INTERNATIONAL LOW WATER

Being a commentary on an article of the same title in the Hydrographic Review, Vol. II N° 2

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I have read with great interest the study of Rear-Admiral Phaff and generally agree with his conclusions. I have a few objections, however, to some points, the publication of which is deemed of sufficient importance to further the settlement of international rules for the fixing of chart datums.

Lines 6 and 7 from the bottom of page 64 state that the mean of the monthly lowest Low water springs may be called arbitrary level, as contrasted with natural levels. As it was accepted in 1921 as the chart datum for the Netherlands, I thought it of interest to investigate as to whether this difference is well founded or not.

The Dutch level was computed by taking the mean of the monthly lowest Low Water springs, as read on the Tide Gauge, during six consecutive years, in the middle of which is a year of mean declination of the moon.

High Water springs has been supposed to be the High Water nearest to the theoretical time of the phenomenon, given by the sum of the date and hour of full or new moon and the age of the tide. The Low waters on both sides of this high water springs have been considered to be low waters springs and from the four low waters springs noted in each calendar month (there may be six in exceptional cases) the lowest has been taken. Finally the mean of six yearly means of these monthly lowest was chosen as the datum of reduction.

What do these lowest low waters springs represent in the light of the harmonic theory of tides ?

The two low waters springs on each side of each high water springs differ mainly by the daily inequality. The two lowest low waters springs in a month differ by the influence of the anomalistic tides *N*, *L*, *etc*..., because the interval between two semi-diurnal spring tides is $\frac{360}{1.02}$ hours, and in that interval the phase of *N* and *L* changes $\frac{360}{1.02} \times 0°54$, or 193°, with regard to the phase of M_2, 0°54 being the difference in angular speed between M_2 and *N* or *L*. The lowest low water springs selected every month may therefore be defined as the mean low water springs owered by the amount of half the daily inequality between nought and the maximum that can occur at semi-diurnal springs and by the corresponding amount of the anomalistic group, varying between the same limits. These amounts increase and decrease according to sines and, for the mean, $\frac{2}{3}$ of the maxima may be accepted mathematically by approximation.

Mean low water can be expressed by $-M$, $-S_2$ $-(M\,S)$, in which expression M represents the amplitude of M_2, which is affected invariably in the same way by the shallow water tides M_4, and M_6; while $(M\,S)$ represents the influence of the compound tides of M_2 and S_2 on the semi-diurnal spring tide. Thus the theoretical level of the Netherands' charts may be represented by: $-M\ -S_2\ -\ (M\,S)\ -\ \frac{2}{3}$ (max. influence diurnal group) $-\ \frac{2}{3}$ (max. influence anomalistic group).

Mr. S. BLOK, Chief Engineer of the Waterstaat-Service, has kindly assisted by deducing formulae for both maximum-influences, which allow the following theoretical levels in *cM.* to be calculated.

	VLISSINGEN	HOEK VAN HOLLAND	YMUIDEN	HELDER
A_0 (1)	—18	—10	—15	—13
M	—165	—62	—68	—61
S_2	—45	—14	—16	—15
2 $M S$.	+11	+ 3	+ 4	+ 3
$M S$.	+ 7	+ 8	+ 3	— 6
2 $S M$.	+ 4	+ 2	+ 2	+ 2
$M_4 + S_2$	— 3	+ 1	+ 5	+ 0
$\frac{2}{3}$ (O, K_1, P)	—12	—11	— 6	— 3
$\frac{2}{3}$ $(N, L, MN, Mm, \quad, \lambda)$	—14	— 3	— 3	— 8
Theoretical level	—235	—86	—99	—101
Level deduced from the tide gaude readings	—250	—103	—113	—111
Difference	15	17	14	10 mean 14

The theoretical levels having been deduced as accurately as possible, even taking into account the smaller shallow water and compound tides, this difference of 14 *cM* is not unimportant. Investigation proved that it cannot be entirely caused by meteorological influences.

