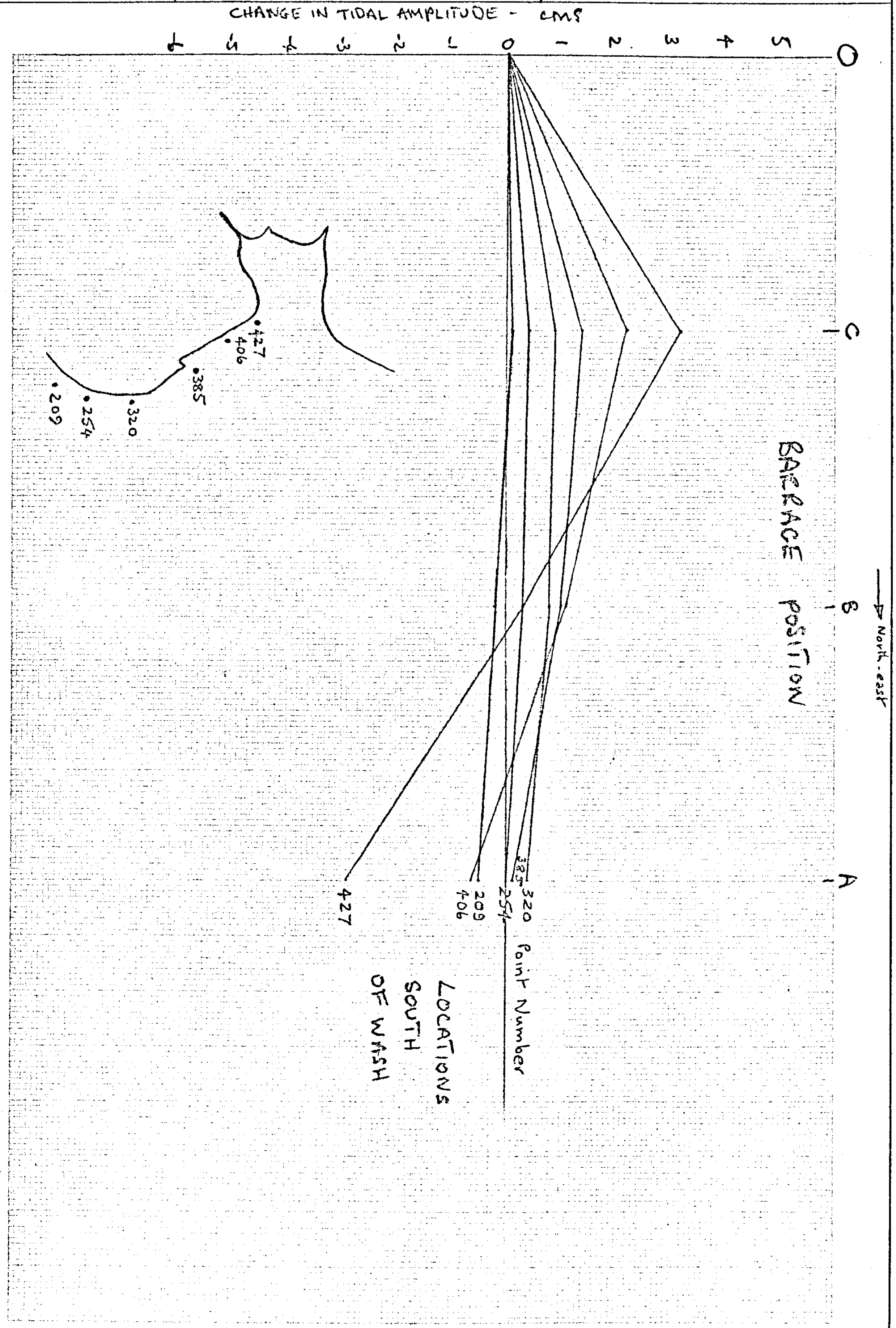


Form No. 143

BINNIE & PARTNERS WESTMINSTER LONDON, S.W.1	Subject Effect of barrage position on tidal amplitudes Computed CH Chkd.	Job Wash BDS Job No. 693-01 Date Jan 1970 Page 2 of 2 pages



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Supplement to the report on the Wash barrage desk study

Run 4) :- Barrier A.

Figs. 4a and 4b have been amended to include the changes in amplitude at coastal points resulting from the introduction of barrier A.

