INTERNATIONAL LOW WATER

By Rear Admiral PHAFF, Director

THE resolution on the subject of the reduction of soundings adopted at the London Conference of 1919 reads as follows :

" Tidal datum should be the same as chart datum, and should be a plane so low that the tide will not frequently fall below it.

" It is greatly to be desired that a uniform datum plane should be adopted by all nations, and the following rule is suggested for the further consideration of Hydrographers for a universal datum plane, which should be called " International low water ".

" That the plane of reference below mean sea level shall be determined as follows : " Take 1/2 the range between mean lower low water and mean higher high water and multiply this 1/2 range by 1.5. "

" Higher high water " and " lower low water " refer to the higher and lower of levels of the two states of tide which occur in 24 lunar hours ; these are exclusively inherent to *one* tidal system, being a combination of a preponderant semidiurnal tide and subordinate diurnal tide, and thus it is impossible to derive from them the basis for a general rule.

In order to investigate the requirements of a general rule for the establishment of the level for reduction of soundings, it is not sufficient to examine theoretically and practically the various systems of tides, but the wants of the seaman and the methods of the hydrographer also should be taken into account.

If the tides, even at one place, were invariably the same, the height of the level of reduction would be practically immaterial, provided that it could be accurately established. In order to get, at a given moment, the correction which should be applied to a sounding shown on the chart, it would be sufficient to consult a diagram deduced from the tidal observations made and in which the level of reduction is inserted. It would be best to select a level which demands but few and, for preference small negative corrections.

However, the tides are anything but invariably the same at a place. Although the movements of a simple tidal system may be more or less uniform when the general features are considered, the series of diagrams which should be consulted would be a lengthy one on account of the numerous and more or less irregular variations of amplitude and time which the tides show when they are examined in detail. This fact causes this method to be inapplicable to a simple system and still more so to a complicated tide.

In the first place the seaman wishes to be informed as to the minimum depth at a certain place without having to apply frequent or large corrections. For this reason it is obviously best to reduce the soundings to a level which is connected with low water but, since there are many of these levels, it should be clearly stated in each case which level is adopted.

Besides being restricted by the condition mentioned, the choice of this level is limited by the requirements that it shall vary but little from one year to an other and that it may be deduced accurately and without difficulty in practice from a series of observations and, for preference, theoretically from the harmonic constants at every place, whatever the tidal systems be. For these reasons it is evident that a natural level, which meets all these requirements, should be chosen rather than an arbitrary level which depends on accidental and, as a rule, meteorological conditions and which cannot be deduced from the harmonic constants.

Natural levels are those of :

(1) Mean low water,
(2) Mean low water springs,
(3) Mean solsticial or equinoxial springs,
(4) Mean equinoxial springs at perigee,
(5) The lowest low tide.

Arbitrary levels may be called : the mean of the monthly lowest low water springs, the mean of the monthly lowest low tides, etc.

If the harmonic constants be given of a place where the diurnal or the semidiurnal tide is very preponderant, it will be possible to establish theoretically levels (1), (2), (3) and (4), which will be found to be below mean sea level (W) at :

(*) (1) the amplitude of K_1, or M_2,

(*) Amplitude is the rise above or the fall below mean sea level.

(2) the amplitude of $K_1 + O$ or $M_2 + S_2$,
(3) ,, ,, ,, $K_1 + O + P$ or $M_2 + S_2 + K_2$
(4) ,, ,, ,, $M_2 + S_2 + N_2 + K_2$

Level (5) can be established by observation only.

It is very important that the level of reduction should be easily and accurately defined practically and theoretically. During an extensive survey the hydrographic surveyor will always have the opportunity to collate a series of observations made at a tide gauge during at least one month and, by the method of approximation, these observations will enable him to deduce, within certain limits of accuracy, the constants of the principal constituents of the tide. From these constants he can deduce the tidal system of the coast which is to be surveyed, choose the level for reduction which is suitable to this system and establish a provisional level which allows of the rough sounding sheet to be begun on board at once. If later on, when a more complete knowledge of the constants is reached, the definitely established level of reduction differs considerably from that provisionally adopted, it is but necessary to apply a uniform factor of correction to all the depths already entered on the sounding sheet. As a rule the difference is so small that no correction is required.

This method of procedure makes for economy in time which has the more weight because it allows the sounding sheet to be continued during the days of weather conditions unfavourable for fieldwork.

If a series of observations, sufficient for the immediate deduction of the data for the establishment of a definite level for reduction, be available at a place, a survey will have been made previously and a level will have been adopted already. The observations of the self registering tide gauge will then serve to check this level and to correct it if required.

If level of reduction (1) be chosen, the theoretical probability of the application of negative corrections will be about 50 % and the amount of these corrections will vary from naught to the amplitude of $O + P$ or $S_2 + N + K_2$. Although these 50 % include numerous cases in which the corrections are but very small, the frequent application thereof, which may amount to a considerable figure, is, as a rule, an objection to the adoption of this level.

If level (2) be adopted, the percentage of negative corrections which should be applied is considerably less and the amount thereof will be limited to the amplitudes of P or $N + K_2$; in the greater number of cases their influence will be but small. The percentage for a diurnal tide will be less than for a semidiurnal because of *N*, which constituent lowers low water springs of the latter system once in 206 days.

Theoretically no negative corrections for a diurnal tide will ensue from the adoption of level (3) and those for a semidiurnal tide will be limited to the amplitude of *N*, low water of which partial tide coincides with equinoxial springs once in 4,5 years only.

Level (4) is applicable to semidiurnal tides only and theoretically no negative corrections will be required.

In order that this combination be included, a series of observations extending over a period of 5 years is required.

In the case of mixed tides, level (1) is not very reliable and levels (2) and (3) cannot be established at all as will be explained below.

In adopting level (5), the mariner will find,—except when atmospheric conditions are still more exceptional than those under which the level has been established—greater, and in general much greater depths than are shown by the soundings on the charts. The necessity for the application of negative corrections is practically excluded and the positive corrections can be divided into two parts, one variable which depends on the tide and another, variable in an inverse direction, which is the result of the concurrence of exceptional conditions, which have lowered the low water level abnormally once only. The latter part is included in every correction unnecessarily.

Besides, the depths in channels and over bars will give an erroneous idea of their navigability and the reduction of soundings to this level may mislead the seaman if banks or rocks, which nearly uncover at normal low water, are to be found near the coast represented. On the chart these dangers will be shown as being visible and the seaman, who trusts to this when navigating, risks the making of mistakes.

These mere theoretical considerations make the adoption of this level inadvisable ; practical reasons militate still more strongly against it.

When reducing soundings to depths which will be shown on the chart, a multiple coefficient of security is always introduced.

In the first place the leadsman who calls the sounding, whether it be obtained by pole or by line, makes a reduction, not only on purpose but also instinctively because he sees the pole or the leadline foreshortened. Next the hydrographic surveyor applies a second coefficient by neglecting some fractions of the unit of measure in substracting the reduction from this sounding and finally the draughtsman introduces a third in applying the special rules which each hydrographic office has established for giving fractions of units below a certain depth.

The total of these manipulations means a diminishing of the real depth which is by no means negligible and thus the hydrographic surveyor has good reasons for not adopting a lower level of reduction than is required, nor to apply an exaggerated reduction (over-reduce his soundings).

As the observation of low water springs may be affected by abnormal conditions, it has been considered preferable to take the mean of this reading and those of the preceding and following low waters. The solsticial (equinoxial) low water springs have been selected as near as possible to 21 June (March) and 21 December (September) ; when these occur about one week before or after these dates, or when they show a notable difference from the preceding or following low water springs, these latter have also been taken into account.

The reliability of a level of reduction depends on the departure from the mean value. The smaller these departures are, or the more regularly the same departures are repeated periodically in the same sequence, the more accurately the level will be defined. For these reasons natural levels are chosen in preference to more or less accidental arbitrary levels which, as already stated, depend for the greater part on atmospheric conditions or on a combination of special circumstances.

Taking into account all these elements, the mean values of the various levels should be deduced from observations made during a period of at least one year for very preponderant diurnal tides and of 5 years for very preponderant semidiurnal and for mixed tides. However, the former period is a minimum only, which, if need be, would be sufficient for regions such as those of the trade-winds or the tropics, where the atmospheric conditions return in regular sequence year after year. It is insufficient for regions in higher latitudes where these levels may differ considerably from one year to another.

The number of constituents and the range of the tide should be taken into account likewise. The more intricate the structure of the tide, the longer the series of observations should be in order to get a trustworthy mean value of the various levels ; for this reason a purely diurnal tide requires the smallest number of observations and a mixed tide embracing shallow water tides the greatest. The greater the amplitude, the smaller the influence of atmospheric disturbance will be and the shorter the series of observations which need be made ; if the amplitude be small, these disturbances will cause considerable departures from the mean for the same level and the number of observations should be great in order to reduce their influence to a minimum.

Lastly, the mean yearly declination of the moon should be taken into account for diurnal and mixed tides. As this declination reaches a maximum and a minimum every 9 1/2 years, a series of observations made over this period would be required, but the influence of these departures from the mean value of the declination on the various levels is small and fairly regular from year to year and approximately corresponds to the theoretical variation of the levels, as expressed in percentage of the amplitudes of the main constituents.

As for mixed tides, the forms of the daily diagrams are so numerous and so variable that even the mean of a great number of observations, *e. g.* mean low water, is not reliable. The combination of the two systems involves the exclusion of a direct connection with the declination of the moon or with its phases, and every observation is simultaneously affected by both phenomena in a constantly varying direction. Therefore a conspicuous point of the daily curves, which returns regularly and in the same way at fairly long intervals, is investigated ; for preference the lowest low tide which can possibly be reached every half year. The moons declination has to be taken into account here also, and this is done as mentioned above.

The percentage of negative corrections which have to be applied to the soundings diminishes in the order assigned to the levels, but it should be realised that the total of these percentages is not a definite measure of the reliability of a level of reduction. The amount of each correction with its number of percentages and with reference to the range of the tide should be taken into account also.

The various percentages of negative corrections are given for each place, the observations of which are elaborated, and those of the positive corrections are added in order to realise the probability of occurrence and of their amount. The maximum percentage of the latter corresponds, for preponderant diurnal and semidiurnal tides, about to mean low water.

Whatever be the system of the tide and the influence of local and other conditions, an accurate establishment of the level of reduction is indispensable to the nautical surveyor as this level is one of the bases of his chart.

In regions where the depths are much beyond the draught of his ship, the seaman does not necessarily require such an extensive knowledge of this level ; it is only in regions where bars are found which he cannot pass at low water that he should be acquainted in detail with this level in order to be able to predict the time at which he can cross these bars.

Even if an earlier notice has informed him that the soundings shown on the chart still indicate the minimum depth on the bar, that the seabottom is not liable to change, so that he can rely nearly implicitly on this datum, and that a tide gauge in the vicinity indicates the rise of the tide, he will not attempt to cross the bar unless there is more water than the ship's draught over it.

But, and this is the normal case, if no former notice to the effect has been issued, he will have to accept the soundings on the chart and to make allowance for possible inaccuracy thereof at that moment; if the seabottom is liable to silting, he will have to take into account that the actual depth may possibly be less than that given; if there be no tide-gauge or if it be not working, he will have to predict the rise, which prediction might not be in accord with the actual rise; besides he will have to take into account the atmospheric and meteorological conditions which affect mean sea level.

Under these circumstances the seaman will have to add to his prediction of the height of the tide an excess of depth, which he must establish with reference to the weather conditions which exist at the moment. For these reasons this excess of depth will sometimes be fairly considerable; special cases excepted, it does not appear excessive to estimate it at not less than 5 dm. (1½ feet).

These considerations make it all the more advisable to adopt a natural level of reduction, not to select a lower level than is required, not to over-reduce soundings and to judge the percentages of negative corrections from a practical standpoint. *So long as the negative corrections which have to be applied are smaller than the excess of depth which the seaman will have to adopt under normal circumstances, the percentages which correspond to these and to smaller corrections may be neglected, even if they be numerous.*

In regions where the seaman is obliged to predict the tide as mentioned, the Sailing Directions should give full details of all circumstances which must be taken into account to obtain this excess of depth, unless the Captain be sure that a well regulated pilot service will always provide him with the advice of a pilot.

It will be advantageous to consider separately the exceptional cases of a very weak and a very irregular tide which conditions, as a rule, coincide because the influence of atmospheric and meteorological disturbances, which are sometimes considerable, are the more apparent as the tide is weaker. In these cases it will be impossible to establish levels (2), (3) and (4) because the connection between the declination of the moon or its phases and spring and neap tides will often be hidden by far greater atmospheric disturbances than the normal increment or decrement of the tide, and the observations will show, from one fortnight to another or at intervals of six months, such departures from the mean value that this is no longer reliable.

Under these conditions it appears advisable to adopt level (1) which will be more reliable on account of the great number of observations from which it is deduced.

In these circumstances it may happen that the time of the rise and the fall of the tide becomes so irregular, that even the tidal system is difficult to determine and then no other way remains open than the adoption of a level of reduction which is directly connected with mean sea level, because this level will show the smallest variations in consecutive years.

In view of the above, it may be said that the first part of the resolution adopted is well worded. The condition that the tide shall not frequently fall below the level of reduction permits a datum to be chosen which best suits the requirements of the seaman and the possibility of its easy and accurate deduction from the observations and from harmonic constants.

In order to judge whether the second paragraph is in accord with reality, the possibility of neglecting local influence on the adopted level should be examined. This possibility and that of establishing the same level for each system of tides can only be investigated by the elaboration of observations made at various places.

The third paragraph can only be tested after an affirmative answer is given to the second paragraph.

The only way to investigate the various levels mentioned and to answer the problems issuing therefrom is to elaborate series of observations made by selfregistering tide gauge at a certain number of places the tides of which can be taken as typical of the various systems of tides. In carrying out this elaboration, the low waters of mixed tides which rise above mean sea level have not been inserted among the low waters as these are really low high waters.

DIURNAL TIDES

The diurnal system is the simplest form of tide which is observed on the coasts of the world.

If the amplitude of the constituent O be given the values of 0,3 K_1, 0,5 K_1 and 0,7 K_1, the hours and amplitudes of high (low) water reckoned from a spring tide at the hour 0 to the following spring tide will be.

	AMPLITUDE O = 0,3 AMPLITUDE K_1			AMPLITUDE O = 0,5 AMPLITUDE K_1			AMPLITUDE O = 0,7 AMPLITUDE K_1		
Day after springs	Time of high water	Daily retardation	Height	Time of high water	Daily retardation	Height	Time of high water	Daily retardation	Height
0 SP.*	$0^h\ 0^m$		1,3 K_1	$0^h\ 0^m$		1,5 K_1	$0^h\ 0^m$		1,7 K_1
		— 18^m			— 29^m			— 37^m	
1	0 18		1,3 ,,	0 29		1,5 ,,	0 37		1,7 ,,
		— 17			— 27			— 36	
2	0 35		1,2 ,,	0 56		1,4 ,,	0 13		1,5 ,,
		— 11			— 22			— 33	
3	0 46		1,1 ,,	1 18		1,2 ,,	1 46		1,3 ,,
		— 2			— 14			— 26	
4	0 48		1.0 ,,	1 32		1,0 ,,	2 12		1,1 ,,
		10			5			— 10	
5	0 38		0,8 ,,	1 27		0,8 ,,	2 22		0,7 ,,
		30			42			39	
6	0 8		0,7 ,,	0 45		0,6 ,,	1 43		0,4 ,,
NP.**		41			1^h26			2^h39	
7	23 27		0,7 ,,	23 19		0,5 ,	23 4		0,3 ,,
		40			1 15			2 1	
8	22 47		0,8 ,,	22 4		0,6 ,,	21 3		0,5 ,,
		23			29			18	
9	22 24		0,9 ,,	21 35		0,8 ,,	20 45		0,9 ,,
		7			— 2			— 16	
10	22 17		1,0 ,,	21 37		1,1 ,,	21 1		1,2 ,,
		— 6			— 16			— 29	
11	22 23		1,1 ,,	21 53		1,3 ,,	21 30		1,4 ,,
		— 13			— 26			— 34	
12	22 36		1,2 ,,	22 19		1,4 ,,	22 4		1,6 ,,
		— 17			— 27			— 36	
13	22 53		1,3 ,,	22 46		1,5 ,,	22 40		1,7 ,,
SP.*		— 19			— 29			— 38	
14	23 12		1,3 ,,	23 15		1,5 ,,	23 18		1,7 ,,

(*) Springs.
(**) Neaps.