The 14 *cM* must include the average depression of the minima of the compound wave of which R. A. Harris speaks in his "*Manual of Tides*" (Part. III, page 133, Report of the Superintendent U. S. Coast & Geodetic Survey, Washington 1895) which depression is estimated to be about ½ *dM*.

The preceding considerations have not been forwarded principally with a view to deciding whether the new chart datum of the Nether-

(1) A_0 is the distance between mean sea level and the official plane of levelling of the Netherlands. (N. A. P.).

lands is an arbitrary or a natural level, which question after all is of little value, but more important conclusions may be drawn from it.

It shows in the first place that the formulae given on page 64 & 65 in Adm. Phaff's article are not given in sufficient detail, even for places where the semi-diurnal (or the diurnal) tide is very preponderant, as is case the for harbours of the Netherlands ;

secondly, that the shallow water and compound tides and tides of long periods should not be disregarded ;

thirdly, that it is required, if possible, to compute the level directly from the tide-gauge readings, and not to judge a theoretically deduced level sufficient for places where series of such readings during several years are available. E. G. the theoretical level + 235 *cM–W* for Vlissingen would give approximately 15 % negative corrections, which is judged to be too much for acceptance of this level as a chart datum.

Moreover it is clear that it is not so simple to satisfy the desiderata expressed on page 65, lines 5 and 6 : "it is very important that the level of reduction should be easily and accurately defined practically and theoretically" at all events not with regard to the latter part. It is desirable that the use of the formulae should be restricted to the theoretical discussion concerning the choice of a level, but that the establishment of the level chosen should be made by using tide gauge readings, if these are available.

Another point on which I wish to comment concerns the rule given on page 69. It is said that on account of several circumstances the seaman will have to add an excess of depth to his prediction of the height of the tide, and that this consideration makes 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. I readily agree to that.

But the author adds : "*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.*"

I must object to this verdict.

The author has estimated "the excess of depth", special cases excepted, at not less than 5 *dM*, which appears to be a reasonable amount. According to my opinion, however, to neglect percentages of negative corrections corresponding to 5 *dM* should not be accepted as a governing rule when choosing a level.

I would prefer the following rule :

As long as the negative corrections which have to be applied are smaller than the inevitable inaccuracy that may be considered to adhere to prediction of the tide on board ship, the percentages which correspond to these and to smaller corrections may be neglected, even if they be numerous (*).

It is of course not possible to establish for each place the same amount for this inevitable inaccuracy, which depends on the character of the tide, the degree of accuracy with which its laws are known etc. But it is evident that in all cases negative corrections corresponding to 1 *dM* and less may be neglected and in several cases even those corresponding to 2 *dM*.

This rule has been the governing principle for the following critical study of the examples of tides given, in which I have tried to choose the most acceptable levels for the considered places. The negative corrections and their given percentages are derived from the original article and it has been accepted that they refer to the observed, and not to the theoretical levels, although this is not clearly stated (**).

POELOE BOEROENG (diurnal). — The information given for this place refers to a year of maximum declination of the moon from August 1913 to July 1914 inclusive only. In a similar year the amplitude of K_1 is increased by 11 %, that of O by 18 %, or respectively by 6 and 7 *cM*; in a year of minimum declination (1922, etc.) the amplitude are decreased by the same amount. Assuming that the observed levels undergo the same variation, the following may be deduced :

	Levels that would have been observed in the years :		
	1913-14	1918	1922
(2) Mean low water springs........................	–111	–93	–79
(3) Mean low water of solsticial springs........	–125	–111	–97

Assuming also that low water springs in the year 1918 will have been equal to (6+7) *cM* or — 1 *dM* higher and in the year 1922 2 (6 +7) *cM* or 2,5 *dM* higher than in 1913-14, and considering that level (3) 1918 is the same as level (2) 1913-14 both being 111 *cM-W* may be concluded to the following percentages of negative corrections for level (3) in the various years :

(*) This rule is preferable indeed. (J. M. P.).
(**) The negative corrections and their percentages refer really to the observed levels. (J. M. P.).

