The Selection of a Tidal Boundary Condition for a Numerical River Model

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CONTENTS

ABSTRACT

Woollard, A.L. 1984. The Selection of a Tidal Boundary Condition for a Numerical River Model. Can. Tech. Rep. Hydrogr. Ocean Sci: 34:v + 10p.

The selection of a particular tide as a boundary condition for a numerical river model may lead to some incorrect conclusions about general flow characteristics in the tidal portion of the river. Various Point Atkinson tides used as boundary conditions for a model of the Fraser River produced predicted flows differing by as much as 60% even for tidal cycles with the same range and sequence of extremes. An analysis of nineteen years of extremes at Point Atkinson showed that only 68% of the tidal cycles were of the same sequence of extremes and the range had a large variation.

Key words: numerical models, boundary conditions, tidal analysis.

RÉSUMÉ

Woollard, A.L. 1984. The Selection of a Tidal Boundary Condition for a Numerical River Model. Can. Tech. Rep. Hydrogr. Ocean Sci: 34:v + 10p.

Le choix d'une marée donnée comme condition limite d'un modèle numérique de cours d'eau peut être la cause de certaines conclusions erronées touchant les caractéristiques générales d'écoulement dans la partie du cours d'eau soumise aux marées. L'utilisation de diverses valeurs tidales à la pointe Atkinson, comme conditions limites d'un modèle du fleuve Fraser, s'est traduite par la prévision d'écoulements dont l'écart pouvait atteindre 60 %, ceci même pour des cycles tidaux identiques quant à la gamme et à la séquence des extrêmes. L'analyse de valeurs extrêmes, portant sur une période de 19 années à la pointe Atkinson, a montré que seulement 68 % des cycles tidaux présentaient une même séquence des extrêmes, la gamme variant de facon considérable.

Mots-clés: modèle numérique, condition limite, analyse tidale.

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I would like to thank Mike Miles, of Mike Miles and Associates, whose initial inquiry about a "typical" tidal cycle at Point Atkinson prompted this study. Thanks are also due to Tony Ma and Fred Stephenson who did the analysis of the accuracy of the predicted values, and Allan Douglas who assisted greatly in the operation of the Hewlett-Packard computer system. I also appreciate the support of Al Ages, who provided helpful comments throughout the project and Rick Thomson who reviewed the draft of the report.

INTRODUCTION

The Fraser River is an important socio-economic waterway of British Columbia, with a highly developed delta area within the environs of Vancouver (see Figure 1). The use of the lower river as a fresh water port has created an increasing demand for accurate predictions of water level and flow. Due to the complexity of the water movement (involving both river discharge and tidal motion), such predictions necessitate the use of numerical or physical models. Both types of models require input of a river discharge at the upstream boundary and tidal heights at the downstream boundary. In the Fraser, the tide is observed to propagate to Chilliwack during periods of low discharge and to Mission during high discharges, with actual flow reversals occurring as far upstream as Mission (Ages and Woollard, 1976). The tidal boundary conditions are commonly based on the observed or predicted water levels at Point Atkinson, a principal tidal reference station in operation since 1914. This report details an analysis of the tides at Point Atkinson and compares river velocities predicted by a mathematical model using a number of different tides as boundary conditions. It also points out how the selection of a particular tide might lead to some incorrect conclusions about general flow characteristics in the tidal portion of the Fraser.

TIDES

The tides at Point Atkinson are mixed, mainly semi-diurnal, with a large variation in daily range and sequence of extremes (see Figure 2). There are typically four extremes (highs and lows) in a lunar day (with the exception of saddle points, discussed later), consisting of higher high water (HHW), lower high water (LHW), higher low water (HLW) and lower low water (LLW). The possible sequences may be characterized as follows: LLW following HHW, LLW following LHW, or HHW may equal LHW (see Figure 2). In the situation where HLW has an equal or higher value than LHW, a saddle point exists, and only two true extremes occur in that lunar day (see Figure 2).

A period of nineteen years was chosen for the analysis of extremes since one of the important factors in the tides (the variation in the inclination of the moon's orbit to the celestial equator) has a period of about 18.6 years (Schureman, 1958).

INPUT DATA

A version of the tidal prediction program (Foreman, 1977) used by the Marine Environmental Data Service for the Canadian Tide and Current Tables, was run for 1964 to 1982. Times and heights of highs and lows at Point Atkinson were predicted by a harmonic method using 62 constituents with the astronomical arguments recalculated for each month.

