RECOMMENDATIONS FOR OPERATION OF TIDE GAUGES AND REDUCTION OF TIDAL RECORDS

INTRODUCTION

Since its formation in 1958 the Permanent Service for Mean Sea Level has been acutely conscious of the fact that the monthly and annual mean values of sea level published at frequent intervals in the *Publications Scientifiques* series of the International Association of Physical Oceanography do not all reach the standard of reliability required by modern scientific investigations. It is hoped that the two contributions which follow will prove useful guides to authorities responsible for the operation of tide gauges, and particularly to those authorities whose responsibility for tidal observations and the subsequent reduction of the records is of a subsidiary nature rather than a major commitment.

The paper by Mr. DISNEY sets out what are considered to be the absolute minimum requirements to be observed in the installation and day-to-day maintenance of the normal types of tide gauge. The remarks concerning the need for intelligent, conscientious observers cannot be overemphasized.

The paper by Mr. ROSSITER is primarily intended as a guide for authorities who are faced with the task of reducing tidal records to monthly and annual means by the most economical method compatible with the standard of accuracy required.

Advice and assistance which will further the production and publication of accurate sea-level data is at all times available from :

Permanent Service for Mean Sea Level,
The Observatory,
Birkenhead,
England.

I. — MINIMUM REQUIREMENTS FOR OPERATION OF A TIDE GAUGE

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It is very important that a tide-gauge station be maintained with the aim of obtaining the highest degree of reliability and precision that is practicable. In order to obtain reliable records the following minimum requirements for the operation of the tide gauge should be met.

1. Special care should be taken in the selection of a site for a tide station. If possible, there should be a depth of not less than 5 feet below the probable lowest tide. This is especially desirable in exposed locations where storm waves of large amplitude are common. When the determination of the height of mean sea level is an important aim, the station should be located on the open coast or in a bay with ample access to the sea. A river or bay connected with the sea by a relatively small inlet is not a suitable location for this purpose because of the probable difference in the mean water level inside of the inlet and on the outer coast.

2. The intake to the float well should be of sufficient size to permit the free access of the tide while damping down the effect of heavy seas. The opening must, however, be large enough so that rough water on the outside will always leave an unmistakable trace upon the tide record. A single intake, preferably in the bottom, is more desirable than several smaller ones, as the former is less likely to become clogged and is more easily cleaned when clogged.

3. Particular care must be taken to keep open the intake to the float well as even a partial clogging may impair the value of the record by creating a lag in both time and height of the tide. Clogging may be caused by an accumulation of sediment inside the well, by marine growth at the intake, or by the shoaling of the water in the vicinity.

4. At the time of the establishment of the station the tide staff or other reference scale should be connected with three or more stable benchmarks. Similar level connections should be made each year, or more frequently if there is any suspected movement in the reference scale, so that any change in the elevation of the tide staff may be detected without unnecessary delay. At certain exposed stations where the wave action is heavy a mechanical nonregistering tape gauge, consisting essentially of a float attached to a tape and counterpoise, may be substituted for a tide staff. With such installation the plane of floatation of the float should be checked each year in addition to connecting the reference mark of the tape gauge to benchmarks. This procedure, relative to measurement of the plane of floatation, is not required when an electric tape gauge is used in place of a tide staff as no float is involved.

5. Marigrams should be related to a tide staff, or other equivalent reference scale, by a comparative time and height reading at least twice each week (preferably each day) in order to maintain a check on any discrepancy in time scale or distortion of height scale. The importance of this procedure should be imparted to the tide observer and he should be cautioned that staff readings should be entirely independent of any scale on the tide gauge. He should be further cautioned that the correct time entry on the marigram should be obtained from an accurate time piece not connected with the tide gauge operation.

6. For satisfactory records the marigram scale should be sufficiently large to be readily tabulated. The minimum time scale should be at least 6 inches (15 cm) per 24 hours, but preferably should be considerably larger, particularly where large ranges of tide are involved. Use of adequate size time scales — up to 24 inches (60 cm) per 24 hours — has the additional

advantage of providing a good record of such phenomena as tsunami, seiches, and storm surges. The height scale for the marigram should be such that readings can be made to the nearest tenth of a foot (3 cm).

7. Most tide gauges are powered by clocks, and clock failure is one of the primary causes of unsatisfactory records. The general conclusion of tidal authorities points up the fact that an accurate 8-day clock mechanism is one of the first requirements in obtaining good records. An accurate clock is required to keep cumulative time errors to a minimum. An 8-day movement is essential to eliminate stoppage at isolated places on occasions when the observer is unable to attend the gauge for several days or more.