1913-14 (max. decl. moon) 4 % (1-2) 2 % (2-3) 1 % (3-4) *dM*.
1918 (mean decl.) 2 % (1-2) 1 % (2-3) *dM*.
1922 (min. decl.) 0,5 % (1-2) *dM*.
or a mean of : 2 % (1-2) 1 % (2-3) 1/3 % (3-4) *dM*.

Judging from these results, level (3) 1918 must be considered barely sufficient; higher levels are certainly not acceptable. The nearest lower level, (3) for a year of max. declination, giving 2 % (1-2) *dM* and none larger, is somewhat lower than necessary, moreover a level for mean declination of the moon is preferable.

DJAMOEANG RIF (diurnal). — From the original article I have deduced the following percentages of negative corrections to be applied to levels (2):

in the year:	level (2) 1913-99		level (2) 1917-18-91			level (2) 1922-77	
	1-2*dM*	2-3*dM*	1-2*dM*	2-3*dM*	3-4*dM*	1-2*dM*	2-3*dM*
1923 (max. moon decl.)...	4	4	8	5	2		
1917-18 (mean decl.)			6	1	½		
1922 (min. decl.)............			1			6	1

This shows that level (2) 1917-18 is insufficient; consequently levels (2) 1922, and (3) 1922, being higher, are not acceptable either.
For level (3) is deduced :

in the year:	level (3) 1913-112	level (3) 1917/18-104		level (3) 1922-81
	1-2 *dM*	1-2 *dM*	2-3 *dM*	1-2 *dM*
1913....................	—	5	2	—
1917/18................	—	1 ½	½	—
1922....................	—	—	—	3

Level (3) 1917-18 involving a mean percentage of 2,2 % for 1-2 *dM* and 0,8 % for 2-3 *dM* is acceptable. The level used, being 105 *cM-W* corresponds with it.

QUEENSTOWN (semi-diurnal). — Level (2) "mean low water springs" not being sufficient, as it gives 4 % negative corrections from 2-4 *dM* and 1 % from 4-6 *dM*, level (3) "mean low water of equinoctial springs" must be chosen, in my opinion. To this level only 1 % from 2-4 *dM* is adherent.

BREST (semi-diurnal). — For this place I have come to the same conclusion. Level (2) gives 4 % for the negative corrections from 2-4 *dM* 2 % from 4-6 *dM* and 1 % from 6-8 *dM*, whereas level (3) only gives 2 % from 2-4 *dM*.

HOEK VAN HOLLAND (semi-diurnal). — For this place level (3) is not low enough, as it gives 7 % negative corrections from 1-2 *dM*, 3 % from 2-3 *dM*, 1 % from 3-4 *dM* and 2 % from 4-5 *dM*, which corrections are important, the more so as the mean range is only 16 *dM*, against 30 *dM* at Queenstown and 44 *dM* at Brest. Therefore Level (4) "mean low water of equinoctial springs at perigee" should be chosen, this level having only 2 % negative corrections from 1-2 *dM*, 1 % from 2-3 *dM* and 1 % from 3-4 *dM*. This level differs only 1 *cM* with that actually used.

It may be remarked that the great difference between the theoretical (80 *cM-W*) and the observed mean low water (64 *cM-W*), mentioned in the original article, is due to neglecting the shallow water tides. If instead of M_2, the theoretical mean low water had been established at M ($M_2 +_4 +_6$ page 2), the difference would have been 2 *cM* ; only, and the same may be said from Helder, where, by so doing, a difference of 7 *cM* would have resulted.

As the shallow water tides are neglected, the theoretical formulae from page 64 and 65 are incomplete.