It can be seen that the most seaward barrier location produces a further decrease in amplitude at all points in comparison with locations B and C. Increases in amplitude are of order ½% or less over the no barrier case and occur only on the north and north-east coasts of Norfolk, between Hunstanton and Great Yarmouth.

The phase of the constituent shows a corresponding decrease indicating a larger time shift than B or C.

From the results shown on figs. 4a and 4b it is now possible to plot graphs showing the effect of barrier location on tidal amplitude at the various points along the coast. Since only four points may be plotted in each case, corresponding to the four runs carried out, and in view of the approximate nature of the model, no firm conclusion may be drawn. However the indications are that a location slightly to the south-west of C might produce the greatest increases in amplitude.

Bidston Observatory,

6th January, 1970. R.A. Flather.

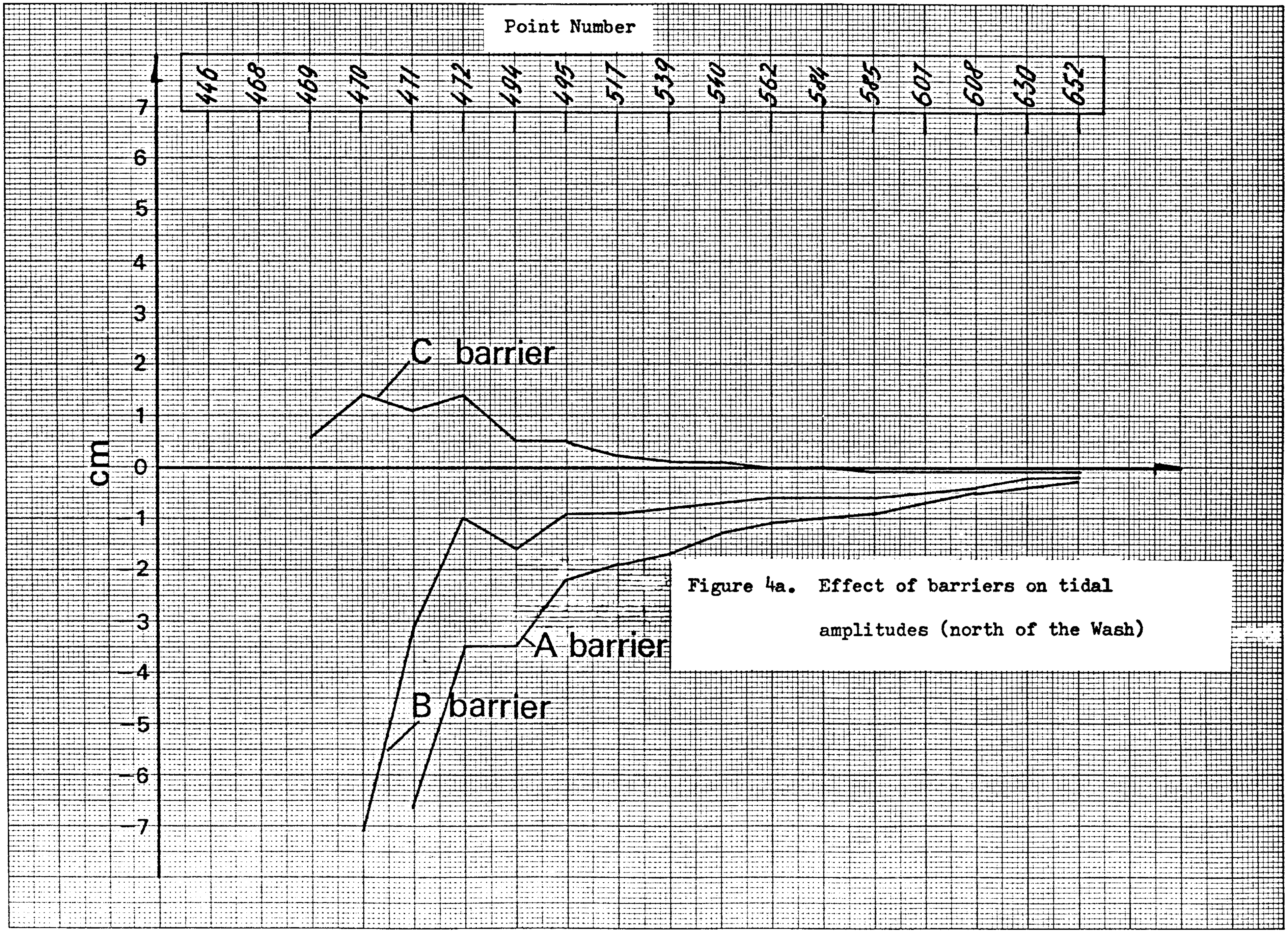

Figure 4a. Effect of barriers on tidal amplitudes (north of the Wash)