8. The satisfactory functioning of a tide gauge depends largely upon the observer in charge. He should be fully instructed in his duties and impressed with the importance of careful observations. Proper maintenance of the gauge requires continuing cooperation between the observer and the office processing the marigrams. Any operating troubles, or changes in equipment or procedures should be promptly recorded by the observer and such information should be sent systematically to the processing office. An effective means of accomplishing this is by the use of a report form which the tide observer should forward at the end of each week. A system of weekly reports enables the processing office to better interpret the record and make any necessary corrections. The information, along with data available for the station, also may provide clues of some malfunctioning which can be brought to the attention of the observer.

Suggestions for tide observers

The satisfactory functioning of a tide gauge depends largely upon the observer in charge. To assist him with his duties there are listed below some general comments on the things he should look for to insure dependable records.

Distortion of the tide curve is a sign of malfunction. To quickly detect such trouble and take remedial steps to eliminate the causes, the observer should acquaint himself with the appearance of the normal curve at the station.

Friction in the moving parts of the gauge may be a major source of trouble. This may be evidenced by abnormal flat traces at high waters or low waters or by a series of steps in the record. The binding may be either in the gauge proper or in counterpoise sheaves if counterweights are used with the gauge. The trouble source should be located and cleaned and lubricated with light oil.

Blockage of the intake to the float well may present a problem. With iron wells, rust flakes falling off the inside of the pipe may cover the intake and act as a one-way valve. This gives a nearly normal tracing on the rising tide, but causes a long, slow runout after high water during which the water height in the well is above the outside level. Although a float well is designed to dampen down the outside waves, there should always be an unmistakable oscillation of the recording stylus whenever the water outside the well is rough. Under these conditions, a smooth regular traced curve should be regarded with suspicion. To reduce the possibility of the intake clogging, the observer should establish the practice of clearing the float well intake at least once a month.

Occasionally the float will rub on the side of the well. If the float well is not plumb, the position of the gauge should be adjusted so that the float will be centred in the well at approximately mean-tide level.

Clocks shoulds be wound at intervals so that they will not run down. Even though the gauge has an 8-day clock it should be wound semi-weekly to insure against stoppage that might result from an unexpected interruption to the observer's regular visits.

A comparative time and tide staff reading is a very important procedure. It is absolutely essential in order to obtain the correct time relations and to establish tidal datum planes. The observer should have an accurate time piece to be used for the correct time entry on the marigram. With respect to staff readings, the individual readings may at times seem rough and inaccurate, the final results, however, depending upon an average of a large number of such readings over a considerable period of time, reach a very satisfactory degree of precision provided they are taken in an unbiased manner. It is essential, therefore, that when taking staff readings one should be uninfluenced by any other consideration, and that such readings should be entirely independent of any scale on the tide gauge. Any operating troubles, or changes in equipment or procedures should be promptly recorded by the observer and such information should be sent systematically to the office processing the marigrams. An effective means of accomplishing this is by the use of a report form which the tide observer should forward at the end of each week.

II. — A ROUTINE METHOD OF OBTAINING MONTHLY AND ANNUAL MEANS OF SEA LEVEL FROM TIDAL RECORDS

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As a result of requests from various authorities for advice on the quickest method of obtaining monthly and annual means of sea level from the normal type of automatic-tide-gauge records, working instructions and sample calculation sheets are reproduced herewith.

The variety of methods in common use throughout the world have been reviewed by the writer in the International Hydrographic Review (May, 1958), and the schedule recommended is derived from the « Z_0 » stencil method referred to there. While no more accurate than, for example, the averaging of 24 or 25 hourly heights per *day*, or the planimetric integration of tide curves, this method offers considerable saving in time by only using heights at 3-hourly intervals. It is superior in accuracy to the use of averages of high- and low-water heights.

The method is not recommended for stations where the normal tide curve is excessively distorted due to the presence of shallow-water tidal constituents. Further reference to this point will be found in the above-quoted paper.

Instructions for the computation of monthly and annual mean values (Z_0) of sea level, using 3-hourly values

First read off from the tide-gauge charts the height of tide at intervals of 3 hours and enter them on an appropriate form. In the example given (tables 1 and 2) the hours chosen are 0, 3, 6, 9, etc. It is assumed that heights are read to 0.1 ft; a suitable unit in the metric system would be 2 cm.

Monthly values

1. Total each day row and enter answers on form in column headed Σ. At this stage a visual examination of the day-to-day run of totals will help to pick out errors in the individual heights.
2. Total each hour column and enter answer on line marked Σ.
3. Total the row totals and enter on form as $\overline{M}$.
4. As a check, total the column totals. If the answer equals $\overline{M}$, proceed to (5). Otherwise seek error(s).
5. Compute δ to 2 decimal places. This is one half the sum of : minus the first three values of tide height on the first day plus the first three values following the last day, for each set of consecutive readings occuring in the month.