HELDER (semi-diurnal). — For this place also Level (3) is not acceptable and (4) must be taken, which gives 3 % for negative corrections from 1-2 *dM*, 1 % for 2-3 *dM* and 1 % for 3-4 *dM* ; it differs not more than 2 *cM* from the level of reductions actually used (98 *cM-W*).

Supposing that the same accordance between level (4) and the one actually used, that has been stated for Hoek and Helder, exists for Vlissingen, the same percentages of negatives corrections that are deduced from Tide-Gauge readings for the last level should apply to level (4), *viz* : 4 % for 0-1,4 *dM*, 1 ½ % for 1,4—3,5 *dM*, and 1 ¼ % for more than 3,5 *dM*.

Considering the vicinity of the three places, this accordance in not improbable.

St. JOHN (semi-diurnal). — I agree that Level (2) "mean low water springs" is not acceptable, but I do not see sufficient reason to accept level (4) "mean low water of equinoctial springs at perigee" and to omit Level (3) "mean low water of equinoctial springs". My opinion is that this level, giving only 3 % negative corrections not exceeding 3 *dM*, is low enough, the more so as the mean range of springs is 70 *dM*.

Moreover, the level of "mean low water of equinoctial springs at perigee" is not easily fixed. Low water equinoctial springs occurs only four times a year and it is not at all certain that the moon will be in its perigee at the moment of one or more of these springs.

SOERABAJA (mixed). — For this place Level (3^a) "mean of lowest low tides at each month for a year of mean declination of the moon" (119 *cM-W*) is thought to be sufficiently low. The following percentages have to be applied to it for negative corrections from 1-2 *dM*:

1913 (max. decl.) 3 %; 1917-18 (mean decl.) 0,5 %; 1922 (min. decl.) 0 %; or a mean of 1,2 %.

ADEN (mixed). — For this place, Level (3^a) (138-W) is also acceptable, giving the following percentages for negative corrections from 1-2 *dM* 1913 (max. decl.) 2 %; 1903-4 (min. decl.) 0 %; or a mean of 1 %.

The theoretical lowest low water (148 *cM-W*) does not agree with the list on page 109, in which several lower readings are mentioned. This may be caused by neglecting the tides of a long period for the theoretical computation of the lowest low water (S^a 11 *cM*).

SEMBILANGAN (mixed). — Level (3^a), 104 *cM-W*, gives the following percentages :

1913.......	1-2 *dM*	2-3 *dM*	1917-18 1-2 *dM*	1922 1-2 *dM*
	4 %	3 %	½ %	0 %

or a mean of 1 ½ % from 1-2 *dM* and 1 % from 2-3 *dM*. On this account the level is judged to be sufficiently low.

Level (3^b) (119-*W*), which gives a mean of ⅓ % for negative corrections from 1-2 *dM*, is lower than is required.

Although level (3^a) is acceptable for all the considered places with a mixed tide, level (3^b) "mean of lowest low tides at interval of six months" is prefered, for reasons which are given afterwards, and this is done more especially for places where no series of tide gauge readings during several years are available.

The results of the preceding study are shown in the following list:

PLACE	TYPE OF TIDE	CHOSEN LEVEL	PERCENTAGES OD NEG. CORRECTIONS
POE. BOEROENG.........	Diurnal	(3) Mean low water of solsticial springs at mean declination of the moon.	2 (1—2 dM) 1 (2—3 dM) 0,3 (3—4 dM)
DJAMOEANG RIF	id.	(3) id.	2,2 (1—2 dM) 0,8 (2—3 dM)
QUEENSTOWN	Semi-diurnal	(3) Mean low water of equinoctial springs.	4 (0—2 dM) 1 (2—4 dM)
BREST	id.	(3) id.	6 (0—2 dM) 2 (2—4 dM)
HOEK VAN HOLLAND..	id.	(4) Mean low water of equinoctial springs at perigee	2 (1—2 dM) 1 (2—3 dM) 1 (3—4 dM)
HELDER	id.	(4) id.	3 (1—2 dM) 1 (2—3 dM) 1 (3—4 dM)
VLISSINGEN.............	id.	(4) id.	2 ½ (1—2 dM) 1 (2—3 dM) 0,5 (3—4 dM)
St. JOHN	id.	(3) Mean low water of equinoctial springs.	3 (0—3 dM)
SOERABAJA	Mixed, both groups of equal force.	(3^a) Mean of monthly lowest low waters.	1,2 (1—2 dM)
ADEN	id.	(3^a) id.	1 (1—2 dM)
SEMBILANGAN	Mixed, diur-dominating	(3^a) id.	1 ½ (1—2 dM) 1 (2—3 dM)