At the solstices of a year of maximum moon's declination, the amplitude of spring tides will be nearly 2 K_1, at the equinoxes of a year of a minimum declination it will fall to about K_1 ; the amplitudes of neap tides will be constantly varying from 3/4 K_1 at the solstices to 1/4 K_1 at the equinoxes.

Pure diurnal tides are very rare ; preponderant diurnal tides occur only in regions where, at the meeting of two mixed tides, the semidiurnal system nearly disappears. In order that this be possible, the amplitudes of the M_2 constituents of these tides should be about the same and their $\varkappa$ should differ about 6 hours. Therefore diurnal tides should be looked for in Archipelagos which have mixed tides and where the channels between the islands allow the tides to enter from different sides and to meet. In fact diurnal tides are found in the East Indian Archipelago, in the China Sea on the coasts of Tonking, and, exceptionally, in places like the S. Coast of Prince Edward's Island in the Gulf of St. Lawrence.

The observations made during a period of at least one year which it has been possible to procure are those from August 1913 to the end of July 1914 at a tide gauge at Poeloe Boeroeng in the Padang Tikar River, one of the estuaries of the Great Kapoeas river on the West Coast of Borneo, and those made from 1916 to 1920 included and in 1922 at the self-registering tide-gauge of Djamoeanrif, at the North entrance of Soerabaja Straits on the N. Coast of Java.

As the observations at the former place have not been registered automatically, the level of the low waters will, as a rule, be too high, but this error does not materially affect the result of the present investigation.

The semidiurnal tide of Po. Boeroeng is so weak that it may be neglected altogether, only 12 observations of two low waters at intervals of less than 9 hours have been made. At Djamoeanrif this tide is somewhat more important and its high or low water springs might disturb the diurnal neap low waters of the latter about half of March and September. However, the coincidence of these two phenomena never occurs at the same hour of the same day, as will be explained when discussing mixed tides. No low waters at intervals of less than 9 hours have been observed in 1913 and in 1922 their number is 21 only.

Diagrams 1 and 3, Plate 1, clearly show the close connection between the moon's declination and spring and neap tides ; the age of the tide is 53 hours at Po. Boeroeng and 51 hours at Djamoeanrif.

0 hours corresponds to noon ; the amplitudes are given in cm. ; the $\varkappa$ *numbers of* S_a *and* S_{sa} *are reduced to 21 March.*

The following table gives the result for Po. Boeroeng.

POELOE BOEROENG (PADANG TIKAR) 1913-14

K_1 55 cm. 147°	M_2 4 cm. 190°	S_a 3 cm. 93°.
O 38 cm. 88°	S_2 1 cm. 346°	S_{sa} 12 cm. 278°.
P 18 cm. 147°.		

Mean sea level (W) 206 cm. — O.

LEVEL OF	BELOW W		PERCENTAGE OF TIDES BELOW
	THEORETIC	OBSERVED	
1 mean low water	62	72	—
2 mean low water springs	106	111	13*a*
3 mean low water of solsticial springs.	124	125	6*b*
5 lowest low tide....................	—	149	—

NEGATIVE CORRECTIONS			POSITIVE CORRECTIONS		
	a	*b*		*a*	*b*
0–1 dm.	6 %	4 %	0–1 dm.	10%	4%
1–2 ,,	4	2	1–2 ,,	13	8
2–3 ,,	2		2–3 ,,	8	14
3–4 ,,	1		3–4 ,,	8	9
			4–5 ,,	9	5
			5–6 ,,	8	10
			6–7 ,,	6	8
			7–8 ,,	9	8
			8–9 ,,	7	7
			9–10 ,,	4	8
			10–11 ,,	3	6
			11–12 ,,	1	5
			12–13 ,,	—	2

In order to investigate whether rainfall has any notable influence on the levels in the mouth of the river, the following table was drawn up. It gives the departure from the annual mean of the monthly values of level (2) after elimination of the constituent *P*, and the departures from the annual mean of the monthly rainfall at Sintang, 150 miles up-river from Po. Boeroeng. The former are given in cm., the latter on a scale of 1/3.7 of the mm. given for 1879 till 1917.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Departure from level 2	10	— 4	6	— 5	6	— 11	— 18	— 22	— 9	4	19	22
Departure from mean of rainfall	11	— 5	4	4	— 4	— 16	— 24	— 5	— 9	14	12	15

Diagram 2, Plate 1, gives them graphically.

Although the observations of a single year only have been considered, the connection between the two is so remarkable, that it cannot be doubted. From November to March, during the wet season, this connection is direct, from April to October the level varies according to the rainfall in the preceding month. This connection shows that rainfall must be taken into account when elaborating tidal observations in an estuary.

The results of the observations made at Djamoeanrif are given in the following table.

DJAMOEANRIF. Latitude 6°,9 S. Longitude 127,7 E.

K_1 54 cm. 325° M_2 4 cm. 38° S_a 4 cm. 36°
O 26 „ 274° S_2 8 „ 11° S_{sa} 4 „ 141°
P 15 „ 326° N 2 „ 70°
K_2 2 „ 321°

W 125 cm. — S. H. V. P. (1).

LEVEL OF	1913				1916			1917			1917-18		1918			1919			1920			1922			
	Below W																					Below W			
	Theoric	Observed	Percentage of tides below	Percentage of tides below level 1917-18	Observed	Percentage of tides below	Percentage of tides below level 1917-18	Observed	Percentage of tides below	Percentage of tides below level 1917-18	Theoric	Levels from curve	Observed	Percentage of tides below	Percentage of tides below level 1917-18	Observed	Percentage of tides below	Percentage of tides below level 1917-18	Observed	Percentage of tides below	Percentage of tides below level 1917-18	Theoric	Observed	Percentage of tides below	Percentage of tides below level 1917-18
1 mean low water..............	57	76	—	—	72	—	—	66	—	—	52	69	73	—	—	69	—	—	64	—	—	47	56	—	—
2 mean low water springs.......	87	99	20[a]	28[aa]	98	12[b]	23[bb]	90	15[c]	15[cc]	77	91	92	19[d]	21[dd]	89	20[e]	15[ee]	82	20[f]	9[ff]	67	77	19[g]	4[gg]
3 mean low water of solsticial springs....................	102	112	5[h]	15[hh]	103	8[i]	10[ii]	104	4[j]	7[jj]	92	100	104	6[k]	10[kk]	91	13[l]	6[ll]	95	7[m]	5[mm]	82	81	10[n]	1[nn]
5 lowest low tide..............	—	129	—	—	123	—	—	125	—	—	—	—	119	—	—	119	—	—	115	—	—	—	104	—	—

(1) S. H. V. P. is the mean level of the highest high waters at Soerabaja.

NEGATIVE CORRECTIONS

	a	b	c	d	e	f	g
0–1 dm.	12%	7%	8%	12%	13%	13%	12%
1–2	4	4	5	6	5	4	6
2–3	4	1	2	1	2	3	1
3–4	—	—	—	—	—	—	—

	h	i	j	k	l	m	n
0–1 dm.	5%	5%	4%	5%	10%	3%	7%
1–2	—	3	—	1	3	4	3
2–3	—	—	—	—	—	—	—
3–4	—	—	—	—	—	—	—

	aa	bb	cc	dd	ee	ff	gg
0–1 dm.	13%	13%	8%	13%	10%	4%	3%
1–2	8	5	5	7	4	4	1
2–3	5	4	1	1	1	1	—
3–4	2	1	1	—	—	—	—

	hh	ii	jj	kk	ll	mm	nn
0–1 dm.	8%	5%	5%	8%	5%	4%	1%
1–2	5	4	1	2	1	1	—
2–3	2	1	1	—	—	—	—
3–4	—	—	—	—	—	—	—

POSITIVE CORRECTIONS

	a	b	c	d	e	f	g
0–1 dm.	14%	14%	16%	16%	16%	16%	13%
1–2	16	16	16	20	18	18	16
2–3	11	13	13	13	16	17	15
3–4	12	15	13	14	14	15	15
4–5	12	12	12	9	10	8	11
5–6	9	10	9	7	5	4	4
6–7	4	5	5	2	1	2	2
7–8	2	3	1	—	—	—	2
8–9	—	—	—	—	—	—	2
9–10	—	—	—	—	—	—	1
> 10	—	—	—	—	—	—	—

	h	i	j	k	l	m	n
0–1 dm.	5%	9%	6%	11%	14%	8%	17%
1–2	14	14	12	17	18	15	12
2–3	12	17	17	16	17	18	16
3–4	16	14	15	14	13	16	16
4–5	11	12	13	13	13	18	13
5–6	13	11	14	12	9	10	7
6–7	10	9	9	7	2	7	3
7–8	9	4	8	3	1	1	2
8–9	4	2	2	1	—	—	2
9–10	2	—	—	—	—	—	1
> 10	—	—	—	—	—	—	1

	aa	bb	cc	dd	ee	ff	gg
0–1 dm.	14%	17%	12%	14%	17%	14%	8%
1–2	14	14	16	20	18	16	16
2–3	12	15	14	11	16	18	13
3–4	13	12	12	14	14	17	16
4–5	9	10	15	10	12	13	16
5–6	6	6	9	6	6	8	13
6–7	4	2	6	2	2	4	6
7–8	—	1	1	2	—	1	3
8–9	—	—	—	—	—	—	2
9–10	—	—	—	—	—	—	2
> 10	—	—	—	—	—	—	1

	hh	ii	jj	kk	ll	mm	nn
0–1 dm.	13%	13%	8%	13%	11%	5%	4%
1–2	14	17	12	18	16	13	10
2–3	14	14	16	16	18	16	15
3–4	12	15	14	13	16	18	14
4–5	13	12	12	14	14	16	15
5–6	9	10	15	10	12	15	17
6–7	6	6	9	5	5	8	12
7–8	4	2	6	1	2	3	7
8–9	—	1	1	—	1	1	2
9–10	—	—	—	—	—	—	2
> 10	—	—	—	—	—	—	2

Considerable atmospheric disturbances, which give rise to sudden and unexpected changes of level, are rare in the E. I. Archipelago ; as a rule the barometer is steady and the direction and strength of the wind vary fairly regularly each day and each monsoon. Thus it is very probable that the theoretical and observed levels will be in close agreement and the latter will be very reliable on account of the small departure from the mean value.

Indeed, 12 cm., the mean difference of the levels No. (1), (2) and (3) in the year of mean lunar declination (1917-1918) and in those of maximum (1913) and minimum (1922) declination, correspond approximately to 11 % of K_1 + 19 % of O ; 89 and 101 cm., the mean values of levels (2) and (3) for the years 1913, 1917, 1918 and 1922, correspond to the value deduced from Diagram 5, Plate 1, and 12 cm., the mean difference of levels (2) and (3), agrees fairly closely with the amplitude of P. Diagram 4, Plate 1, gives the monthly low water springs at Djamoeanrif for 1913 and 1922, according to the following table.

	MEAN	DEPARTURE FROM MEAN											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1913........	99 cm. — W	— 11	— 3	15	21	15	— 6	— 14	— 17	1	9	1	— 16
1922........	77 cm. — W	— 15	— 5	7	21	13	— 5	— 13	— 12	2	9	2	— 4

and Diagram 5, Plate 1, shows, more clearly than the preceding table, the rise of the levels (1), (2) and (3) from 1913 to 1922. The fall is more rapid when starting from the year of minimum declination than when approaching that of maximum declination.

As it is not possible to adopt a level of reduction of soundings which varies from one year to another, either that of a year of mean declination or that of the maximum or minimum declination should be chosen. The percentages of the negative corrections for such years are :

	LEVEL OF 2	LEVEL OF 3
1913..................................	4-20 %	0-8 %
1917-1918.............................	4-28 ,,	1-15 ,,
1922.....................................	19-40 ,,	7-56 ,,

Levels (2) of the three years and level (3) of 1922 cannot be adopted on account of the maximum of percentages which they show; *the level of reduction recommended should* therefore *be that of solsticial springs in a year of* mean or of maximum declination. As half of the 15 % of the negative corrections for the year 1917-1918 do not exceed 1 dm. (4 inch), it appears advisable to adopt that of a year of *moon's mean declination.*

Solsticial low water springs at Do-son, Tonking, falls 166 cm. (5 1/2 ft.) below *W*. Unfortunately a series of observations made over a long period at this place could not be obtained, but there is no reason to believe that the level adopted for Djamoeanrif would not be convenient for Do-son where, according to the results of observations made during a short period, the tidal system is nearly purely diurnal.

The level to which the soundings in the mouth of the Padang Tikar river have been reduced during the hydrographic survey of 1880 can no longer be ascertained, for the tidegauges of this survey have disappeared. Taking into account the tendency to the over-reduction of soundings at that time, it is very probable that a level corresponding fairly closely with level (3) will have been used.

At the North entrance of Soerabaja Straits, soundings are reduced to a level of 23 dm. (7 1/2 ft.) below S(oerabaja) H(aven) V(loed) P(eil),(*) which corresponds with 105 cm. (3 ft. 5 1/2 inch) — *W* and is a trifle lower than the level of reduction recommended.

(*) See Table on page 17.

SEMI-DIURNAL TIDES

Compared to the diurnal system, the semi-diurnal has the advantage that high and low water springs and neaps occur at fixed hours instead of at hours which become earlier throughout the year.

This advantage is neutralised by the constituent N, which returns to the same phase about every 10 days and which makes the combination more intricate but—as long as its amplitude is not greater than the theoretical, and the computation by approximation which, as a rule, gives sufficiently accurate results for the seaman, can be applied—this complication is not serious. Giving to the constituents S_2, N and K_2 their theoretical values, the maximum amplitude at equinoxial springs will be about 1 7/8 M_2 and the minimum at equinoxial neaps 1/8 M_2.