The use of observed values, although desirable, was unrealistic due to the number of years involved. The Tidal Section of the Institute of Ocean Sciences undertook a study to estimate the accuracy of the predictions of water levels at Point Atkinson. The results of this study (Table 1) show that the predicted values are quite satisfactory.

ANALYSIS PROGRAM

Starting with the first extreme of the first day, the analysis program examines the extremes in groups of four. If two consecutive extremes are more than 14 hours apart, an intermediate saddle point containing two extremes (see Figure 2) is assumed to occur.

Each extreme is categorized and the sequence of the group of four is determined. This sequence may be LLW following HHW, LLW following LHW, or HHW may equal LHW. Groups containing a saddle point are of the sequence LLW following LHW, although HLW and LHW are not identified (by definition HLW has an equal or higher value than LHW). The range is calculated as HHW-LLW, and the appropriate counter for this sequence and range is incremented. The program then cycles to consider the next group of four extremes. When nineteen years have been completed, the tabulation is listed (Table 2) and a histogram is drawn (Figure 3). The number of tidal cycles (i.e. groups of four extremes) for each range and sequence is plotted versus the tidal range (in 15 cm increments). The different sequences are identified by shading as noted in the legend.

RESULTS

During the nineteen year period 68% of the cycles had a sequence of LHW, LLW (including three saddle points in the 1968 predictions and six in 1969), compared with 31.5% for HHW, LLW and 0.5% for HHW = LHW. All of the ranges were between 180 cm and 510 cm, with a mean of 321 cm and a standard deviation of 62 cm.

BOUNDARY CONDITIONS

To study the effect of different tidal boundary conditions on the model predictions, several cases were examined (see Table 3). These cases were chosen from model predictions based on predicted tides at Point Atkinson for January, February and March 1983, and all comparisons used the same upstream discharge at Hope (600 m^3/s for January and February, and 700 m^3/s for March). The maximum upstream and downstream flows predicted by the model at Steveston and New Westminster were determined for each tidal cycle. Only the Steveston velocity predictions are discussed below, since the change in predicted velocities at New Westminster followed the same pattern, with the change in the downstream velocity being about 50% of that experienced at Steveston.

Groups of four extremes were characterized by range (the difference between higher high and lower low waters) and sequence of extremes (lower low water following higher high water, or lower low water following lower high water). For groups with the same range and a different sequence of extremes, the predictions varied by 0.3 m/s for both upstream and downstream velocities. For groups with the same sequence of extremes, a range increase of 1.77 m resulted in an increase of 0.6 m/s in the downstream flow only, whereas a range increase of 0.61 m resulted in an increase of 0.1 m/s downstream and 0.2 m/s upstream. For groups with a different sequence of extremes a range increase of 2.07 m resulted in an increase of flow of 0.4 m/s downstream and 0.2 m/s upstream, while a range increase of 1.22 m resulted in an increase of flow of 0.3 m/s downstream and 0.1 m/s upstream. Even with the same range and the same sequence of extremes results were not consistent. In one case both upstream and downstream flow predictions were identical, but in another flows varied by 0.1 m/s downstream and 0.3 m/s upstream. This is likely due in part to the greater difference in actual heights in the latter case, as well as the history of the tidal motion.

The examples illustrate the influence of different tides on model predictions when used as downstream boundary conditions. The changes in predicted velocities show that unless a specific case is to be studied, a variety of tides should be considered as boundary conditions in order to obtain a representative model.

CONCLUSIONS

The analysis shows that the predominant sequence of the extremes in tidal elevation at Point Atkinson is lower low water following lower high water with an average range of 321 cm. However, about one-third of the tidal cycles are not of this sequence, and the range varies considerably. An examination of the effect of several tides as boundary conditions shows that flow predictions vary both with sequence and range of the tidal extremes. Even for tides with the same sequence and range the predicted velocities may differ by as much as 60% due to different tidal heights or preceding tidal motion. Since a "typical" tidal cycle does not exist several different semi-diurnal cycles may be necessary to represent the tidal motion. A model simulation with a single tide as a boundary condition may not detect some important aspects of the Fraser's flow regime with possible unfortunate consequences for navigation or engineering.