Judging from these data, it would appear at first sight to be easy to find a leval suitable for universal use and a nearer study only shows the objections to which this level is liable.

A similar level should be either (3) or (4) or a level such as (3^a).

In the first place, levels (3) and (4) differ from diurnal and semi-diurnal tides, even if we define the latter for diurnal tides as "mean low water of solsticial springs at perigee". This difference, however, could be met by the wording of the universal level.

A more serious objection is that both levels are unfit for mixed tides, as the expression "low water springs" is not compatible with such tides. Yet level (3) is not sufficiently low for such places as the harbours of the Netherlands, where the semi-diurnal tide includes diurnal, anomalistic and shoal-water groups that should not be neglected. *e. g.* for Hoek this level gives 7 % negative corrections from 1—2 *dM*, 3 % 2—3 *dM*, 1 % 3—4 *dM* and 2 % 4—5 *dM*. As for level (4), the difficulty remains to establish this level with accuracy as is shown for St. John, page 10.

It is tempting at first sight to choose level (3^a). The values, however, from which the mean level should be computed, are not bound to fixed days, like those selected for establishing the Netherlands charts datum. Consequently they will be much more influenced by meteorological conditions which may lower every low water of the month to the lowest one. It is therefore impossible to give a theoretical formula for that level and it should be deduced from a very long series of tide-gauge readings, in order that the mean be free from abnormal meteorological influences. For this reason it was said above that level (3^b) was preferred, for places which have a mixed tide, as it is possible to calculate theoretically the lowest low waters at intervals of 6 months which are more exclusively connected with astronomical influences.

If we do not consider these meteorological influences, level (3^a) will be higher than (3) for diurnal or semi-diurnal tides as, of course, a monthly mean must be higher than a mean of solsticial or equinoctial springs.

For the length of period from which the values for averaging level (3^a) should be chosen, comes into consideration a synodic month if the tide is semi-diurnal, a tropical month if the tide is diurnal and one or the other if the tide is mixed, depending on the dominating group.

Lastly, it is not at all certain that the study of the tides of the places considered allow a rule for universal use to be based on them. The characters of the tides are so varying that it is dangerous to put down a hard and fast rule for the whole world. I therefore conclude that it is neither recommendable nor desirable to try to bind the Hydrographic Offices to such a rule.

Still, I should like, to point out that the rule, laid down in the second part of the Resolution of London 1919, is certainly not acceptable.

According to page 63 of the original publication, "higher high" and "lower low water" point to the highest of both high waters and the lowest of both low waters which occur in 24 lunar hours (*), and which are raised and lowered respectively by the daily inequality. The mean can be represented by (see page 4):

$$+M^{max.} + \frac{2}{3} \text{ (max. infl. diurnal group) } + \text{W and } - M^{min.} - \frac{2}{3} \text{ (max. infl. diurnal group } + \text{W.)}$$

$M^{max.}$ and $M^{min.}$ represent the rise of M above and the fall below mean sea level. These two values often differ for the same place if the M_2 tide is considerably distributed by the shallow water tides M_4, M_6, etc...