If M_2 and S_2 only be considered and the relations 0,3, 0,5 and 0,7 be assigned to their amplitudes, the hours of high (low) water and the total amplitudes, reckoned from a springtide at 0 hours to the following springtide, will be :

	AMPL. S_2 = 0,3 AMPL. M_2			AMPL. S_2 = 0,5 AMPL. M_2			AMPL. S_2 = 0,7 AMPL. M_2		
Day after springs	Time of high water	Daily retardation	Height	Time of high water	Daily retardation	Height	Time of high water	Daily retardation	Height
0 SP.*	$0^h\ 0^m$		1,3M_2	$0^h\ 0^m$		1,5M_2	$0^h\ 0^m$		1,7M_2
		38^m			32^m			28^m	
1	0 38		1,3 ,,	0 32		1,5 ,,	0 28		1,7 ,,
		40			33			29	
2	1 18		1,2 ,,	1 5		1,4 ,,	0 57		1,6 ,,
		40			36			30	
3	1 58		1,1 ,,	1 41		1,2 ,,	1 27		1,4 ,,
		47			40			33	
4	2 45		1,0 ,,	2 21		1,1 ,,	2 0		1,1 ,,
		52			47			38	
5	3 37		0,9 ,,	3 8		0,8 ,,	2 38		0,9 ,,
		$1^h\ 2$			$1^h\ 4$			55	
6	4 39		0,8 ,,	4 12		0,6 ,,	3 33		0,6 ,,
		1 11			1 34			$2^h\ 2$	
7	5 50		0,7 ,,	5 46		0,5 ,,	5 35		0,3 ,,
NP.**		1 13			1 39			2 31	
8	7 3		0,7 ,,	7 25		0,5 ,,	8 6		0,3 ,,
		1 4			1 12			1 4	
9	8 7		0,8 ,,	8 37		0,7 ,,	9 10		0,4 ,,
		56			51			41	
10	9 3		0,9 ,,	9 28		0,9 ,,	9 51		0,9 ,,
		48			40			33	
11	9 51		1,0 ,,	10 8		1,1 ,,	10 24		1,2 ,,
		41			37			30	
12	10 32		1,1 ,,	10 45		1,3 ,,	10 54		1,3 ,,
		40			34			30	
13	11 12		1,2 ,,	11 19		1,4 ,,	11 24		1,6 ,,
		39			33			30	
14	11 51		1,3 ,,	11 52		1,5 ,,	11 54		1,7 ,,
SP.*		38			32			27	
15	12 29		1,3 ,,	12 24		1,5 ,,	12 31		1,7 ,,

As has been mentioned, the high and low waters of the four constituents coincide at the same hour of the same day once only in 4,5 years, so, in order to include this combination, a series of observations made during at least 5 years will have to be elaborated. The following results are obtained from observations made at Queenstown, on the S. Coast of Ireland, from November 1904 to October 1907 inclusive; at Brest, on the West coast of France, from 1916 to 1920 inclusive; at Hoek van Holland and Helder, on the Dutch coast of the North Sea, during the same period and St. John, New Brunswick, on the East Coast of Canada, from 1919 to 1923 inclusive.

The diurnal and the shoalwater tides of the first, the second and the fifth place are so small, that it is permissible to call the tides purely semidiurnal, the diagrams are regular and symmetrical; at the third and

(*) Springs.
(**) Neaps.

the fourth places the semi-diurnal tide is very preponderant only and, besides, it is seriously affected by shoalwater tides.

At Hoek van Holland, highwater of the combined shoalwater tides coincides at springs with semi-diurnal low water. Under these circumstances a low water will be observed which has a smaller amplitude than the theoretical tide, which may last 4 hours and which shows, in the middle of this period, a more or less visible rise ; as neap tides approach, the curve again assumes a normal form though the rise is always shorter than the fall.

The result is that low water is generally badly defined. Sometimes the two consecutive low waters are very distinct, sometimes there is only one and, on an average, 5 low waters correspond to 4 high waters.

At Helder, the inverse takes place. At springs the low waters of the combined shoalwater tides coincide with semi-diurnal low water and thus the latter is well defined and lower than the theoretical tide ; at this place a double high water is observed and 3 high waters correspond, as a rule, to 2 low waters. Near neap tides the form of the diagram is normal again, but the rise is still shorter than at Hoek van Holland ; at springs it sometimes lasts but an hour.

In view of the range of the tide at Queenstown and Brest, the unit of measure for the corrections established for Hoek van Holland and Helder has been doubled, and for St. John N. B. it has been trebled.

This last place is situated on the coast of the Bay of Fundy, where the tides reach the maximum for the whole world. Thanks to its enormous rise, the tide is very regular and very little affected by atmospheric disturbances.

As the amplitude of S_2 at St. John N. B. has one third of its normal value only, it is less than that of N, so the proximity of the moon has a notable influence. Springtides at full and new moon are weaker than tides at perigee and the rise reaches a maximum when the hour of full or new moon precedes that of perigee by 36 hours. In the second half of March and September, the tide may then fall to 4.30 m. (14.1 ft.) below W.

The difference of level between perigee neaps and apogee springs is but small. Since these two levels alternate during three weeks after perigee springs, the coincidence indicated does not show, between two very low tides at the interval of a month, a less low springtide and two neap tides, but it shows a series of low waters, the level of which vary little in comparison to the very great rise, as Diagram 10 *a*, Plate 2, shows. While after the coincidence of perigee (apogee) and the quarters of the moon, the interval of time between these two phenomena changes rapidly from day to day, this change is but very slow after the coincidence of perigee (apogee) with the new or the full moon ; for this reason it is possible to observe this small change of low water level during three or even four consecutive months. The coincidence of neaps and apogee gives the highest low water levels.

The rise of the tide increases considerably at the head of the Bay of Fundy and is doubled at Burncoat Head, in the Eastern inner bay leading to Truro ; perigee springs at this place have a rise exceeding 15 m. (49.1/4 ft.).

Diagrams 6 and 7, Plate 1, show clearly the close connection between the moon's phases and the low water springs and neaps which follow these phases at certain ages of the tide, which are 43 hours for Queenstown and 39 hours for Brest.

For Hoek van Holland, where the age of the tide is 52 hours, this connection cannot always be indicated, as the shallow water tides make the low water springs too uncertain. Perigee, apogee and the declination of the moon have been inserted in order to investigate whether the low waters and the daily inequality show the influence of these phenomena. Of the Diagrams 8*a* to 8*e* inclusive, Plate 1, only the last shows the influence of the moon's phases ; neither is it found clearly in Diagram 8*f*, in which are given the mean values of mean low water during a lunar month for the 5 months of August, classified according to the age of the moon.

It is to be noted that the greater number of the high levels is produced suddenly by a considerable diurnal inequality. The lowering influence of perigee and the raising influence of apogee, which might be thought to exist judging from Diagrams 8*a* and 8*b*, is not shown in the other diagrams and the close connection between the moons declination and the daily inequality is nowhere indicated ; inequalities varying from a few to 95 cm. (3.1 ft.) occur at declination nought as well as at maximum declination.

At Helder the age of the tide is 70 hours. Diagram 9*a*, Plate 1, shows the normal influence of the phases and too early neap low waters which are produced, in the same way as at Hoek van Holland, by considerable diurnal inequalities. The influence of perigee and apogee is not clear either in this or in the other diagrams; that of 1917 shows even considerable rise of level when the moments of perigee and new moon approach each other. Diagram 9*b* shows dissimilar influences of apogee.

The other diagrams show also sudden leaps and various levels at spring as well at as neap tides; the diagram which corresponds to No. 8*f* of Hoek van Holland shows a sufficiently close connection between the phases of the moon and spring and neap tides.

Diagrams 10*a* to *d*, Plate 2, on the same scale as the former diagrams, show the influence of perigee and apogee, the moons phases and its declination on the low waters of St. John N. B. The first diagram gives the coincidence of perigee (apogee) with the full and new moon, which gives the lowest low water springs, the second gives perigee (apogee) alternating with the phases of the moon and the last two give the coincidence of apogee and of perigee and the quarters of the moon which former gives the highest neap low waters.

The various levels of the 5 places are :

QUEENSTOWN. Latitude 51°,8 N. Longitude 8°,3 W.

M_2 137 cm. 133°	K 2 cm. 160°	M_4 6 cm. 210°.
S_2 43 cm. 177°	O 4 cm. 37°	M_3 4 cm. 254°.
N 26 cm. 114°		$2M_S$ 3 cm. 208°.
K_2 15 cm. 174°		

W 187 cm. + 0.

LEVEL OF	1904/5			1905/6		1906/7		MEAN	
	BELOW W		PERCENTAGE of tides below	OBSERVED	PERCENTAGE of tides below	OBSERVED	PERCENTAGE of tides below	OBSERVED	PERCENTAGE of tides below
	THEORETIC	OBSERVED							
1 mean low water..........	137	150	—	152	—	153	—	152	—
2 mean low water springs....	180	181	13[a]	184	17[b]	153	19[c]	182	16[d]
3 mean low water of equinoxial springs...........	206	201	4[e]	207	5[f]	199	6[g]	202	5[h]
5 lowest low tides..........	—	236	—	243	—	274	—	—	—

NEGATIVE CORRECTIONS

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*
0–2 dm.	9 %	11 %	13 %	11 %	4 %	4 %	5 %	4 %
2–4	4	4	5	4	—	1	1	1
4–6	—	2	1	1	—	—	—	—
POSITIVE CORRECTIONS								
0-2 dm.	21 %	16 %	20 %	19 %	12 %	9 %	13 %	11 %
2-4	25	24	23	24	21	17	19	19
4-6	20	19	16	18	24	18	21	21
6-8	10	15	10	13	19	22	17	19
8-10	7	5	7	6	10	18	11	13
10-12	2	3	3	3	7	7	8	7
12-14	1	1	2	1	2	3	4	3
14-16	1	—	—	—	1	1	1	1

BREST. Latitude 48°,4 N. Longitude 4°,5 W.

M_2 206 cm. 99°	K_1 6 cm. 69°	M_4 6 cm. 85°.
S_2 75 cm. 139°	O 7 cm. 324°	MS 8 cm. 107°.
N 42 cm. 80°	P 2 cm. 66°	2MS 8 cm. 89°.
K_2 22 cm. 137°.		

W 445 cm. + W.

LEVEL OF	1916			1917		1918		1919		1920		MEAN	
	BELOW W												
	THEORETIC	OBSERVED	PERCENTAGE of tides below	OBSERVED	PERCENTAGE of tides below	OBSERVED	PERCENTAGE of tides below	OBSERVED	PERCENTAGE of tides below	OBSERVED	PERCENTAGE of tides below	OBSERVED	PERCENTAGE of tides below
1 mean low water	206	205	—	216	—	214	—	221	—	218	—	215	—
2 mean low water springs	281	279	14[a]	291	12[b]	293	13[c]	291	16[d]	295	13[e]	290	13[f]
3 mean low water of equinoxial springs	323	312	8[g]	328	9[h]	330	6[i]	323	9[j]	323	8[k]	323	8[l]
5 lowest low tides	—	353	—	383	—	381	—	359	—	359	—	—	—

NEGATIVE CORRECTIONS

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*
0–2 dm.	7 %	4 %	5 %	7 %	6 %	6 %	6 %	6 %	5 %	6 %	6 %	6 %
2–4	4	3	4	6	5	4	2	2	1	2	2	2
4–6	2	3	3	2	2	2	—	1	—	1	—	—
6–8	1	2	1	1	—	1	—	—	—	—	—	—

POSITIVE CORRECTIONS

0-2 dm.	9 %	7 %	7 %	8 %	11 %	8 %	7 %	6 %	9 %	7 %	7 %	7 %
2-4	13	13	10	10	9	11	8	8	8	7	12	9
4-6	12	11	10	12	11	11	11	7	9	10	8	9
6-8	10	11	10	12	8	10	10	8	9	12	10	9
8-10	10	11	11	10	9	10	8	12	10	12	8	10
10-12	10	7	8	9	10	9	10	10	11	10	9	10
12-14	8	8	9	9	11	9	9	15	10	9	10	11
14-16	6	8	8	7	7	7	10	10	10	10	10	10
16-18	5	8	8	4	5	6	6	6	5	7	7	6
16-20	2	3	5	2	4	3	6	2	5	4	5	4
> 20	1	1	1	1	2	1	7	7	8	3	6	7

HOEK VAN HOLLAND, Latitude 52°, 0. N. Longitude 4°,1 E.

M_2 80 cm.	73°		K_1 7 cm.	355°		M_4 18 cm.	134°.
S_2 18 „	126°		O 11 „	182°		M_6 4 „	74°.
N 13 „	44°					MS 10 „	176°.
K_2 5 „	126°					2MS 8 „	201°.

W 12 cm. — N. A. P.

LEVEL OF	1916 below W THEORIC	1916 below W OBSERVED	1916 PERCENTAGE of tides below	1917 OBSERVED	1917 PERCENTAGE of tides below	1918 OBSERVED	1918 PERCENTAGE of tides below	1919 OBSERVED	1919 PERCENTAGE of tides below	1920 OBSERVED	1920 PERCENTAGE of tides below	MEAN OBSERVED	MEAN PERCENTAGE of tides below
1 mean low water	80	59	—	67	—	65	—	67	—	62	—	64	—
2 mean low water springs	98	71	32^{a}	83	28^{b}	78	29^{c}	76	31^{d}	76	26^{e}	77	29^{s}
3 mean low water of equinoxial springs	103	72	32^{g}	88	21^{h}	82	25^{i}	79	30^{j}	85	16^{k}	81	25^{l}
4 mean low water of equinoxial springs at perigee	116	85	15^{m}	101	8^{n}	95	9^{o}	92	12^{p}	98	5^{q}	54	10^{r}
5 lowest low tide	—	136	—	154	—	154	—	166	—	137	—	198	—

NEGATIVE CORRECTIONS

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*	*p*	*q*	*r*
0–1 dm.	14%	13%	14%	15%	13%	14%	14%	11%	13%	14%	9%	12%	9%	4%	6%	7%	3%	6%
1–2	9	7	9	8	8	8	9	5	7	8	4	7	4	2	2	3	1	2
2–3	6	5	4	5	3	5	6	2	3	4	1	3	1	1	1	1	1	1
3–4	2	2	1	2	2	2	2	1	1	2	1	1	1	1	—	1	—	1
4–5	1	1	1	1	—	1	1	2	1	2	1	2	—	—	—	—	—	—

POSITIVE CORRECTIONS

0–1 dm.	19%	16%	18%	17%	18%	18%	17%	13%	17%	17%	13%	15%	13%	7%	11%	13%	6%	10%
1–2	17	17	20	19	19	18	15	17	18	18	19	17	17	14	16	16	12	15
2–3	13	15	12	13	16	14	14	16	15	12	18	15	17	18	17	18	16	17
3–4	8	10	8	10	10	9	9	13	10	11	16	12	13	16	18	14	20	16
4–5	5	7	6	6	5	6	6	8	6	5	10	7	11	14	11	11	17	13
5–6	2	3	4	2	2	3	2	5	5	4	4	4	7	9	7	7	13	9
6–7	2	2	2	1	2	2	1	3	3	1	2	2	3	5	5	4	7	5
7–8	—	1	1	1	1	1	1	1	1	1	1	1	1	3	3	2	2	2
8–9	—	1	—	—	1	—	—	1	—	—	1	—	1	2	2	1	1	1
9–10	1	—	—	—	—	—	1	1	—	—	—	—	2	1	1	1	1	1
>10	1	—	—	—	—	—	2	1	—	—	—	1	—	3	—	1	—	1

HELDER. Latitude 53°, o. N. Longitude 4°,7 E.

M_2	53 cm.	166°	K_1	5 cm.	0°	M_4	11 cm.	191°.
S_2	15 „	237°	O	8 „	196°	M_6	6 „	294°.
N	8 „	151°				MS	6 „	236°.
K_2	5 „	237°				2MS	6 „	266°.

W 13 cm. — N. A. P.