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TABLE 1. The Accuracy of Predicted Extremes at Point Atkinson (1980)

Error = Predicted - Observed

TIME

Range (Min.)		# Errors
-35	-31	2
-30	-26	3
-25	-21	9
-20	-16	45
-15	-11	117
-10	- 6	216
- 5	- 1	360
0	4	329
5	9	207
10	14	74
15	19	39
20	24	8
25	29	2
30	34	0
35	39	2

Bracketed: -5 to 4: 48·8%; -10 to 9: 78·7%; -15 to 14: 92·2%

HEIGHT

Range (cm)		# Errors
-80	-76	1
-75	-71	1
-70	-66	0
-65	-61	1
-60	-56	5
-55	-51	0
-50	-46	7
-45	-41	9
-40	-36	10
-35	-31	17
-30	-26	46
-25	-21	49
-20	-16	72
-15	-11	107
-10	- 6	155
- 5	- 1	201
0	4	240
5	9	201
10	14	131
15	19	83
20	24	52
25	29	17
30	34	8

Bracketed: -5 to 4: 31·2%; -10 to 9: 56·4%; -15 to 14: 73·2%

Maximum Time Errors:
-32 Min, +35 Min

Maximum Height Errors:
-78 cm, +31 cm

TABLE 2. 19 Years of Point Atkinson Extremes by Tidal Range

Range Up To	Sequence of Extremes: LHW,LLW	HHW,LLW	HHW=LHW	TOTAL
120 cm	0	0	0	0
135 cm	0	0	0	0
150 cm	0	0	0	0
165 cm	0	0	0	0
180 cm	0	0	0	0
195 cm	6	6	0	12
210 cm	25	31	1	57
225 cm	87	86	0	173
240 cm	143	164	0	307
255 cm	214	238	1	453
270 cm	260	231	3	494
285 cm	333	260	5	598
300 cm	351	241	3	595
315 cm	388	204	4	596
330 cm	416	181	2	599
345 cm	394	149	2	545
360 cm	365	99	1	465
375 cm	373	72	3	448
390 cm	296	67	3	366
405 cm	218	35	3	256
420 cm	184	21	1	206
435 cm	177	12	2	191
450 cm	137	4	0	141
465 cm	96	0	1	97
480 cm	62	0	0	62
495 cm	27	0	0	27
510 cm	5	0	0	5
525 cm	0	0	0	0
540 cm	0	0	0	0
555 cm	0	0	0	0
570 cm	0	0	0	0
585 cm	0	0	0	0
Higher	0	0	0	0
Total	4557	2101	35	6693

TABLE 3. Effect of Point Atkinson Tides on Model Predicted Velocities at Steveston

Date	Point Atkinson Extremes				Range (HHW-LLW)	Maximum Model Predicted Velocities at Steveston	
						Downstream	Upstream
1983	(M wrt Chart Datum)				(M)	(M/S)	(M/S)
Jan. 9	4.02	3.57	4.39	1.25	3.14	1.2	0.5
19	1.49	4.63	2.83	3.44	3.14	0.9	0.8
Jan. 1	0.12	5.12	3.57	4.42	5.00	1.4	0.9
5	1.74	4.97	2.44	3.41	3.23	0.8	0.9
Mar. 2	1.58	4.72	1.89	4.05	3.14	1.0	0.7
7	4.05	3.54	3.75	1.52	2.53	0.9	0.5
Jan. 1	0.12	5.12	3.57	4.42	5.00	1.4	0.9
7	3.44	2.87	4.66	1.74	2.93	1.0	0.7
Feb. 1	1.04	5.00	2.59	3.93	3.96	1.2	0.9
3	2.13	4.79	2.04	3.60	2.74	0.9	0.8
Jan.12	4.69	3.75	4.18	0.91	3.78	1.2	0.8
16	0.94	4.72	3.44	3.96	3.78	1.2	0.8
Feb. 3	2.13	4.79	2.04	3.60	2.74	0.9	0.8
5	3.66	3.20	4.39	1.65	2.74	1.0	0.5