Half the range is represented by:

$$\tfrac{1}{2} M \text{ (max.} + \text{min.) } \frac{2}{3} \text{ (max. infl. diurnal group),}$$ which amount is not equal to M_2.

Multiplying this by $1\frac{1}{2}$ to establish the plane below mean sea level, according to the Resolution, means that the influence of the sun is supposed to be: $\frac{1}{4} M$ (max.+min.) $+ \frac{1}{3}$ (max. influence diurnal group).

Although the theoretical proportion of S_2 and M_2 is 1 : 2 this proportion is very often different and the last given formula is not equal to S_2.

For the Netherlands harbour the rule of the Resolution gives the following levels:

		actual Chart datum	*difference*
Vlissingen	–299	–250	–49
Hoek	–133	–103	–30
Ymuiden......................	–136	–113	–23
Helder	–101	–111	+10

(*) This definition shows clearly that the man who schemed this rule has only had semi-diurnal tides in view, certainly not diurnal ones.

The proportional inequality of these differences and the reversed algebraic sign for Helder show that the rule is not acceptable. The level would be much too low for Vlissingen, too low for Hoek and Ymuiden and yet not low enough for Helder.

The question arises as to what is the advantage of an international rule ?

The principal condition that has to be satisfied from a sailor's point of view is, that nowhere is there any chance of the sea level falling more than an important amount below chart datum, while at the same time the soundings given by the chart must differ as little as possible from the situation as low water. The only sure way of investigating this is by deducing the percentages of negative corrections for the chart datums under consideration and to make a choice on the basis of the results of such investigation.

The first paragraph of the London rule 1919 has been worded satisfactorily. It is no hard and fast rule, and it is sufficiently elastic to allow the local circumstances for each place to be taken into account, such as the type of the tide, the range, the detail of knowledge of the law of the tide, the influence of meteorological circumstances etc. It might be considered whether it would not be useful to lessen the elasticity somewhat by putting "but seldom" instead of "not frequently."

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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 and which are larger than the unavoidable inaccuracy of tidal prediction on board ship, are neither numerous nor important.

When choosing a chart datum it is recommended, in the first place that some levels on theoretical mareological principles should be selected, next to compute for each of them the percentages of negative corrections and to decide, in the light of these percentages and taking into account the range and type of the tide, which level should be accepted. Although theoretical considerations will be of great advantage when choosing a level, it is essential to establish, if possible, its distance below mean sea level or below a fixed plane of levelling *directly* from a series of tide gauge readings made during several years.

In countries where an official service exists, which controls permanent tide gauges with levelled zeros, this condition will be easily realised; in countries where such a service does not exist it will be often unavoidable to base the distance more or less on considerations which, in their turn, are based on constants computed from theoretical relatively short series of tide gauge readings.

The first paragraph of the London Resolution concerning reduction of soundings should be amended as follows:

"Tidal datum should be the same as chart datum, and should be on a plane so low that the tide will but seldom fall below it".

The second and third paragraphs of the Resolution should be cancelled.

The "note by the Bureau" on page 130 of the article "Co-ordination of chart datums" by Commander H. D. Warburg is not exact. It says that "the chart datum of the Schelde is the mean of the lowest tides in each calendar month", this should be changed to the "mean of the lowest *spring* tides choosing one in each calendar month."

The same remark is made concerning the note on page 131. Moreover the level is not called "Low water springs" but "mean of *low* water springs" and the explanation why the level should have the first mentioned denomination is applicable for the chart datum of the East Indian Archipelago only. In this Archipelago the majority of the tides are of a mixed type and it is not possible to give a short characteristic general name for the level used (3^b). As prior to the application of the harmonic theory the soundings were said to be reduced to "low water springs", this definition has been maintained, although the notion "low water springs" is in fact inconsistent with mixed tides, because the expression is familiar to seamen and it conveys to them the idea, which is indeed a fact, that negative corrections will not be or will very seldom be necessary.