LEVEL OF	1916 below W THEORIC	1916 below W OBSERVED	1916 PERCENTAGE of tides below	1917 OBSERVED	1917 PERCENTAGE of tides below	1918 OBSERVED	1918 PERCENTAGE of tides below	1919 OBSERVED	1919 PERCENTAGE of tides below	1920 OBSERVED	1920 PERCENTAGE of tides below	MEAN OBSERVED	MEAN PERCENTAGE of tides below
1 mean low water	53	64	—	70	—	68	—	68	—	70	—	68	—
2 mean low water springs	68	76	36a	86	27b	83	30c	80	34d	87	24e	82	80f
3 mean low water of equinoxial springs	73	85	19g	86	27h	93	12i	82	32j	93	17k	88	21l
4 mean low water of equinoxial springs at perigee	81	93	9m	94	16n	101	7o	90	14p	101	5q	96	11r
5 lowest low tide	—	127	—	—	—	162	—	158	—	162	—	223	—

NEGATIVE CORRECTIONS

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r
0–1 dm.	18%	12%	18%	16%	14%	16%	12%	12%	8%	15%	11%	12%	6%	7%	4%	10%	5%	6%
1–2	12	7	8	11	7	9	5	7	2	9	4	5	2	4	1	4	2	3
2–3	4	4	2	4	1	3	1	4	2	4	1	2	1	3	1	2	1	1
3–4	1	2	2	2	2	2	1	2	—	2	1	1	—	1	1	1	1	1
4–5	1	2	—	1	—	1	—	2	—	2	—	1	—	1	—	1	—	—

POSITIVE CORRECTIONS

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r
0–1 dm.	21%	16%	17%	15%	19%	18%	19%	16%	18%	17%	13%	7	13%	14%	12%	16%	11%	13%
1–2	15	17	15	16	20	17	21	17	17	14	20	18	21	17	16	17	14	17
2–3	9	15	12	12	10	11	13	15	15	12	18	15	19	17	18	16	22	18
3–4	7	8	8	8	11	8	9	8	12	9	11	10	14	14	13	12	16	14
4–5	4	6	6	6	5	5	7	6	8	7	7	7	8	7	12	8	10	9
5–6	2	2	4	4	4	3	4	2	6	4	5	4	6	4	7	6	6	6
6–7	2	3	3	2	3	3	2	3	4	2	4	3	3	3	6	3	5	4
7–8	2	2	2	1	2	2	2	2	3	1	1	2	2	2	4	2	3	3
8–9	1	1	2	1	1	1	2	1	2	1	2	2	2	2	2	1	1	2
9–10	1	1	1	1	1	1	1	1	2	—	1	1	1	1	1	1	2	1
>10	—	2	—	—	—	—	1	2	1	1	1	1	2	3	2	—	1	2

ST. JOHN N. B., Bay of Fundy. Latitude 45°,3 N. Longitude 66° W.

M_2	299 cm.	337° (1)	K_1	15 cm.	135° (1)	Sa	4 cm.	128° (1)
S_2	49 „	17°	O	12 „	116°	Ssa	5 „	124°
N	61 „	307°	P	5 „	136°.			
K_2	14 „	17°						

W 427 cm. + 0

LEVEL OF	1916 below W: THEORIC	1916 below W: OBSERVED	1916: PERCENTAGE of tides below	1917: OBSERVED	1917: PERCENTAGE of tides below	1918: OBSERVED	1918: PERCENTAGE of tides below	1919: OBSERVED	1919: PERCENTAGE of tides below	1920: OLSERVED	1920: PERCENTAGE of tides below	MEAN: OBSERVED	MEAN: PERCENTAGE of tides below
1 mean low water	299	314	—	320	—	323	—	325	—	328	—	322	—
2 mean low water springs	344	366	3[a]	276	15[b]	373	15[c]	380	16[d]	319	17[e]	375	15[f]
3 mean low water of equinoxial springs	362	402	3[g]	397	8[h]	423	2[i]	423	2[j]	427	3[k]	414	3[l]
4 mean low water of equinoxial springs at perigee	423	420	—[m]	427	2[n]	430	1[o]	434	1[p]	443	1[q]	437	1[r]
5 lowest low tide	—	434	—	445	—	436	—	451	—	460	—	—	—

(1) x numbers are given in standard time for the 60th meridian West of Greenwich.

NEGATIVE CORRECTIONS

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r
0–3 dm.	10%	11 %	9%	8%	9%	9%	3%	6%	2%	2%	3%	3%	—	2%	1%	2%	1%	1%
3–6	5	3	5	7	7	5	—	2	—	—	—	—	—	—	—	—	—	—
6–9	—	1	1	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—

POSITIVE CORRECTIONS

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r
0-3 dm.	18 %	17 %	18%	12%	16%	16%	9%	13%	8%	8%	8%	9%	5%	6%	7%	8%	5%	6%
3–6	22	23	23	23	24	23	18	18	12	8	11	13	10	12	10	8	9	10
6–9	22	22	23	25	21	23	23	25	18	16	21	21	18	18	16	16	14	16
9–12	16	13	15	18	15	15	22	18	27	25	24	23	22	25	26	25	23	24
12-15	6	8	5	6	7	6	16	10	20	23	18	17	22	18	23	23	22	22
15–18	1	2	1	—	—	1	7	7	10	15	12	10	16	10	12	15	17	14
18-21	—	—	—	—	—	—	2	1	3	3	3	2	6	7	4	3	8	6
21-24	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	1	1

These data give rise to the following conclusions :

Low water springs give already an acceptable level of reduction for tides such as those of Queenstown and Brest. At the former place the negative corrections do not exceed 6 dm. (2 ft.) and 2/3 of these do not exceed 2 dm. (0.7 ft.). At the latter the maximum of the negative corrections is 8 dm. (2.7 ft.) and half of them do not exceed 2 dm.

If the level of equinoxial low water springs be adopted, the negative corrections are considerably reduced in number and do not exceed 4 dm. (1.3 ft.).

At Queenstown the soundings are reduced to lower low water springs and at Brest to the lowest low water observed.

The percentages of negative corrections and their amount for levels (2) and (3) at *Hoek van Holland and Helder* are considerably higher, although half of the number does not exceed 1 dm. (0.3 ft.). *The level of equinoxial springs at perigee* (4) *shows a very much smaller and fewer corrections, more than half of which do not exceed* 1 *dm.*

The soundings at these places are still reduced to mean low water but will be reduced to the mean of the lowest low waters of each month at the next survey.

The differences between the theoretic levels Nos. (1), (2) and (3) and the observed levels in 5 years at St. John N. B., respectively 23, 27 and 52 cm. (0.7, 0.9 and 1.7 ft.) are the more remarkable as this difference for level (4*a*) is 7 cm. (0.2 ft.) only. Since the harmonic constants have been deduced from the observations made during 20 years, their reliability cannot be doubted and this discrepancy should possibly be ascribed to the influence of numerous constituents which have not been taken into account and the principal of which may be L and ν, which have amplitudes of 18 and 15 cm. (0.6 and 0.5 ft.) respectively. The continuous lowering of the levels from 1919 to 1923 is not less remarkable ; it was not possible to find an acceptable reason for this increase of amplitude (*).

It appears that the level of low water springs *at St. John N. B.* is not acceptable as a level of reduction on account of the great influence of perigee, although 3/5 of the negative corrections do not exceed 3 dm. (1 ft.) ; *the level of equinoxial springs at perigee, which shows the smallest percentage of negative corrections, should be selected.*

The soundings are reduced to mean perigee springs.

(*) *See* : Perturbations of Harmonic Tidal constants, by A.-T. DOODSON, *Proceedings of the Royal Society*, A, vol. 106, 1924.

MIXED TIDES

Mixed tides are those the diurnal and semi-diurnal systems of which act simultaneously while the amplitude of the weaker system is at least 25 % of the stronger. Each observation is the algebraic sum of simultaneous heights of the two systems and, in order fully to understand such observation, it should be divided into its two elements before each main element can be split up analytically into the constituents of its system. This division is made by the harmonic method, so that *knowledge of the harmonic constants is indispensable to understand mixed tides.*

When elaborating these tides, the continuous changes of amplitude and times of high and low water of each system during the cyclus which these have to go through before they return to the same phase should constantly be borne in mind ; the moon's phases will have to be considered as well as its declination.

The work will be facilitated considerably by diminishing the number of constituents. Since P, N and K_2, the shallow water tides and those of long periods are, as a rule, all of a subordinate order, it will be sufficient to consider K_1, O, M_2 and S_2 in order to establish the principal features of mixed tides. If required, the algebraic sum of the amplitudes of some secondary constituents can be added afterwards.

The first question which requires an answer is the following :

Do these four constituents act absolutely independently of each other, so that every possible combination can occur ?

Theory teaches that such is not the case.

High (low) waters springs or neap tides of both systems can occur everywhere on the same day, but their coincidence at the same hour of the same day can occur twice a year only *viz* : in the month in which the constantly earlier hour of the high (low) water of K_1 is the same as one of the two constant hours of high (low) water of S_2.

The $\varkappa$ numbers of O and M_2 decide this coincidence. M_2 completes exactly 27 revolutions in 13.66 ..... days of 24 hours which represent the interval of diurnal spring tides. Thus, if the time of high (low) water of diurnal springs coincides on the same day with the time of high (low) water of M_2, this coincidence will be permanent and the high (low) water springs of the two systems will be observed simultaneously in the way mentioned above.

The number of places where this coincidence is observed is rather limited.

If high (low) water of M_2 does not coincide on the same day with the time of high (low) water of diurnal springs, this interval will remain constant and the high (low) water of the spring tide of both systems will never occur simultaneously.

This is the case with every other combination also, that of high (low) waters of neap tides of the two systems and that of high (low) waters springs of one system with low (high) water neaps of the other.

The daily curve of a mixed tide changes continually because the amplitudes of the two systems vary incessantly within by no means restricted limits. The proportion of these two instantaneous amplitudes decides the character of the curve, and thus a diurnal character may be changed into a semidiurnal and the converse.

With regard to the constituents of each system, it should be remarked that sometimes their amplitudes differ much more from the theoretical proportion than do those of a pure or very preponderant system. For mixed tides the amplitude of O may be equal to that of K_1 and may even exceed it ; the same occurs for S_2 and M_2.

Adopting as a typical mixed tide that with equal amplitudes of both systems, it will be possible to investigate the extreme daily curves for a certain number of combinations. These are given on Plate 3, Diagrams 11 to 14 inclusive, for intervals of the time of high water varying from 0 to 11 hours; the high water of the semi-diurnal tide precedes that of the diurnal tide.

In Diagram 11 the semi-diurnal amplitude is three times the diurnal, which proportion will occur at the coincidence of semidiurnal springs and diurnal neaps.

For each interval of time a well defined semi-diurnal character is maintained and the high and low waters are observed at about the normal hours, the amplitudes only vary. If the interval be 0 hours, two high waters having unequal amplitudes and two low waters having equal amplitudes will be observed ; if the interval be 6 hours, the amplitudes of the former are equal and those of the latter unequal. For all other intervals, the amplitudes of high as well as of low water are unequal but this inequality is not considerable.

Diagram 12 is the result of a combination in which the diurnal tide is three times as strong as the semi-diurnal, *viz* : that of diurnal springs and semi-diurnal neaps.

The diurnal character is maintained throughout and, except at the intervals of 3 and 9 hours, the amplitudes are unequal. At the interval of 0 hours the curve shows a well defined high water and a low water which has less amplitude, which is nearly constant during 8 hours and is preceded by a fall and followed by a rise which last 8 hours each. When the interval is 6 hours, low water is well defined and high water is nearly constant during 8 hours.

The times of high and low water retard in accordance with the increment of the interval ; however, if the interval be between 5 and 7 hours and 11 and 1 hour, these times suddenly become earlier by 8 hours. The fall continues to be regular and lasts 8 hours as long as the interval is less than 6 hours ; at an interval of 7 hours it suddenly increases to 16 hours, becomes irregular and does not recover its normal form and duration of 8 hours until the interval is increased to 12 hours. The rise shows the same anomalies but in an inverse direction.

Diagrams 13 and 14 give the coincidences for equal amplitudes of the two systems, the former for springs and the latter for neap tides. The curves of these diagrams have a semi-diurnal character except for intervals of 0 and 6 hours, which show hybrid curves. At the first interval, it shows one well defined high water, preceded by a rise and followed by a fall which last 7 hours each and two low waters of less amplitude which differ 10 hours in time and show, in the middle, a rise which reaches mean sea level. At the second interval there is only one low water and two high waters between which the curve drops to mean sea level.

Calling minimal high water the rise to mean sea level of low water and minimal low water the fall to that level of high water, the times of high and of low water lag constantly and approximately in gradual accordance with the increment of the interval. The daily inequality is considerable for all the curves and reaches a maximum in the hybrid curves.

The particulars of Diagram 14 show up less clearly than those of Diagram 13 on account of the amplitude of the former being only one third of the latter.

The transformation of the character from a diurnal into a semi-diurnal, which occurs when the curve passes from Diagram 12 to one of the others, is always preceded by a retardation of a very long rise or fall about mean sea level. This retardation is changed into an oscillatory movement and, as soon as the oscillations go beyond mean sea level on either side, the semidiurnal character, with great daily inequalities of high as well as of low water, is established.

The transformation of the semi-diurnal character into a diurnal can always be predicted by a continuous diminishing of the amplitude of lower high or higher low water ; as soon as the high water falls below or the low water rises above mean sea level, the diurnal character is established with an irregular and lengthened fall or rise.

Although, at the same place, these transformations are, as a rule, always accomplished in about the same manner, their frequency shows variations in a cycle of 19 years, because the limits of the diurnal amplitudes vary in accordance with the declination of the moon ; maximum (minimum) declination will correspond with a maximum (minimum) of observations which show a diurnal character.

The observations made at Soerabaja, on the North Coast of Java, show this clearly, although the decrease of the diurnal percentage is not absolutely regular from 1913 to 1922.

	1913	1918	1919	1920	1921	1922
Number of observations......	536	514	555	518	598	583
Percentage of semi-diurnal tides	51	46	55	58	67	63
Percentage of diurnal tides...	49	54	45	42	33	37

This lack of regularity is probably caused by an accidental rise or fall of some cm. of mean sea level which, as will be shown later on, may cause the character of the curve to change. Theoretically the percentage of diurnal observations will always be lower than that of semi-diurnal observations and the greater percentage of the former in 1918 is undoubtedly accidental.

In order to understand fully how low water of a typical mixed tide changes from one day to another, Diagrams 15 to 20 inclusive of Plate 3 show these for Soebaraja, where the spring and neap tides of the two systems cannot coincide at the same hour of the same day. The difference of time of these moments is at least 2 hours.

Diagram 15 represents the low waters which have been observed shortly before and after the coincidence on the same day of springs and neap tides of both systems.

For the sake of clearness, the phases of the moon and the hours of maximum and minimum declination, given in the former diagrams, have been replaced by an indication of when low water springs and neaps of both systems should occur theoretically, but in fact do occur on one occasion only, because the age of the tide, 31 hours for the diurnal and 4 hours for the semidiurnal system, is a mean value.

The coincidence of spring tides on 5th. July is preceded and followed by the coincidence of neap tides and a nearer approach and gradual separation of spring tides. From 20 June to 5 July the conditions are the same as those from 5 to 19 July, thus complete symmetry of the two parts of the diagram might be expected but, although this symmetry exists for the diminishing and increasing amplitude of low water with a minimum at neaps and for the diurnal character from neaps to springs, it does not exist as to the character from springs to neaps. While the character of the curve is constantly diurnal from 20 to 29 June, with the exception of two days, it is semidiurnal from 5 to 12 July.

This difference is easily explained.

At this epoch, the spring tides of the two systems do not differ more than half a day, therefore the amplitudes of the diurnal and semi-diurnal tides are approximately equal and, at intervals of 12 hours, the algebraic sums of these amplitudes will be : a lower low water and a high low or low high water, which has an amplitude which is not more than a few cm. Now the character of the diagram depends exclusively on the sign of the latter amplitude. If it be negative, the curve shows a second low water and the character is semi-diurnal; if it be positive, there is the lower low water only and the character is diurnal.

A gust of wind which raises or lowers mean sea level some cm. only, or a temporary increase or decrease of the semi-diurnal amplitude, caused by the constituent N, are therefore sufficient to change a semi-diurnal character into a diurnal or the converse. Indeed, the high waters of N diminish the negative semi-diurnal amplitudes from 21 to 26 June and the low waters of this constituent increase them from 5 to 11 July.

Under these circumstances, the daily curves at and near the coincidence of springs and of neaps of the two systems have no well defined character.