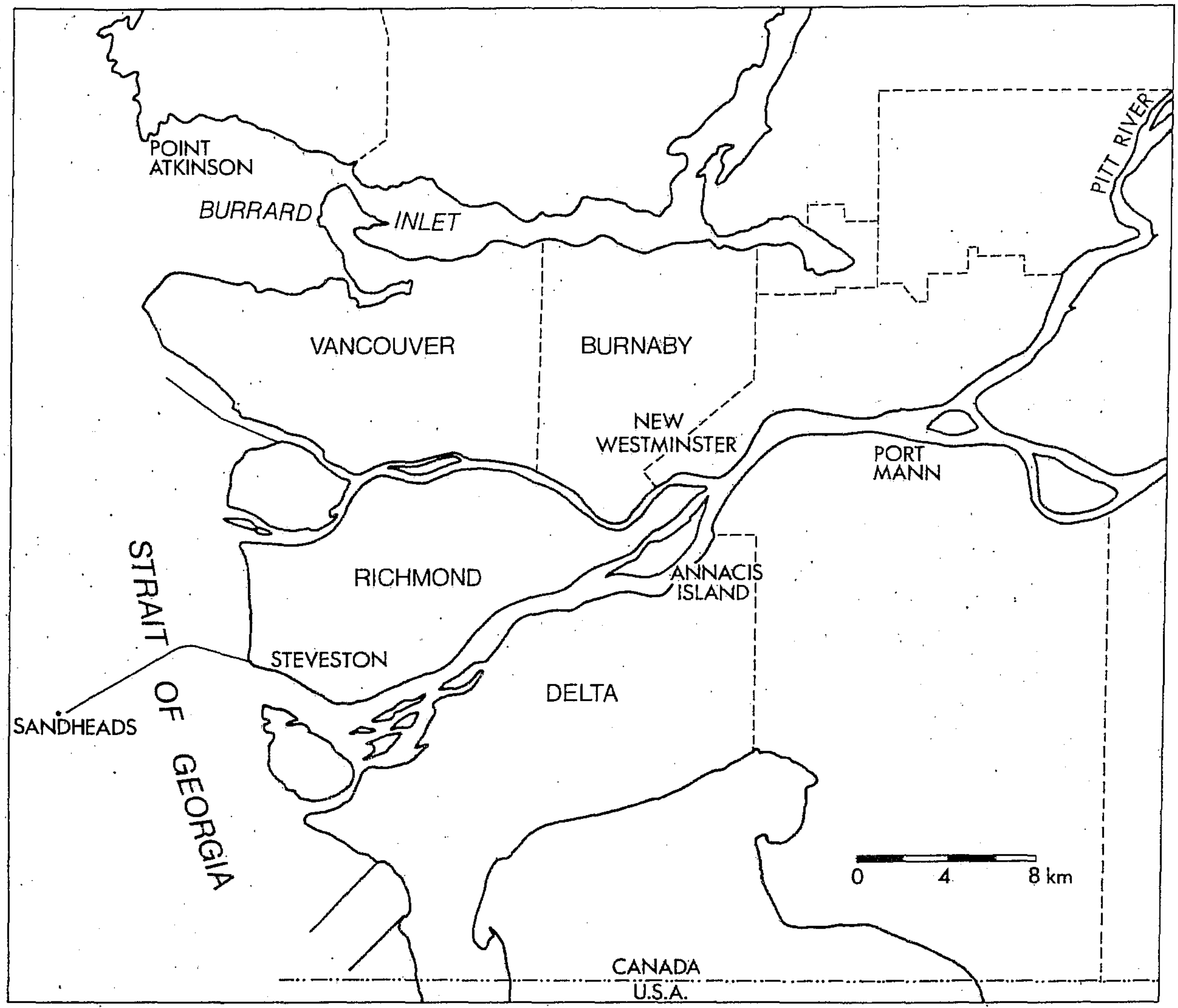

Fig. 1. The Lower Fraser River.