WELL Graph Data Ref. 5501 mm, ½ and 1 cm

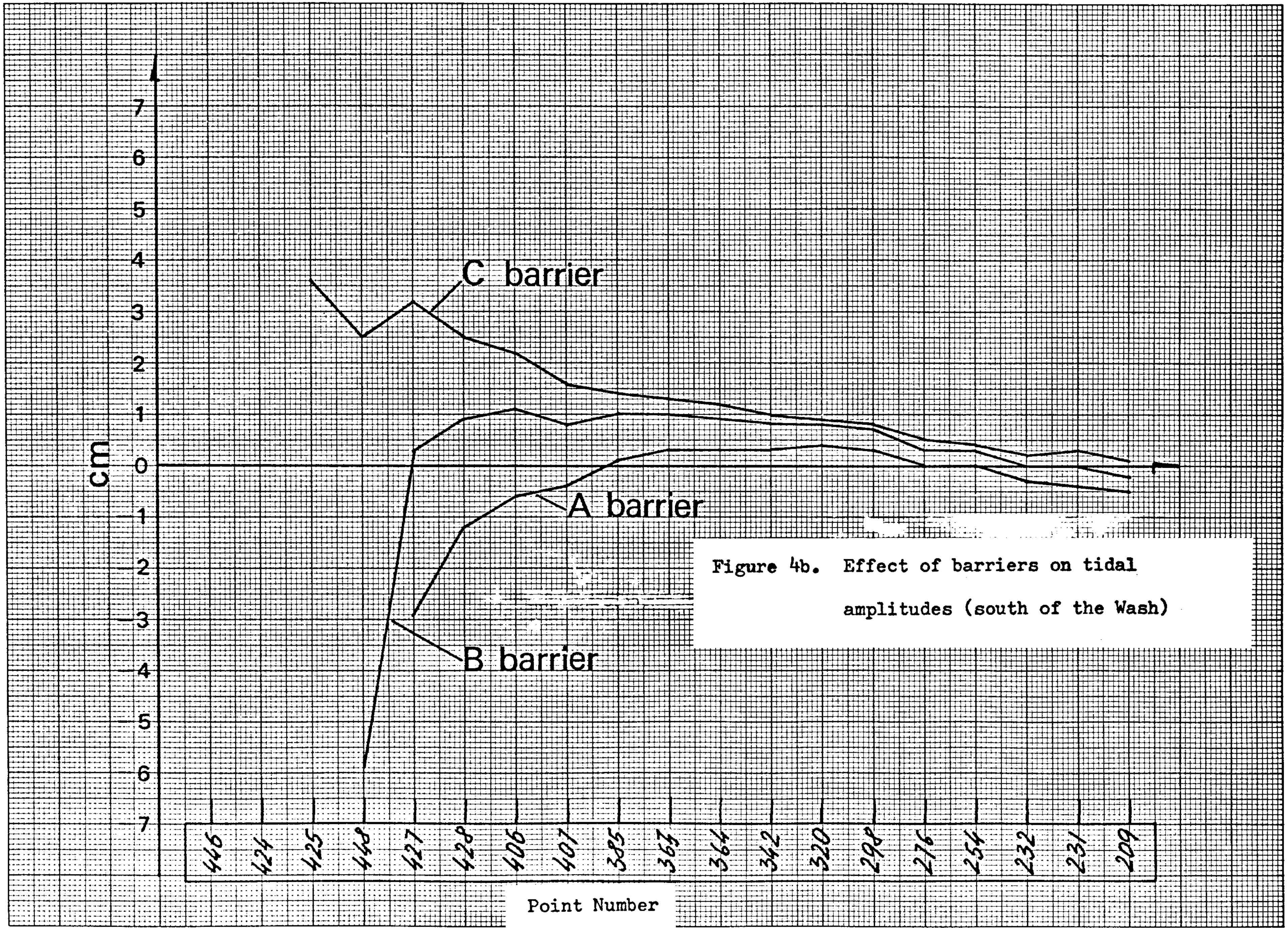

Figure 4b. Effect of barriers on tidal amplitudes (south of the Wash)