   If there are no gaps in the month's record, this simply means using the first three readings on the first day of the month and the first three readings on the first of the next month.
6. Calculate $M = \overline{M} + \delta$.
7. Enter n, the number of days in the month with 8 readings to the day.
8. Calculate $Z_0 = M : 8n$, to 2 decimal places.
9. Repeat for successive months.

Yearly value

1. Total the monthly values of M and n.
2. Calculate the annual mean to 3 decimal places by dividing the sum of M by 8 times the sum of n.

TABLE 1

JANUARY, UNITS ARE FEET. ALFRED DOCK, BIRKENHEAD 1959

HOUR	0	3	6	9	12	15	18	21	Σ						
DAY 1	15.6	25.4	14.4	6.0	15.0	27.8	19.4	10.5	134.1						
	12.0	26.0	20.4	7.8	10.0	24.4	20.7	8.0	129.3	MONTH	$\bar{M}$	δ	M	n	Z_o
3	5.6	19.7	23.1	11.4	6.6	19.0	24.2	13.3	122.9						
	5.6	15.1	25.2	15.9	6.4	12.4	25.2	18.4	124.2	JAN.	3359.4	-.30	3359.10	27	15.55
5	7.0	7.8	23.0	21.2	9.5	7.9	22.8	23.3	122.5						
	10.7	4.2	19.0	26.0	13.3	4.4	16.3	27.0	120.9	FEB.	2817.1	12.55	2829.65	24	14.74
7	15.3	3.9	12.8	27.6	17.9	4.9	8.2	26.5	117.1						
	19.7	5.8	5.2	25.6	22.8	7.0	2.9	23.8	112.8	MAR.	3787.9	-1.90	3786.00	31	15.27
9	26.6	9.7	2.2	22.4	28.0	10.9	0.8	18.0	118.6						
	28.6	13.0	1.3	16.8	30.3	15.2	2.0	11.3	118.5	APR.					
11	29.1	17.3	3.4	11.4	30.3	20.0	5.0	5.7	122.2						
	27.5	22.0	6.8	7.4	27.8	23.8	7.1	2.9	125.3	MAY					
13	23.4	24.4	8.7	4.3	23.2	26.7	10.8	3.0	124.5						
	19.8	25.8	11.7	4.2	19.1	27.6	14.1	4.5	126.8	JUNE					
15	15.6	26.8	15.7	6.6	15.0	26.5	16.5	6.0	128.7						
	11.4	23.5	16.8	7.4	10.5	23.5	19.1	8.8	121.0	JULY					
17	9.2	21.2	20.0	11.2	10.1	21.2	22.7	12.9	128.5						
	9.0	17.8	21.6	14.3	9.8	16.4	22.9	16.1	127.9	AUG.					
19	10.2	15.0	22.6	18.8	11.5	13.3	23.1	20.6	135.1						
	12.2	11.2	20.9	22.4	13.7	10.2	19.9	23.5	134.0	SEPT.					
21	14.0	8.5	18.1	25.0	16.3	7.5	14.7	25.0	129.1						
	17.4	8.0	14.6	26.7	20.1	8.5	10.6	25.3	131.2	OCT.					
23	21.0	8.9	9.7	25.4	23.0	9.4	6.6	24.0	128.0						
	24.4	9.3	4.7	22.0	25.9	10.7	2.8	19.9	119.7	NOV.					
25	27.0	11.4	2.4	18.9	28.3	13.5	2.0	15.0	118.5						
	28.8	14.5	2.4	14.3	29.7	17.5	3.4	9.3	119.8	DEC.					
27	28.8	18.4	3.8	8.5	28.7	21.0	5.2	3.7	118.1						
									-						
29	*	*	*												
		GAUGE OUT OF ACTION									ANNUAL TOTALS				
31															
Σ	475.5	414.6	350.5	429.5	502.8	431.2	349.0	406.3							