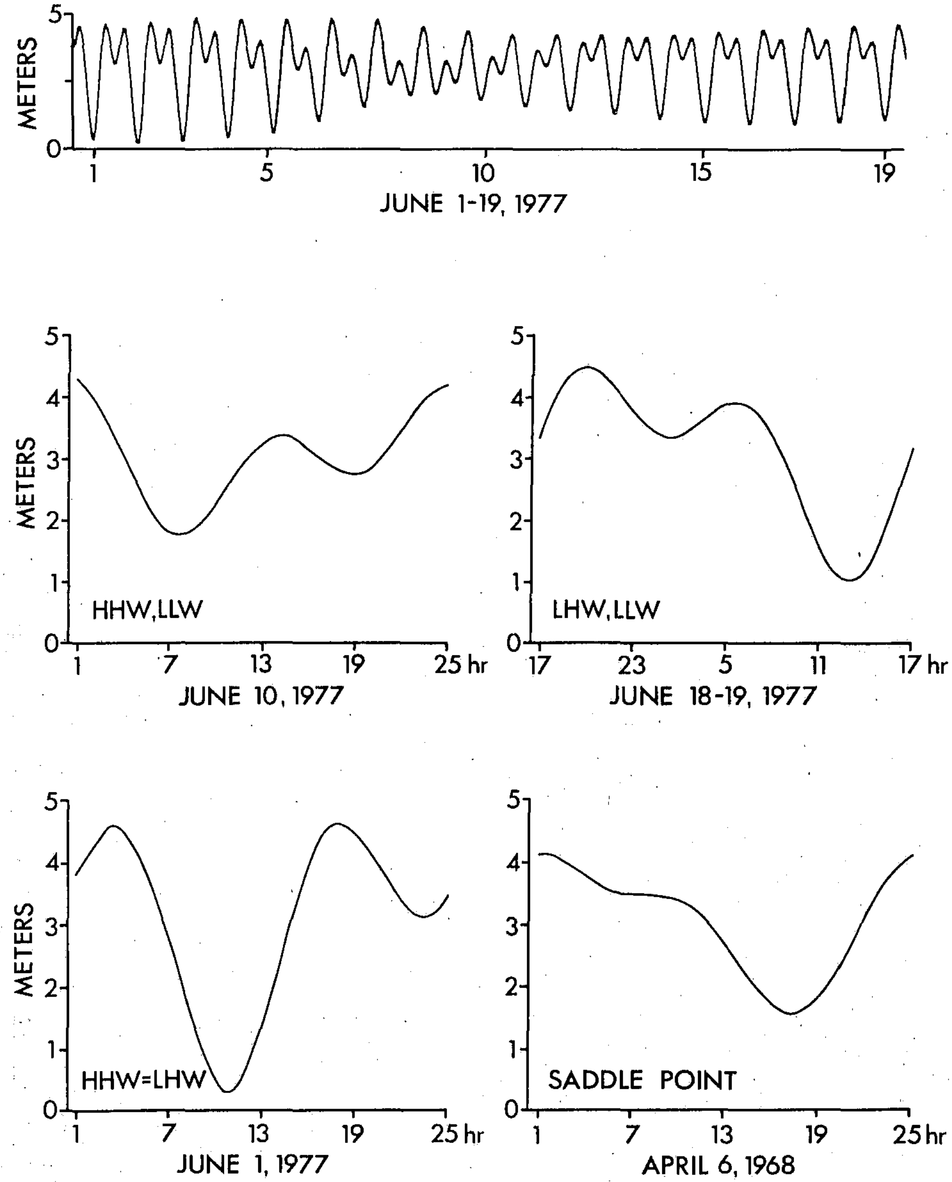

Fig. 2. Sequences of Tidal Extremes at Point Atkinson.

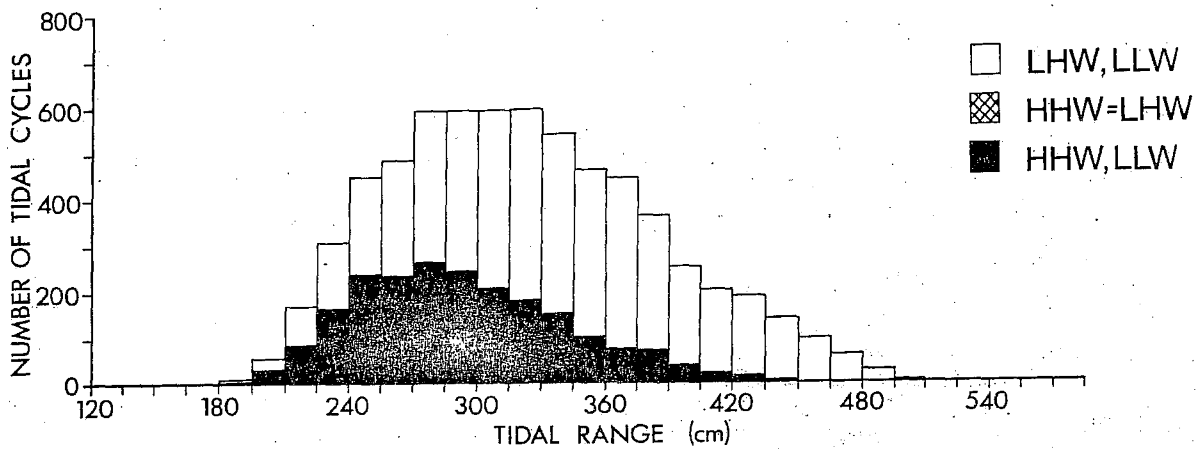

Fig. 3. 19 Years of Point Atkinson Extremes by Tidal Range.