On 5th July, the time of diurnal high water springs is 20 hours after noon, that of semi-diurnal high water springs noon ; the time of the preceding and following neap tides of both systems would be 21 and 19 hours for the diurnal and 18 hours for the semi-diurnal systems.

At the coincidence on the same day of the springs of the two systems, the diurnal high water time precedes that of the semidiurnal tide by 4 hours and the daily curve will be analogous to the 5th of Diagram 13; at the coincidence of neap tides, diurnal high water falls two hours later than semidiurnal high water and the curve will have the form of the 11th curve of Diagram 14.

In order to predict theoretically the extreme points of the daily curves from 25th June to 5th July, the times and amplitudes at low water of the principal constituents of the two systems should be investigated and combined.

The amplitudes which correspond to a given moment are found by the following table which gives, at intervals of half an hour, the rise above and fall below mean sea level for a diurnal and a semi-diurnal tide having an amplitude 100.

	AMPLITUDE	AMPLITUDE AFTER HIGH OR LOW WATER											
		1/2 hour	1 hour	1 h. 1/2	2 hours	2 h. 1/2	3 hours	3 h. 1/2	4 hours	4 h. 1/2	5 hours	5 h. 1/2	6 hours
Diurnal tide...........	100	99	97	92	87	79	71	61	50	38	26	13	0
Semi-diurnal tide......		97	87	71	50	26	0						

The dates of diurnal springs are 20th June, 5th July and 18th July with low water at 8 hours, the dates of semi-diurnal springs are 20th June, 5th and 20th July, with low water at 6 hours. On the first dates the amplitudes of $K_1 + P$ are 56, 52 and 48 cm., on the second those of $S_2 + K_2$ are 18, 21 and 24 cm., therefore the results of the following combinations must be investigated :

June 20th	8^h	$K_1 + P$ —56 cm.	O—23 cm.	June 20th	6^h	$S_2 + K_2$ —18 cm.	M_2—44 cm.
July 5th		—52		July 5th		—21	
18th		—48		20th		—24	

adding to the three days — 2, — 2 and 5 cm. for N. and 4, 4 and 6 cm. for $S_a + S_{sa}$.

Using the preceding table, these results are :

	20 JUNE	5 JULY	19 JULY
Computation by approximation .	7^h, 128 cm. — W	7^h, 127 cm. — W	7^h, 117 cm. — W
Observation	6^h, 103 cm. — W	6^h, 108 cm. — W	6^h, 101 cm. — W

The dates of diurnal neap tides are 28th June and 11th July, with low water at 8 hours and amplitudes $K_1 + P$ of 54 and 49 cm. and those of semi-diurnal neaps 28th June and 12th July, with low waters at midnight and amplitudes $S_2 + K_2$ of 19 and 22 cm.

The results of the following combinations :

$$\left.\begin{array}{l}\text{June 28th}\\ \text{July 11th}\end{array}\right\} 8^h \left\{\begin{array}{r} K_1 + P - 54\text{ cm.}\\ -49\end{array}\right\} O + 23\text{ cm.} \qquad \left.\begin{array}{l}\text{June 28th}\\ \text{July 12th}\end{array}\right\} 12^h \left\{\begin{array}{r} S_2 + K_2 + 19\text{ cm.}\\ +22\text{ cm.}\end{array}\right\} M_2 - 44\text{ cm.}$$

give, at 10 hours of 28th June and of 11/12 July, 39 and 34 cm. — W.

The amplitudes of N at these moments are — 5 and 0 cm., those of $S_a + S_{sa}$ 4 and 5 cm., thus the results will be :

	28 JUNE	11 JULY
Computation by approximation	10^h, 40 cm. — W	10^h, 29 cm. — W
Observed	10^h, 49 cm. — W	10^h, 42 cm. — W

The theoretical daily curves of the central part of the diagram are shown in Diagram 16, Plate 3. It will be explained later on why, in the given circumstances, the curves which were observed but are not available, cannot differ considerably from the theoretical curves.

On 28th June, at which date the neap tides of the two systems coincide, the curve still shows the influence of the hybrid curve (two high waters and one low water) of the preceding day. On the next day, the amplitude of higher high water begins to increase and the lower high water has already fallen below mean sea level, establishing in this way the diurnal character which lasts 3 days only. Next, the amplitude of higher low water increases while that of lower low water diminishes, the crest between the two approaches mean sea level gradually, passes it

4 days after the coincidence of the neap tides of both systems and reestablishes the semi-diurnal character of the curve which shows large daily inequalities and lasts 9 days. The high water reaches a maximum on the day which precedes that of coincidence of the spring tides of both systems, the low water maximum is reached the day after; during the decrease of these maxima, the amplitudes of the weak secondary high and low waters vary but little. On the day of diurnal neaps, the amplitudes of the two high waters are approximately the same and, the day following the semi-diurnal neaps, the former maximum high water falls below mean sea level. The diurnal character is then reestablished.

The curves of 27th to 30th June are nearly identical with those of 11th to 14th July.

A dip in mean sea level of 10 cm., in consequence of a strong gust of wind, would change the semi-diurnal character of two third of the observed curves of Diagram 15, and half of the theoretical curves of Diagram 16, into a diurnal. A similar rise would only affect the character of 7 diurnal observations which have not been inserted, because these are low high waters, and it would not produce any change in the character of a single curve of Diagram 16.

The second combination which should be considered is that of springs (neaps) of one system and neaps (springs) of the other.

It is given in Diagram 17 which, as might be expected, shows alternately a diurnal and a semi-diurnal character near the homonymous spring-tides. The two halves of the diagram are identical.

On 6th October, the middle date of the diagram, the amplitude of diurnal spring tide would be 54 cm. and that of neap tide is 10 cm., both with low water at 2 o'clock; the amplitude of semi-diurnal springs is 76 cm. with low water at 6 o'clock and would be 12 cm. with low water at noon for neap tides.

The daily curve corresponding to the coincidence of diurnal springs and semi-diurnal neaps will therefore have the form of No. 3 of Diagram 12 and the curve which corresponds to the coincidence of semi-diurnal springs and diurnal neaps will resemble No. 5 of Diagram 11. Except when the curve changes its character and shows very low high and very high low waters, the inequalities of the positive and negative amplitudes of the diurnal curves and the daily inequalities of the semi-diurnal curves will all be small.

The dates of diurnal springs are 28 September and 13 October, those of neap tides 21 September, 6 and 19 October; the dates of the semi-diurnal tide are 21 September, 6 and 20 October for spring tides and 28 September and 13 October for neap tides.

This gives the following combinations :

21 September	diurnal at 2 h.	— 5 cm.	21 September	semi-diurnal	— 78 cm. at 6 h.
28 „		— 51 „	28 „		— 11 „ „ noon.
6 October		— 10 „	6 October		— 76 „ „ 6 h.
13 „		— 57 „	13 „		— 14 „ „ noon.
19 „		— 15 „	20 „		— 72 „ „ 6 h.

Which give : 21 September 6 hours — 82 cm., 28 September 1 hour — 60 cm., 6 October 6 hours — 83 cm., 13 October 0 hour — 70 cm. and 20 October 6 hours — 76 cm., to which should be added : for *N*, — 9, — 8, + 9, + 2 and — 9 cm. and : for $S_a + S_{sa}$, — 3, — 4, — 5, — 5 and — 6 cm.

The result will be :

	COMPUTATION by approximation	OBSERVED
21 September	6^h, 94 cm. — *W*	5^h, 97 cm. — *W*
28 September	1^h, 72 cm. — *W*	0^h, 66 cm. — *W*
6 October	6^h, 79 cm. — *W*	5^h, 67 cm. — *W*
13 October	0^h, 73 cm. — *W*	
12 October		22^h, 61 cm. — *W*
20 October	6^h, 91 cm. — *W*	5^h, 67 cm. — *W*

The daily curves of diagram 18 agree with the foregoing conclusions.

Under the influence of semi-diurnal neap tide of that day and diurnal springs of the next day, these curves begin on 27th September with a diurnal character. On the following days high water developes, in consequence of the combined low waters of M_2 and *N*, a double crest, the valley between which has already fallen below mean sea level on the third day, establishing in this way the semi-diurnal character which becomes gradually more conspicuous and lasts 10 days. The daily inequality of the low waters diminishes and, the day of the coincidence of semi-diurnal springs and diurnal neaps, the semi-diurnal character is nearly pure. After this date the daily inequality of the high as well as that of the low waters increases and, 2 days before the coincidence of diurnal springs and semi-diurnal neaps, the low high water falls below mean sea level and the diurnal character is again visible. The curves of 13 and 14 October are identical with those of 27 and 28 October.

The combination which remains to be considered is that of springs (neaps) of one system alternating with neaps (springs) of the other system.

In April and May, the diurnal springs are followed, at an interval of

3 to 4 days, by semi-diurnal neaps and the semi-diurnal springs are preceded, at the same interval, by diurnal neaps; thus, every 7 days, an alternating semi-diurnal and diurnal character of the tide may be expected.

Indeed, Diagram 19 shows a diurnal character 5 to 7 days after diurnal springs and a semidiurnal character during 6 to 7 days before the semi-diurnal springs. The discrepancies which the diagram shows between the semi-diurnal and diurnal neaps (4 to 8 and 18 to 21 April) and between the semi-diurnal and diurnal springs (10 to 14 and 26 to 29 April) may be explained in the same way as is done for Diagram 15.

In this case the table given on page 86 is not sufficient to compute by approximation the height of the tide; the tables given on pages 71 and 71 will have to be considered also.

Choosing 9, 15 and 21 May as the days on which the time and amplitude of low water should be investigated, the following data are given:

1	May	diurnal	springs	with	low	water	at	$11^h.5$	and	height	74	cm.	— *W*.
10	,,	semi-diurnal	,,	,,	,,	,,	,,	$5^h.8$	,,	,,	70	,,	,,
14	,,	diurnal	,,	,,	,,	,,	,,	$11^h.5$	,,	,,	77	,,	,,
25	,,	semi-diurnal	,,	,,	,,	,,	,,	$17^h.8$	,,	,,	67	,,	,,

9 May, 8 days after diurnal springs, diurnal high water will occur at 9.5 hours with amplitude — 30 cm.; semi-diurnal low water occurs, 1 day before semi-diurnal springs, at 5.3 hours with amplitude — 70 cm.;

15 May, 1 day after diurnal springs and 5 days after semi-diurnal springs, diurnal low water will occur at 10.5 hours with 77 cm. — *W* and semi-diurnal low water at 8.9 hours with 37 cm. — *W*;

21 May, day of diurnal neap tides and 4 days before semi-diurnal springs, gives: diurnal low water at 10.7 hours and 26 cm. — *W*, semi-diurnal low water at 15.6 hours and 49 cm. — *W*.

The result will be:

9 May 6 o'clock and 94 cm. — *W*, 15 May 9 o'clock and 106 cm. — *W* and 21 May 15 o'clock and 37 cm. — *W*. Adding: 8, 3 and 9 cm. for *N* and 0, 1 and 2 cm. for $S_a + S_{sa}$, we get:

	9 MAY	15 MAY	21 MAY
Computation by approximation .	6^h, 102 cm. — *W*	9^h, 102 cm. — *W*	15^h, 26 cm. — *W*
Observed	5^h, 74 cm. — *W*	11^h, 78 cm. — *W*	15^h, 30 cm. — *W*

Diagram 20, which gives the daily curves of the middle part of No. 19, begins, 4 days after diurnal springs and 1 day after semi-diurnal neaps, with a diurnal curve which is on the point of changing into a semi-diurnal and the next day this character is nearly purely established. During the following days, the amplitude of the first low water increases continually and that of the second decreases while the level of the first high water varies but little and the second rises gradually.

On 11th May, the day after semi-diurnal spring tide, the positive and negative amplitudes reach a maximum, then the secondary high and low waters approach nearer to mean sea level every day and on 15 May, 2 days after diurnal springs, the curve re-assumes its practically pure diurnal character. This character is maintained during 6 days with fairly weak positive and negative amplitudes till the high water of M_2 succeeds, on the day after semi-diurnal neaps, in pushing the crest between the two low waters beyond mean sea level. The semi-diurnal character which the curve now assumes, is practically pure at once.

The mean of the differences between the observations and the 13 computations by approximation works out at + 0.6 hours and + 10 cm. Considering that the approximation is somewhat rough and that the principal constituents only have been taken into account, these discrepancies may practically be called unimportant.

It still remains to be proved that the theoretical daily curves of Diagrams 16, 18 and 20 cannot differ considerably from the curves which have been observed, but which are not available. As the observations of high and low water only are given, the material is limited to the following :

	NUMBER OF OBSERVATIONS	DIFFERENCE BETWEEN OBSERVATION AND COMPUTED HIGH AND LOW WATER						
		TIME			HEIGHT			
		0^h	1^h	2^h	0—1 dm.	1—2 dm.	2—3 dm.	3—4 dm.
High water....	92	47 %	45 %	8 %	55 %	24 %	13 %	8 %
Low water.....	92	48 %	46 %	6 %	56 %	22 %	15 %	7 %

Since the agreement of the differences between the observed and the computed high and low waters, the extreme points of the curves, may be said to be perfect, it appears to be permissible to assert that, apart from a possibly bodily removal, the theoretical curves will be identical with the observed.

Having studied the three preceding combinations, it is evident that it is useless to investigate levels (2) and (3) for mixed tides.

Level (1) has been calculated, but it is not very reliable on account of the great differences of the height of low water, which varies from naught to the maximum negative amplitude.

Level (3 *a*), giving the mean of the lowest low tides of each month according to the following table, is far more reliable :

1913			1918			1919			1920			1921			1922		
22 I	20^h	139 — W	12 I	19^h	120 — W	15 I	19^h	132 — W	7 I	19^h	116 — W	23 I	19^h	123 — W	14 I	19^h	116 — W
19 II	19^h	136	10 II	18^h	118	1 II	19^h	135	3 II	19^h	123	6, 9 II	18^h, 19^h	105	11 II	18^h	119
20 III	17^h	120	9 III	16^h	114	1 III	17^h	111	2 III	17^h	111	21 III	17^h	101	10 III	16^h	107
18 IV	16^h	100	8 IV	16^h	100	17, 30 IV	7^h, 6^h	98	8 IV	8^h	95	24 IV	7^h	87	8 IV	15^h	89
20 V	7^h	105	12 V	18^h	110	31 V	7^h	114	18, 19 V	5^h, 8^h	83	31 V	3^h	102	29 V	7^h	91
19 VI	6^h	116	25 VI	7^h	110	28, 29 VI	7^h, 8^h	112	17 VI	7^h	118	8 VI	8^h	105	25 VI	6^h	99
4 VII	7^h	127	23 VII	5^h	120	12, 26 VII	5^h	114	16 VII	7^h	122	5, 6 VII	6^h, 7^h	108	24 VII	5^h	114
2 VIII	7^h	129	22 VIII	5^h	126	11, 25 VIII	5^h	110	12 VIII	5^h	116	3 VIII	6^h	108	22 VIII	4^h	107
28 IX	4^h	123	18 IX	3^h	120	8 IX	5^h	116	10 IX	4^h	106	17, 28 IX	5^h, 3^h	98	5 IX	4^h	107
30 X	18^h	115	21, 22 X	19^h	107	7 X	4^h	108	7 X	3^h	93	30 X	18^h	92	23 X	19^h	97
29 XI	20^h	129	19 XI	18^h	119	11 XI	20^h	114	27 XI	20^h	125	17 XI	19^h	108	20 XI	19^h	107
27 XII	19^h	141	17 XII	20^h	130	7 XII	19^h	125	25 XII	19^h	125	29 XII	18^h	122	7 XII	20^h	117
Mean : 123 cm. — W, Lowest mean at intervals of 6 months : 133 cm. — W.			116 cm. — W 122 cm. — W			117 cm. — W 124 cm. — W			111 cm. — W 121 cm. — W			105 cm. — W 116 cm. — W			106 cm. — W 115 cm. — W		

Diagram 21 Plate 4 gives, in cm., the mean of the monthly departures from the mean of each year, which are :

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Departure in cm....	— 11	— 9	— 1	18	12	3	— 5	— 3	1	11	— 4	—14

The lowest tide of each month is accidental, therefore these departures do not correspond to the amplitude of $P + K_2 + S_a + S_{sa}$ and, from one year to another, level (3*a*) will be liable to freakish variations Besides, this level cannot be established theoretically and it should not be used as a level of reduction.