* Required for calculation of

TABLE 2

FEBRUARY — ALFRED DOCK, BIRKENHEAD 1959 — MARCH

HOUR	0	3	6	9	12	15	18	21	Σ	0	3	6	9	12	15	18	21	Σ
DAY 1									-	13.0	27.4	15.7	3.9	11.1	26.5	18.2	6.2	122.0
		GAUGE OUT OF ACTION							-	8.3	24.6	20.2	8.1	7.1	22.2	22.4	11.0	123.9
3									-	6.8	19.5	24.0	13.3	6.7	16.6	24.5	16.3	127.7
									-	8.2	12.8	23.9	18.0	8.5	10.4	23.0	21.9	126.7
5	14.2	4.5	12.3	26.3	16.7	4.8	8.9	25.5	113.2	11.8	8.6	21.7	24.6	13.9	7.8	19.0	25.9	133.3
	18.7	6.2	6.6	25.4	21.8	6.8	5.4	23.0	113.9	15.7	6.8	16.7	27.6	17.7	6.3	12.1	26.6	129.5
7	23.6	8.9	2.5	22.2	26.4	10.0	0.9	19.1	113.6	19.0	6.9	9.9	26.6	20.3	6.3	5.1	24.1	118.2
	28.2	11.9	1.2	17.8	29.0	13.3	1.1	13.4	115.9	22.8	8.0	4.1	23.7	24.6	8.8	1.9	20.8	114.7
9	28.0	15.0	2.0	11.9	29.4	17.0	2.8	8.4	114.5	26.0	10.5	1.5	20.1	27.9	12.1	1.3	17.2	116.6
	28.0	19.0	4.0	7.0	27.6	20.1	4.5	3.5	113.7	27.8	13.5	1.9	16.3	29.7	15.1	2.4	13.0	119.7
11	25.3	21.4	6.0	3.8	24.5	23.6	7.6	2.4	114.6	28.6	16.5	3.2	12.1	29.7	18.9	4.5	9.4	122.9
	22.2	24.2	9.0	3.4	21.1	25.6	10.5	3.0	119.0	28.2	20.3	5.5	7.3	27.2	21.0	5.8	5.2	120.5
13	19.0	25.2	11.8	4.0	17.5	26.1	13.4	4.3	121.3	24.9	22.1	7.0	4.3	23.8	23.5	8.5	4.8	118.9
	15.7	25.0	14.4	5.8	14.0	25.3	15.9	6.0	122.1	22.6	24.6	10.3	4.7	21.1	25.2	11.3	4.1	123.9
15	11.2	22.6	16.2	7.4	10.3	22.3	18.2	8.8	117.0	19.8	25.9	12.4	4.7	16.8	24.7	13.2	5.4	122.9
	10.0	20.5	19.1	10.7	9.1	18.7	20.2	11.5	119.8	15.6	24.3	14.3	6.1	13.4	23.8	15.5	7.2	120.2
17	8.6	16.3	20.5	14.0	8.7	14.0	20.8	15.2	118.1	12.4	22.7	17.0	8.4	10.1	20.9	18.0	9.9	119.4
	9.2	16.3	20.3	17.4	10.1	9.9	19.5	19.2	121.9	10.0	19.2	19.0	11.6	9.2	17.4	20.5	13.2	120.1
19	11.0	8.2	17.6	21.4	12.5	6.9	15.8	22.9	116.3	9.3	15.6	21.1	15.3	9.2	12.4	21.0	17.2	121.1
	14.0	6.6	15.2	25.0	16.9	6.8	11.6	24.7	120.8	10.0	10.8	20.5	19.4	10.8	8.3	18.9	21.9	120.6
21	17.0	6.0	9.7	24.9	20.1	7.4	7.1	24.4	116.6	12.0	7.3	17.4	23.6	13.6	5.4	14.9	25.2	119.4
	21.4	7.3	5.0	23.1	23.7	8.2	1.6	21.1	111.4	15.2	5.6	13.4	26.2	17.3	5.3	9.9	26.6	119.5
23	25.6	9.7	1.7	20.7	27.9	11.7	1.0	17.5	115.8	19.4	6.2	7.7	26.0	21.5	6.4	3.4	24.4	115.2
	28.8	12.7	0.7	15.4	(29.7)	14.6	1.0	11.1	114.0	24.1	8.2	2.7	24.2	26.6	9.6	0.5	21.6	117.5
25	29.9	16.8	2.2	9.9	30.0	19.5	3.7	5.5	117.5	28.9	11.4	0.6	20.1	30.4	13.3	0.1	15.8	120.6
	28.6	21.1	4.5	4.0	27.9	24.4	7.2	1.5	119.2	31.2	15.2	1.0	14.0	31.8	17.8	2.1	8.4	121.5
27	24.8	25.6	8.1	1.3	23.2	27.7	10.6	0.0	121.3	30.8	20.1	3.2	7.2	30.6	23.2	5.6	3.4	124.1
	19.9	28.4	12.6	2.1	17.5	28.4	14.1	2.6	125.6	28.2	24.9	7.0	2.2	25.7	26.9	9.3	1.3	125.5
29										22.6	28.1	11.2	2.0	20.0	29.3	14.0	3.4	130.6
										17.2	28.7	15.5	3.7	12.4	26.9	17.2	5.4	127.0
31										10.0	25.4	19.0	7.2	7.9	23.0	21.4	10.3	124.2
Σ	482.9	379.4	223.2	324.9	495.6	393.1	223.4	294.6		580.4	521.7	368.6	432.7	576.6	515.3	365.5	427.1	
		( ) Inferred							April 1	7.8	20.9	23.6						