Level (3*b*), the yearly mean of the lowest water at intervals of 6 months, is more reliable because it is a natural level which varies but little if the decrease, which is a consequence of the declination of the moon, be not considered.

For 1913, 1921 and 1922, this level is the mean of the two observations made in January and July, for 1918, 1919 and 1920, it is respectively the mean of those made in February and August, March and September, June and December. However, these latter three levels differ respectively 2,1 and 2 cm. only from the mean of the observations made in January and July, so that there is no impediment to the adoption always of the mean of the two lower low waters of these months.

Diagram 22, Plate 4, gives the gradual, but not proportional fall of the two levels from 1913 to 1922 ; it will be noted that the curve of level (3*b*) for Soerabaja has less inclination than that for Djamoeanrif, Diagram 5, Plate 1.

Theoretically, level 3*b* can be computed by approximation as follows :

The combinations $-(K_1 + O + S_2)$ and $-(M_2 + S_2 + K_1)$ are always possible, so that the required amplitudes can be represented by : $-(K_1 + O + S_2 + \frac{1}{x} M_2)$ and $-(M_2 + S_2 + K_1 + \frac{1}{y} O)$; $\frac{1}{x}$ and $\frac{1}{y}$ are found by the table on page 96.

For Soerabaja, the following data are available for 1913 :

Time of low water semi-diurnal springs : 5.8 hours and 17.8 hours.

Months in which low water of K_1 falls at these hours : first week of August and February.

Dates of diurnal springs having low water at about 6 and 18 hours : 31 July and 3 February.

Dates of semi-diurnal springs as near as possible to these: 2 August and 5 February.

Amplitude of K_1 : — 52 cm., of O — 32 cm.

Thus, the low water springs of the two systems do not coincide at the same hour of the same day and the interval of time will be 2 hours at least.

On 31st July low water of M_2 falls at 4 hours, so at 6 hours $\frac{1}{x} M_2$ will be — 22 cm., and the total amplitude of low water at 6 hours 132 cm. — W, as it is also on 3 February at 18 hours.

The 2nd August low water of O falls at 11 hours; at 6 hours $\frac{1}{y} O$ will therefore be — 8 cm., and the low water reached 130 cm. — W ; on 5th February at 18 hours it will be 144 cm. — W.

Adding to these : 5, — 3, — 5 and 6 cm. for N and 5, 3, 5 and 2 cm. for $S_a + S_{sa}$, the result will be :

	COMPUTATION BY APPROXIMATION	OBSERVED
3 February	18^h, 132 cm. — W	15^h, 116 cm. — W
5 February	18^h, 136 cm. — W	fails
31 July	6^h, 122 cm. — W	6^h, 101 cm. — W
2 August	6^h, 130 cm. — W	7^h, 129 cm. — W

Computation by approximation gives a mean of 130 cm. — W, exact calculation gives 141 cm. — W.

The complete data for Soerabaja are :

SOERABAJA. Latitude 7°,2 S. Longitude 112°,6 E.

K_1 47 cm. 318°	M_2 44 cm. 351°	S_1 4 cm. 58°.
O 27 cm. 284°	S_2 26 cm. 355°	S_{sa} 5 cm. 120°.
P 14 cm. 321°	N 9 cm. 337°.	
	K_2 8 cm. 357°.	
	W 130 cm. — S. H. V. P.	

LEVEL OF	1913				1917-18	1918				1919				1920				1921				1922			
	Below W Theoretic	Below W Observed	Percentage of tides below	Percentage of tides below level 1917-18	Levels from curve	Below W Theoretic	Below W Observed	Percentage of tides below	Percentage of tides below level 1917-18	Below W Theoretic	Below W Observed	Percentage of tides below	Percentage of tides below level 1917-18	Below W Theoretic	Below W Observed	Percentage of tides below	Percentage of tides below level 1917-18	Below W Theoretic	Below W Observed	Percentage of tides below	Percentage of tides below level 1917-18	Below W Theoretic	Below W Observed	Percentage of tides below	Percentage of tides below level 1917-18
1 mean low water	—	60	—	—	—	—	65	—	—	—	62	—	—	—	59	—	—	—	53	—	—	—	54	—	—
3ª mean of lowest low tides of each month	—	123	4[a]	6[aa]	119	116	116	5[b]	2[bb]	—	117	3[c]	3[cc]	—	111	5[d]	2[dd]	—	105	5[e]	1[ee]	—	106	4[f]	—[ff]
3ᵇ mean of lowest low tides at interval of 6 months	141	133	1[g]	3[gg]	126	123	122	1[h]	—[hh]	123	124	1[i]	1[ii]	123	121	1[j]	—[jj]	131	116	1[k]	—[kk]	122	115	—[l]	—[ll]
4 lowest low tides	—	141	—	—	—	—	130	—	—	—	135	—	—	—	125	—	—	—	123	—	—	—	119	—	—

NEGATIVE CORRECTIONS

	a	*b*	*c*	*d*	*e*	*f*	*aa*	*bb*	*cc*	*dd*	*ee*	*ff*	*g*	*h*	*i*	*j*	*k*	*l*	*gg*	*hh*	*ii*	*jj*	*kk*	*ll*
0–1 dm.	3 %	4 %	2 %	4 %	4 %	4 %	3 %	2 %	2 %	2 %	1 %	—	1 %	1 %	1 %	1 %	1 %	—	2 %	—	1 %	—	—	—
1–2 ,,	1	1	1	1	1	—	3	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—

POSITIVE CORRECTIONS

	a	*b*	*c*	*d*	*e*	*f*	*aa*	*bb*	*cc*	*dd*	*ee*	*ff*	*g*	*h*	*i*	*j*	*k*	*l*	*gg*	*hh*	*ii*	*jj*	*kk*	*ll*
0–1 dm.	6 %	8 %	9 %	7 %	7 %	9 %	8 %	7 %	7 %	5 %	2 %	2 %	3 %	5 %	3 %	4 %	3 %	4 %	4 %	1 %	2 %	3 %	1 %	—
1–2 ,,	9	10	8	9	9	8	11	10	10	8	7	6	6	10	9	7	7	9	9	5	9	7	3	4 %
2–3 ,,	10	9	10	9	10	8	8	9	9	8	8	8	9	9	10	9	9	8	10	10	8	7	7	9
3–4 ,,	11	12	9	9	10	12	10	10	10	9	10	8	10	9	10	9	9	8	9	9	10	9	9	8
4–5 ,,	8	9	10	9	10	9	8	11	10	10	10	11	11	12	9	9	11	12	9	9	9	9	9	8
5–6 ,,	8	8	8	9	9	8	8	9	9	8	9	11	8	10	10	9	9	9	8	12	10	9	11	12
6–7 ,,	8	8	7	9	6	9	8	8	7	9	10	8	8	6	8	9	9	8	8	10	8	10	9	9
7–8 ,,	7	7	8	8	9	8	7	7	7	9	7	9	8	9	8	9	7	9	8	6	7	8	9	8
8–9 ,,	6	8	7	8	10	9	7	8	8	8	7	8	7	8	8	8	8	8	7	9	8	9	7	9
9–10 ,,	7	6	6	9	9	10	6	7	7	7	10	8	6	7	6	8	9	9	7	8	7	8	8	8
10–11 ,,	8	6	8	8	6	6	8	6	7	10	9	8	7	6	7	9	9	10	7	7	6	8	9	9
11–12 ,,	5	4	7	1	—	—	5	6	6	7	10	11	8	6	7	8	9	6	6	6	8	8	9	10
12–13 ,,	3	—	—	—	—	—	—	—	—	—	—	—	5	2	4	1	—	—	5	8	7	5	9	6
13–14 ,,	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—

It will be noted that the maximum percentage of positive corrections no longer coincides with mean low water, as occurs for tides of a simple system. This discrepancy is caused by the fact that the low waters no longer oscillate freely about level (1), because their upper oscillations are stopped by mean sea level; as soon as they rise beyond this level, they are no longer low waters.

Except for Soerabaja and its approaches, the soundings of the East Indian Archipelago are reduced to level (3 *b*). Though wrongly, it is still called "Laagwater spring" (low water springs) because this name is familiar to the seaman and it was given to the level of reduction at the time when knowledge of the tides in these regions was still imperfect. The tendency to over-reduce soundings which, as a rule, existed in hydrographic surveys made before exact knowledge of the tides of the Archipelago had been attained, probably compensates for the lowering of the level which was adopted later on.

In order to have an absolutely stable level of reduction for the periodic surveys of Soerabaja roads, soundings are reduced to 260 cm. — S. H. V. P. (*see* note on page 75) which corresponds to 130 cm. — *W* and differs 4 cm. only from level (3 *b*) for a year of mean lunar declination.

ADEN provides an example of this sort of mixed tides where the low water springs of the two systems coincide at the same hour of the same day at intervals of 6 months. This coincidence occurs at the end of June at 14 hours and at the end of December at 2 hours, the theoretical level reached in both cases is 148 cm. — *W*.

The lowest tides which are observed in each month of the years which are available, are as shown on page 109.

Represented as curves, the maxima at intervals of 6 months give Diagram 23, Plate 4, which shows less inclination and greater distance between the curves than that of Soerabaja.

Deducing from the diagram the heights of 138 cm. — *W* and 153 cm. — *W* for levels (3*a*) and (3*b*) for the year 1918 of mean declination of the moon, the complete data for Aden are given on page 110.

1903			1904			1916			1915		
13 I	2^h	150 — W	3 I	2^h	142 — W	4, 5 I	1^h, 2	150 — W	15 I	2^h	142 — W
II	—	—	1 II	2	135	2 II	1	137	11 II	0	132
12, 31 III	2	97	3 III	3	84	1 III	0	109	1 III	2	99
29 IV	2	112	30 IV	14	114	19 IV	15	127	30 IV	15	142
28 V	2	127	29 V	14	114	19 V	3	147	29 V	15	152
25 VI	14	140	13 VI	14	129	16 VI	15	152	26 VI	14	160
25 VII	2	145	12 VII	14	139	23 VII	13	142	25 VII	14	148
22 VIII	1	135	11 VIII	14	137	12 VIII	13	158	22 VIII	13	132
23 IX	3	112	8 IX	13	127	8 IX	12	127	13 IX	4	120
22 X	3	122	10 X	2	132	28 X	2	140	11 X	3	140
7 XI	3	135	9 XI	3	142	26 XI	2	145	8, 9 XI	2, 3	157
5 XII	2	138	7 X II	2	140	25 XII	2	152	6 XII	1	162
Mean : 128 cm. — W			128 cm. — W			141 cm. — W			141 cm. — W		
Maximum mean at interval of 6 months : 147 cm. — W			140 cm. — W			152 cm. — W			161 cm. — W		

1914			1912			1913		
12 I	2^h	145 — W	4, 5 I	2^h	160 — W	22 I	2^h	155 — W
10 II	2	132	2 II	2	150	20 II	2	137
14, 15 III	16, 17	114	2 III	1	127	20 III	1	112
11 IV	15	137	20 IV	16	111	22 IV	3	125
10 V	2	145	17, 18 V	14, 15	142	20 V	2	130
7 VI	14	150	16 VI	15	147	18 VI	2	132
6 VII	13	153	13 VII	13	160	4, 5 VII	14, 2	145
3, 5 VIII	13, 14	137	11, 12 VIII	13, 14	160	3 VIII	2	157
23 IX	4	142	9 IX	13	137	1 IX	2	140
21 X	3	160	11, 12 X	14, 15	132	31 X	3	160
18 XI	2	167	26 XI	3	147	28 XI	2	152
17 XII	2	160	24 XII	2	155	26 XII	1	137
Mean : 145 cm. — W			144 cm. — W			140 cm. — W		
Maximum mean at interval of 6 months : 155 cm. — W			160 cm. — W			150 cm. — W		

ADEN. Latitude 12°,8 N. Longitude 5° E.

M_2 47 cm. 226° K_1 44 cm. 35° S_1 11 cm. 345°.
S_2 21 cm. 245° O 24 cm. 37° S_{sa} 4 cm. 128°.
N 13 cm. 222° P 12 cm. 32°
K_2 6 cm. 239°

W 178 cm. + O.

LEVEL OF	1913 Below W THEORETIC	1913 Below W OBSERVED	1913 PERCENTAGE of tides below	1913 PERCENTAGE of tides below level 1917-18	1914 Below W THEORETIC	1914 Below W OBSERVED	1914 PERCENTAGE of tides below	1914 PERCENTAGE of tides below level 1917-18	1912 Below W THEORETIC	1912 Below W OBSERVED	1912 PERCENTAGE of tides below	1912 PERCENTAGE of tides below level 1917-18	1915 Below W THEORETIC	1915 Below W OBSERVED	1915 PERCENTAGE of tides below	1915 PERCENTAGE of tides below level 1917-18
1 mean low water	—	74	—	—	—	70	—	—	—	70	—	—	—	68	—	—
3a mean of lowest low tides of each month	—	140	4^{a}	4^{aa}	—	145	3_{b}	6^{bb}	—	144	4^{c}	5^{cc}	—	141	4^{d}	4^{dd}
3b mean of lowest low tides at interval of 6 months	148	150	2^{h}	3^{hh}	151	155	1^{i}	2^{ii}	158	160	$—^{j}$	$—^{jj}$	155	161	$—^{k}$	1^{kk}
5 lowest low tides	—	160	—	—	—	167	—	—	—	160	—	—	—	162	—	—

LEVEL OF	1916 Below W THEORETIC	1916 Below W OBSERVED	1916 PERCENTAGE of tides below	1916 PERCENTAGE of tides below level 1917-18	1908 LEVELS FROM CURVE	1904 Below W THEORETIC	1904 Below W OBSERVED	1904 PERCENTAGE of tides below	1904 PERCENTAGE of tides below level 1917-18	1903 Below W THEORETIC	1903 Below W OBSERVED	1903 PERCENTAGE of tides below	1903 PERCENTAGE of tides below level 1917-18
1 mean low water	—	69	—	—	—	—	69	—	—	—	59	—	—
3a mean of lowest low tides of each month	—	141	4^{e}	5^{ee}	138	—	128	3^{f}	1^{ff}	—	128	3_{g}	1^{gg}
3b mean of lowest low tides at interval of 6 months	152	152	$—^{l}$	$—^{ll}$	153	138	140	$—^{m}$	$—^{mm}$	146	147	$—^{n}$	$—^{nn}$
5 lowest low tides	—	—	—	—	—	—	142	—	—	—	150	—	—

NEGATIVE CORRECTIONS

	a	b	c	d	e	f	g	aa	bb	cc	dd	ee	ff	gg	h	i	j	k	l	m	n	hh	ii	jj	kk	ll	mm	nn
0–1 dm.	2%	2%	2%	2%	3%	2%	2%	2%	4%	3%	2%	3%	1%	1%	2%	1%	—	—	—	—	—	1%	2%	1%	1%	—	—	—
1–2 ,,	2	1	2	2	1	1	1	2	1	2	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2–3 ,,	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

POSITIVE CORRECTIONS

	a	b	c	d	e	f	g	aa	bb	cc	dd	ee	ff	gg	h	i	j	k	l	m	n	hh	ii	jj	kk	ll	mm	nn
0–1 dm.	4%	3%	3%	2%	3%	3%	3%	5%	3%	3%	3%	3%	2%	2%	2%	2%	2%	2%	2%	2%	1%	2%	3%	2%	2%	2%	—	—
1–2 ,,	7	5	5	4	5	6	4	8	5	4	4	5	3	3	4	3	3	2	2	3	2	4	3	3	3	3	2%	2%
2–3 ,,	8	5	3	5	4	6	6	8	4	6	5	6	6	4	7	5	3	2	5	4	3	7	5	5	2	5	3	2
3–4 ,,	7	6	8	7	8	6	9	7	8	7	11	9	6	6	8	5	4	4	5	6	6	7	6	4	6	4	4	2
4–5 ,,	8	8	8	9	10	8	10	8	6	8	7	8	6	9	7	6	6	5	8	5	8	8	6	8	4	8	6	4
5–6 ,,	7	6	7	7	7	7	8	7	12	8	8	6	8	10	8	8	7	7	10	7	9	8	8	8	11	10	5	7
6–7 ,,	8	9	9	9	8	9	9	9	8	9	9	9	7	8	7	6	8	9	8	9	9	7	8	9	7	6	7	9
7–8 ,,	8	9	8	8	7	9	8	6	7	7	7	6	9	9	8	9	8	7	8	8	8	8	8	8	9	9	9	9
8–9 ,,	7	7	6	8	7	7	9	8	9	7	9	8	9	8	8	9	9	9	7	11	9	8	7	8	8	6	8	8
9–10 ,,	7	8	7	7	8	10	7	7	7	8	6	8	7	9	7	7	7	8	7	7	9	7	8	7	8	7	11	9
10–11 ,,	8	6	8	6	8	7	6	7	6	7	7	6	10	6	7	8	7	8	8	8	8	7	6	7	8	9	7	8
11–12 ,,	6	7	5	8	5	9	9	6	6	6	6	6	7	8	8	6	8	7	8	8	8	7	7	8	5	8	8	8
12–13 ,,	6	6	7	7	6	10	9	6	6	7	7	6	9	9	6	7	7	6	4	9	7	6	7	3	8	6	8	7
13–14 ,	5	8	8	7	8	—	—	3	7	8	7	9	10	9	6	6	6	8	6	13	7	6	7	8	7	6	9	8
14–15 ,,	—	4	4	2	2	—	—	—	—	—	—	—	—	—	5	8	7	7	7	—	6	6	8	7	7	7	11	10
15–16 ,,	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	8	9	4	—	—	1	1	4	4	4	2	7

For predicting the hours and heights of high and low waters at Aden, 24 constants have been taken into account by the Physical Laboratory of Teddington and the result is :

	NUMBER OF OBSERVATIONS	DIFFERENCE OF LEVEL			DIFFERENCE OF TIME					MEAN ERROR	
		0—1 dm.	1—2 dm.	2—3 dm.	0—5 min.	6—15 min.	16—20 min.	21—30 min.	> 30 min.	LEVEL	TIME
1903 high water.....	674	96%	4%	—	42%	46%	5%	5%	2%	5 cm.	8m
low water	673	96	4	—	39	47	6	6	2	5 ,,	9
'4 high water.....	689	96	4	—	32	44	13	9	2	5 ,,	11
low water......	665	96	4	—	25	39	13	7	6	5 ,,	14
'12 high water.....	679	95	5	—	42	46	6	4	2	5 ,,	8
low water......	676	93	3	—	39	44	7	7	3	5 ,,	9
'13 high water.....	664	92	8	—	40	47	7	4	2	—	9
low water......	661	94	5	—	42	20	10	5	3	—	9
'14 high water.....	673	96	4	—	29	39	11	13	8	5 ,,	13
low water......	666	92	8	—	29	43	12	9	7	5 ,,	13
'15 high water.....	682	92	8	—	48	46	4	2	—	5 ,,	7
low water......	677	95	5	—	47	45	5	2	1	5 ,,	7
'16 high water.....	667	92	8	—	32	46	11	8	3	5 ,,	11
low water......	660	92	8	—	33	44	11	8	4	5 ,,	11
mean..........	672	94%	6%	—	3%	43%	9%	7%	3%	4 cm.	10m

The fact that 94 % of the observations give a departure of less than 1 dm. from the theoretical amplitude and 80 % differ at most 15 minutes in time, prove the correctness of the constants.

SEMBILANGAN, to the North of Soerabaja, gives an example of a mixed tide with a preponderant diurnal tide, $\frac{K_1 + O}{M_2 + S_2}$ being $\frac{71}{33}$.

The low water springs of the two systems do not coincide at the same hour of the same day, the lowest tides are observed early in February and August.

For 1922 the following combinations of low water springs are found :

Diurnal : 9 February at 18 hours with 59 cm. — *W* and semidiurnal : 11 February 18 hours with 31 cm. — *W* ;

Diurnal : 5 August at 6 hours with 59 cm. — *W* and semidiurnal : 8 August at 6 hours with 36 cm. — *W*.

The result of these combinations is : 10 February at 18 hours : 86 cm. — *W*, and 7 August at 6 hours : 87 cm. — *W*, to which levels should be added respectively : 5 and 5 cm. for $S_a + S_{sa}$, thus the following are obtained :

	10 FEBRUARY	7 AUGUST
Computation by approximation.......	18^h, 81 cm. — W	6^h, 82 cm. — W
	11 FEBRUARY	6 AUGUST
Observation	20^h, 102 cm. — W	7^h, 85 cm. — W

The character of the tide is preponderantly diurnal and this shows up best in years of maximum declination of the moon as is shown in the next table.

	1913	1916	1917	1918	1919	1920	1922
Number of observations....	397	386	366	417	420	423	453
Percentage { diurnal	80	83	75	65	68	62	59
Percentage { semi-diurnal..	20	17	25	35	32	38	41

The complete data for Sembilangan are :

SEMBILANGAN. Latitude 7°1 S. Longitude 112°7 E.
K_1 46 cm. 319° M_2 18 cm. 356° S_1 4 cm. 46°
O 25 ,, 277° S_2 15 ,, 4° S_a 5 ,, 133°
P 10 ,, 322°
W 127 cm. — S. H. V. P.

LEVEL OF	1913 Below W Theoretic	1913 Below W Observed	1913 Percentage of tides below	1913 Percentage of tides below level 1917-18	1916 Below W Theoretic	1916 Below W Observed	1916 Percentage of tides below	1916 Percentage of tides below level 1917-18	1917 Below W Theoretic	1917 Below W Observed	1917 Percentage of tides below	1917 Percentage of tides below level 1917-18	1917-18 Level from curve
1 Mean low water	—	73	—	—	—	67	—	—	—	61	—	—	—
3a Mean of lowest low tides of each mouth	—	113	7[a]	14[aa]	—	112	3[b]	9[bb]	—	97	10[c]	4[cc]	104
3b Mean of lowest low tides at interval of 6 months	109	128	1[h]	5[hh]	103	131	1[i]	2[ii]	102	116	1[j]	1[jj]	119
5 Lowest low tides	—	133	—	—	—	143	—	—	—	129	—	—	—

LEVEL OF	1918 Below W Theoretic	1918 Below W Observed	1918 Percentage of tides below	1918 Percentage of tides below level 1917-18	1919 Below W Theoretic	1919 Below W Observed	1919 Percentage of tides below	1919 Percentage of tides below level 1917-18	1920 Below W Theoretic	1920 Below W Observed	1920 Percentage of tides below	1920 Percentage of tides below level 1917-18	1922 Below W Theoretic	1922 Below W Observed	1922 Percentage of tides below	1922 Percentage of tides below level 1917-18
1 Mean low water	—	63	—	—	—	63	—	—	—	57	—	—	—	44	—	—
3a Mean of lowest low tides of each mouth	—	102	6[d]	4[dd]	—	100	5[e]	3[ee]	—	98	3[f]	1[ff]	—	88	5[g]	—[gg]
3b Mean of lowest low tides at interval of 6 months	96	112	1[k]	—[kk]	95	116	1[l]	—[ll]	91	109	1[m]	—[mm]	88	99	1[n]	—[nn]
5 Lowest low tides	—	121	—	—	—	125	—	—	—	123	—	—	—	106	—	—

NEGATIVE CORRECTIONS

	a	b	c	d	e	f	g	aa	bb	cc	dd	ee	ff	gg	h	i	j	k	l	m	n	hh	ii	jj	kk	ll	mm	nn
0–1 dm.	4%	2%	8%	5%	4%	2%	4%	7%	6%	3%	4%	2%	1%	—	1%	1%	1%	1%	1%	1%	1%	4%	1%	1%	—	—	—	—
1–2 ,, ...	3	1	1	1	1	1	1	4	2	1	—	1	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—
2–3 ,, ...	—	—	1	—	—	—	—	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

POSITIVE CORRECTIONS

	a	b	c	d	e	f	g	aa	bb	cc	dd	ee	ff	gg	h	i	j	k	l	m	n	hh	ii	jj	kk	ll	mm	nn
0–1 dm.	8%	7%	7%	10%	10%	8%	10%	12%	7%	7%	10%	8%	4%	2%	4%	1%	1%	5%	2%	2%	4%	6%	4%	1%	2%	2%	1%	—
1–2 ,, ...	12	8	13	11	12	12	15	12	15	11	11	10	9	7	5	3	8	10	5	7	8	11	7	6	8	5	2	1%
2–3 ,, ...	12	16	15	14	16	13	10	14	14	13	13	16	13	11	11	7	7	11	12	11	15	12	12	8	10	11	7	4
3–4 ,, ...	14	12	11	10	13	16	15	11	12	15	11	13	14	13	12	10	15	14	15	14	10	12	14	12	11	14	11	8
4–5 ,, ...	11	14	10	12	11	12	11	12	13	12	12	13	16	11	13	13	15	10	15	15	16	13	12	15	14	14	14	15
5–6 ,, ...	12	12	10	10	12	13	11	9	10	8	9	11	11	14	12	13	12	12	12	13	11	12	13	13	12	12	15	10
6–7 ,, ...	8	9	8	9	8	9	9	7	8	9	11	9	12	13	12	15	10	10	10	12	11	10	11	10	10	10	13	16
7–8 ,, ...	7	8	8	6	5	7	7	4	7	8	6	8	6	10	9	12	10	9	10	10	10	8	8	10	11	12	12	11
8–9 ,, ...	4	7	5	5	5	5	7	2	3	7	6	4	7	9	10	7	8	6	7	7	8	4	8	8	8	8	10	11
9–10 ,, ...	2	2	3	4	3	2	—	2	2	5	4	3	5	7	4	8	7	5	5	5	6	3	5	7	6	6	7	10
10–11 ,, ...	3	2	—	3	—	—	—	1	—	1	3	2	2	3	3	6	4	4	3	3	—	2	3	6	4	3	5	8
11–12 ,, ...	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	2	3	3	—	—	2	1	3	4	3	3	6
12–13 ,, ...		—	—	—	—	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—

It appears from these three examples that *level* (3*b*), *the yearly mean of the lowest tides at intervals of* 6 *months for a year of mean lunar declination, constitutes an appropriate level of reduction for mixed tides.* If abnormal cases be not considered, minimal negative corrections will have to be applied in years of great lunar declination only.

TIDES HAVING SMALL RANGES

As the mixed tides of the Mediterranean, and even the semi-diurnal tides of the Zuiderzee in the Netherlands, still have ranges of sufficient importance to be discussed in the same way as is done for the tides of these systems, the tides of the Baltic and in the gulf of Bothnia have been chosen as typical small range tides.

The tides of this inland sea are mixed with a preponderant diurnal character and the sum of the amplitudes of the four principal constituents does not exceed 3 to 5 cm. (1.2 to 2 inch.). The atmospheric disturbances and those caused by ice are much more important and their influence varies considerably from one year to an-other.

The available observations are those made at Arkona, on the North Coast of Germany, during the years 1882, 1883 and 1887 ; those made at Ystad, on the South Coast of Sweden, from 1907 to 1910 inclusive, and those made at Ratan, on the Swedish Coast of the Gulf of Bothnia, during the same years.

Mean sea level deduced from a long series of years, the same level for the years in which the observations were made and the monthly departures from the mean of each year are as follows :

	YEARLY MEAN	DEPARTURE FROM ANNUAL MEAN IN CENTIMÈTRES											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
ARKONA. 1882-1904, 441,2 cm. — O (0,035 M — Normal Null)													
1882	444,4 cm. — o	5,8	7,8	16,8	— 7,1	3	5,1	2,6	10,7	8	— *20*	— 8,3	— 18,6
1883	444,6 ,,	— 18,2	— 19,1	— 3,8	— 10,6	— 9	3,1	4,4	9,7	9,1	2,4	9,9	**22,1**
1887	441,6 ,,	— 15,5	— 12,1	— 2,8	— 9,2	— 7	0	4,3	9,6	9,6	5,1	4,8	13
Mean	443,5 ,,	— 9,2	— 7,8	3,4	— 8,7	— 6,3	2,7	3,8	10	8,9	4,1	2,1	5,5
Average departure of mean		6,2	5,2	4,8	1,4	2,2	1,8	0,8	0,5	0,6	6,2	5,6	12,4
YSTAD, 1887-1922, 402,4 cm. — O													
1907	403,6 cm. — o	0,6	— 8,4	5,6	— 8,4	— 0,4	— 6,4	8,6	17,6	17,6	— 0,4	— 18,4	— 7,4
1908	408,1 ,,	— 6,9	**24,1**	— 9,9	— *19,9*	— 5,9	— 1,9	1,1	9,1	14,1	— 0,9	— 13,9	11,1
1909	403,9 ,,	— 12,1	2,9	— 17,1	— 14,1	— 10,1	0,9	6,9	19,9	7,9	— 2,1	15,9	0,9
1910	402,6 ,,	16,6	3,6	— 6,4	— 9,4	— 0,4	— 5,4	9,6	5,6	— 2,4	2,6	— 1,4	— 12,6
Mean	404,5 ,,	— 0,4	5,6	— 6,9	— 12,9	— 4,2	— 3,2	6,5	13	9,3	— 0,2	— 4,4	— 2
Average departure of mean		7,6	6,5	3,8	3,8	3,8	2,2	2,7	5,7	5,3	1,3	9,5	6,5
RATAN. 1892-1920, 382,2 cm. — O													
1907	380,4 cm. — o	9,4	6,4	12,4	— 16,6	— 11,6	— 8,6	— 2,6	28,4	25,4	— 6,6	— 14,6	— 20,6
1908	390,9 ,,	4,9	30,9	— 19,1	— 30,1	— 6,1	— 4,1	— 7,1	6,9	17,9	— 2,1	— 5,1	13,9
1909	384,6 ,,	14,6	— 4,4	— 31,4	— *28,4*	— 13,4	— 5,4	8,6	24,6	6,6	14,6	4,6	9,6
1910	386,2 ,,	**33,2**	26,2	— 0,8	— 6,8	— 8,8	— 12,8	0,2	— 9,8	— 10,8	— 1,8	2,2	— 10,8
Mean	385,5 ,,	15,5	14,8	— 9,7	— 20,5	— 10	— 7,7	— 0,2	12,5	9,8	1	— 3,2	— 2
Average departure of mean		8,8	11,6	10,7	8,8	2,5	3	4,4	9,1	7	5,3	4,9	11,7

The best datum from which to judge the constancy of the influence of meteorologic disturbances and that of ice in the various months is undoubtedly the mean of the monthly departures from their mean, which is given in the last line of the table and called " average departure of mean ", the algebraic sign being neglected.

It shows that, for the years considered, this influence is most constant at Arkona from April to September inclusive, for Ystad in June, July and October and at Ratan in May and June.

Giving the amplitudes in cm. and counting the $\varkappa$ numbers of S_a and S_{sa} from 21 March, the harmonic constants for the three places are :

	K_1	O	M_2	S_2	S_a	S_{sa}	N_2
ARKONA							
Reichs Marine Amt, 1898	1,3 cm. 169°	1,5 cm. 156°	1,0 cm. 267°	0,5 cm. 262°	—	—	—
Reichs Marine Amt, '99	1,5 ,, 167	1,6 ,, 178	0,9 ,, 265	0,5 ,, 283	—	—	—
Witting, 1892–1900	—	—	1 ,, 249	0,6 ,, 283	5,8 cm. 202°	2,7 cm. 291°	—
Witting, 1904	—	—	—	—	11,5 ,, 183	7,8 ,, 192	—
YSTAD							
Tidal Institute of Liverpool, 1907	1,6 cm. 147°	1,6 cm. 148°	1,1 cm. 171°	0 cm. 207°	8,1 cm. 133°	9,7 cm. 306°	0,4 cm. 177°
Tidal Institute of Liverpool, '08	1,5 ,, 148	1,9 ,, 117	1,2 ,, 166	0,5 ,, 209	5,3 ,, 205	10,1 ,, 272	0,2 ,, 210°
Tidal Institute of Liverpool, '09	1,6 ,, 163	1,2 ,, 139	1,2 ,, 173	0,6 ,, 227	12,1 ,, 178	4,3 ,, 242	0,1 ,, 180
Tidal Institute of Liverpool, '10	1,8 ,, 147	1,4 ,, 112	1,2 ,, 169	0,5 ,, 196	2,1 ,, 190	6,4 ,, 257	0,2 ,, 169
Mean	1,6 ,, 151	1,5 ,, 129	1,2 ,, 170	0,6 ,, 210	6,9 ,, 176	7,6 ,, 269	0,2 ,, 184
Witting, 1892–1900	—	—	—	—	6,1 ,, 201	2,5 ,, 284	—
RATAN							
Witting, 1892–1900	—	—	—	—	12,3 cm. 215°	2,5 cm. 286°	—
Witting, 1904	1,4 cm. 7°	1,1 cm. 324°	0,2 cm. 13°	0,2 cm. 2°	13,3 ,, 195	13,4 ,, 182	—
Witting, '05	—	—	—	—	12,3 ,, 253	14,8 ,, 262	—

In examining these constants, the first question which arises directly is whether the accuracy of the observations is such as to allow the constants to be given in mm.

The " Deutsche Marine Amt " gives the observations made at Arkona in mm., but does not give any information on the subject. The Kungl. Nautisk-Meteorologiska Byran of Sweden gives them in cm., and announces that the " periodicity " of the observations made at Ystad and Ratan does not exceed 1 to 2 mm.

This accuracy is undoubtedly reached by the use of first class instruments, by taking minute precautions to quench, nearly absolutely, movements of the surface of the water at the float and by maintaining a nearly constant temperature in the shed of the selfregistering tide-gauge. But, even if the observations have not been made with the accuracy stated, there would not be any impediment to expressing the constants in mm., provided that it be well understood that this is a result of computation and not a reliable absolute measure.

The four principal constituents at Arkona and Ystad agree far better in the years mentioned than was expected, the maximum departure from the mean amplitude is not more than a few mm. and the greatest departure from the mean $\varkappa$ number does not exceed 1.3 hours for the diurnal tide and 0.6 hours for the semi-diurnal. Although the diurnal tide is more important than the semi-diurnal, the mean of the yearly constants of the former has less weight than that of the latter, because the number of revolutions from which the semi-diurnal constants are deduced is twice as great as that from which the diurnal are calculated.

The same agreement is not found for the constituents S_a and S_{sa}.

Notwithstanding that, except for the amplitude of S_{sa} at Ystad, the mean constants of the Tidal Institute of Liverpool agree fairly well with those found by Prof. WITTING, the departures from the mean for the years 1907 to 1910 inclusive are fairly considerable, both for the amplitudes and for the $\varkappa$ numbers. Except for the amplitudes of S_a at Ratan, the great differences between the mean constants which Prof. WITTING deduced for the years 1892-1900 and those for the years 1904 and 1905 show that these constants for Arkona and Ratan are not very reliable either.

Accepting for the constants of S_a and S_{sa} at these two places the mean constants for 1892-1900 of Prof. WITTING and for Ystad the mean of these constants and those of Liverpool, we get for the amplitudes in cm.:

	K_1	O	M_2	S_2	TOTAL	S_a	S_{sa}	TOTAL
Arkona.......	1,4 cm.	1,5 cm.	1 cm.	0,5 cm.	4,4 cm.	5,8 cm.	2,7 cm.	8,5 cm.
Ystad........	1,6 cm.	1,5 cm.	1,2 cm.	0,6 cm.	4,9 cm.	6,5 cm.	5 cm.	11,5 cm.
Ratan........	1,4 cm.	1,1 cm.	0,2 cm.	0,2 cm.	2,9 cm.	12,3 cm.	2,5 cm.	14,8 cm.

The fact that the sum of the amplitudes of S_a and S_{sa} for the three places is respectively 2, 2 1/2 and 5 times that of the four principal constituents, indicates that the harmonic constants of the Baltic and the Gulf of Bothnia should be used with great caution. They may serve to compare the tides of different places, but they are of no value for the calculation of the absolute height of the tide.

On this account it is impossible to deduce a theoretical level of reduction by means of the constants.

Computation by approximation of the constants for each month separately gives an excellent result for tides which have a normal range. In order to investigate whether this method is applicable also for tides having very small ranges, if these months only in which the atmospheric disturbances and the influence of the ice are fairly constant be considered, the results for Arkona and Ystad are given. This computation by approximation has not been made for Ratan, because two months only would be dealt with.

1887	K_1	O	M_2			S_2
			1882	1883	1887	
IV	0,5 cm. 131°	2,7 cm. 111°	0,8 cm. 257°	1 cm. 220°	1 cm. 247°	0,5 cm. 267°
V	1,9 ,, 168	2,8 ,, 124	1,2 ,, 262	1,1 ,, 236	1 ,, 250	0,6 ,, 261
VI	1,4 ,, 101	1,2 ,, 145	1,2 ,, 265	0,9 ,, 239	0,5 ,, 254	0,7 ,, 278
VII	1,7 ,, 212	2,4 ,, 156	0,7 ,, 243	1 ,, 244	1,3 ,, 273	0,4 ,, 315
VIII	0,5 ,, 170	0,5 ,, 148	1,2 ,, 241	1,3 ,, 256	1 ,, 267	0,5 ,, 290
XI	1,1 ,, 220	2,2 ,, 216	1,2 ,, 246	0,9 ,, 252	1,2 ,, 258	1,1 ,, 258
Mean	1,2 ,, 167°	2 ,, 150°	1 ,, 252°	1 ,, 241°	1 ,, 258°	0,6 ,, 270°
Average departure of mean.....	0,5 ,, 34°	0,7 ,, 24°	0,2 ,, 9°	0,1 ,, 9°	0,2 ,, 8°	0,2 ,, 16°

YSTAD	K_1	O	M_2	S_2
1907 VI	2,9 cm. 116°	2,2 cm. 181°	1 cm. 167°	0,3 cm. 191°
VII	1,7 ,, 123	2,3 ,, 162	1,2 ,, 170	0,5 ,, 210°
X	1,3 ,, 137	0,9 ,, 130	1,3 ,, 160	1,1 ,, 192
Mean	2 ,, 125°	1,8 ,, 158°	1,2 ,, 166°	0,6 ,, 198°
1908 VI	1,9 cm. 89°	1,3 cm. 158°	1,2 cm. 169°	0,5.cm. 232°
VII	2 ,, 165	0,8 ,, 120	1,3 ,, 181	0,5 ,, 259
X	2,5 ,, 140	2,6 ,, 126	1,1 ,, 186	1,3 ,, 197
Mean	2,1 ,, 131°	1,6 ,, 135°	1,2 ,, 179°	0,8 ,, 229°
1909 VI	2 cm. 162°	1,6 cm. 164°	1,2 cm. 165°	0,2 cm. 186°
VII	1 ,, 162	0,9 ,, 85	1 ,, 176	0,9 ,, 254
X	1,1 ,, 57	1,9 ,, 62	1,3 ,, 196	1 ,, 205
Mean	1,4 ,, 127°	1,5 ,, 104°	1,2 ,, 179°	0,7 ,, 215°
1910 VI	1,6 cm. 133°	1,6 cm. 115°	1,2 cm. 159°	0,2 cm. 221°
VII	2,6 ,, 160	2,9 ,, 121	1,1 ,, 173	0,6 ,, 213
X	0,9 ,, 204°	4 ,, 192	1,1 ,, 163	0,8 ,, 227
Mean	1,7 ,, 166°	2,8 ,, 143°	1,1 ,, 165°	0,5 ,, 220°
General mean	1,8 cm. 137°	1,9 cm. 135°	1,2 cm. 172°	0,6 cm. 215°
Average departure of mean	0,5 cm. 28°	0,7 cm. 31°	0,1 cm. 9°	0,3 cm. 19°

It can be said beforehand that this method will not give satisfactory results for the $\varkappa$ numbers, because the tangent of the auxiliary angle, which should be added to the astronomical argument in order to find this number, is the quotient of two values which depend on the sums and on the differences of the observations. If these observations rise but little above mean sea level or fall but a trifle below it, each disturbance may entail a considerable change of this quotient and, as soon as angles are involved the tangent of which varies but little, the result may be a considerable number of degrees out.

Indeed, although the mean of the $\varkappa$ numbers found by computation by approximation agrees fairly well with the result of exact calculation, the former is not very trustworthy on account of the considerable departures from the mean shown by the monthly values.

The reliability of the mean amplitudes is not very great either.

Thus the method of computation by approximation is not suitable for tides having very small amplitudes.

Although the tides of the Baltic and the Gulf of Bothnia be mixed, the impossibility of establishing a theoretical level of reduction and the very small range resulted in the investigation of the possibility of deducing a level of reduction from the observations by computing mean low water.

The great difficulty is to decide which observations refer to high and which to low water. An amplitude which has been established beforehand cannot constitute a firm basis from which to start, for the time of the rise and fall of the tide is exceedingly variable and, in those of long duration, the movement in either direction is often interrupted by inverse movements which evidently represent oscillations and not tides. Hence the uninterrupted curve of the observations had to be mentally pictured and the conspicuous points, where the rise and fall unquestionably change their direction, had to be noted as high and low water. The range obtained in this manner is seldom less than 3 cm.

Admitting these rules, the following tables have been drawn up for Arkona and Ystad ; it was impossible to establish high and low water for Ratan.

ARKONA

	1882	1883	1887	MEAN
Mean low water below W	6,4 cm.	5,8 cm.	5 cm.	5,7 cm.
Lowest tide below mean low water	62 ,, 16 XI	63 ,, 5 II	60 ,, 17 XI	—
Duration of rise: minimum ...	2h	1h	1h	—
Duration of rise: maximum ...	43h	38h	44h	—
Rise per hour: mean........	1,3 cm.	1,3 cm.	1,3 cm.	1,3 cm.
Rise per hour: maximum ...	8,3 ,,	7,8 ,,	7,8 ,,	—

	1882	1883	1887	MEAN
Mean high water above W	6,1 cm.	5,2 cm.	6,5 cm.	5,9 cm.
Highest tide above mean high water	98 ,, 21 II	100 ,, 7 XII	101 ,, 25 X	—
Duration of fall: minimum ...	1h	1h	1h	—
Duration of fall: maximum ...	45h	69h	93h	—
Fall per hour: mean.......	1,2 cm.	1,1 cm.	1,1 cm.	1,1 cm.
Fall per hour: maximum ...	7,8 ,,	6,0 ,,	7,1 ,,	—

YSTAD

	1907	1908	1909	1910	MEAN
Mean low water below W...	6,6 cm.	6,6 cm.	6,1 cm.	7,1 cm.	7 cm.
Lowest tide below mean low water	76 ,, 16 II	62 ,, 18 XI	90 ,, 20 XII	81 ,, 24 XII	—
Duration of rise: minimum	1h	1h	1h	1h	
Duration of rise: maximum	53h	53h	42h	39h	—
Rise per hour: mean	1,5 cm.	1,6 cm.	1,4 cm.	1,5 cm.	1,5 cm.
Rise per hour: maximum	9 ,,	7,5 ,,	12,7 ,,	11,5 ,,	—

	1907	1908	1909	1910	MEAN
Mean high water above W.	8,2 cm.	7,5 cm.	7,5 cm.	7,7 cm.	8 cm.
Highest tide above mean high water............	61 ,, 23 III	84 ,, 9 II	74 ,, 30 XII	101 ,, 13 X	—
Duration of fall: minimum	1h	1h	1h	1h	—
Duration of fall: maximum	65h	58h	58h	55h	—
Fall per hour: mean	1,3 cm.	1,4 cm.	1,3 cm.	1,4 cm.	1,3 cm.
Fall per hour: maximum.....	11,5 ,,	7,6 ,,	10 ,,	6 ,,	—

It may appear to be an exaggeration to refer to cases where the rise and fall last no longer than one hour as tides, but the discussion of the tides at Helder shows that such tides really exist, even for a mean range of more than 1 metre (3 1/3 feet). Besides, similar tides were recorded in exceptional cases only, their number does not exceed 4 % of 2.682 rises and falls at Arkona and 3 % of 3.395 at Ystad.

Although these tables appear to be reliable on account of the agreement of the yearly mean values, they are not really trustworthy.

For Arkona as well as for Ystad, the mean amplitude exceeds the sum of the amplitudes of the four principal constituents. Taking into account that for Soerabaja, Aden and Sembilangan the mean amplitude is not more than 40 to 60 % of this sum, mean low water at Arkona and Ystad could not be expected to fall more than 2 or 3 cm. below mean sea level under normal circumstances. The rise of the tide is prolonged at Arkona to 44 hours and the fall to 93 hours and the amplitudes show maxima of 57 cm. below mean low water and 95 cm. above mean high water ; for Ystad these data are respectively 53 and 65 hours and 84 and 93 cm. Under these conditions it is evident that a mean value is entirely untrustworthy.

Therefore it is not possible either to deduce a level of reduction from the observations.

As neither a theoretical nor a practical level of reduction can be found for the places under consideration, this level should be directly connected with mean sea level, this being the only level which can be established accurately.

In Germany, Sweden and Finland sounding made in the Baltic are reduced to this level. Formerly Swedish soundings were reduced to mean low water which was found by taking the mean of the lowest low tides of the 4 quarters of the year which begin 1 December, 1 March, 1 June and 1 September. This level varied for the different places from 20 to 60 cm. below mean sea level.

CONCLUSIONS

International low water is an erroneous conception ; it is impossible to establish a general hard and fast rule for a level of reduction of soundings which is applicable to every system of tides.

The level of reduction should be such, that the negative corrections to be applied to the soundings on the chart are neither numerous nor important.

The following levels are therefore recommended :

For pure and very preponderant diurnal tides : mean solsticial low water spings in a year of mean lunar declination $(K_1 + O + P) - W$.

For pure and very preponderant semi-diurnal tides: mean equinoxial low water springs $(M_2 + S_2 + K_2) - W$; if the constituent N has a considerable amplitude : mean equinoxial low water springs at perigee $(M_2 + S_2 + N + K_2) - W$.

For mixed tides : the mean of the lowest low tides at intervals of six months in a year of mean lunar declination : $(K_1 + O + S_2 + \frac{1}{x} M_2) - W$ for diurnal preponderance and $(M_2 + S_2 + K_1 + \frac{1}{y} O) - W$ for semi-diurnal preponderance.

For tides having very small ranges : mean sea level or a datum directly connected with this level.