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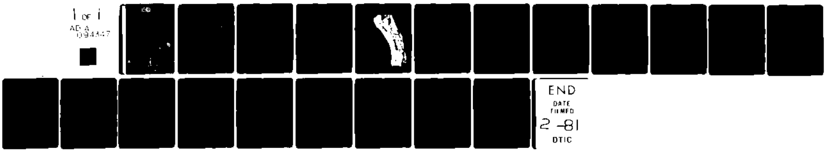

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REPORT

June 1973

A STUDY OF THE FEASIBILITY OF INCREASING CIRCULATION IN THE WATERWAYS OF THE COLLIER BAY AREA MARCO ISLAND, FLORIDA

by

John F. Michel, Associate Professor
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A STUDY OF THE FEASIBILITY OF INCREASING CIRCULATION
IN THE WATERWAYS OF THE COLLIER BAY AREA
MARCO ISLAND, FLORIDA

Purpose of the Study

This study was designed to determine the feasibility of improving the circulation of the Landmark and Castaways Waterway systems at Marco Island. In view of the fact that many of the waterways had already been built, only minor changes in configuration could be considered.

Description of the Area

Marco Island is located on the Gulf Coast of Florida at Latitude 25°56'N. The island itself is approximately four miles long and is isolated from the mainland by the Marco River. Major inlets consisting of Big Marco Pass to the north and Caxambas Pass to the south provide good exchange between the River and the Gulf. The tide is well mixed and has a mean range of 1.7 feet and a spring range of 2.6 feet.

Description of the Systems

The waterways systems are shown on Figure 1. The Landmark system has a planned surface area of approximately 2200 acres and is tributary to Caxambas Pass on the south. The longest distance to Caxambas Pass is 11,000 feet.

The Castaways system has an area of 2400 acres and drains into the Marco River near Big Marco Pass via Collier Bay. Its maximum distance to the Marco River is 9,500 feet.

The landward ends of the two waterways are separated only by State Road 92 and a tier of lots on both sides, a total of 350 feet.

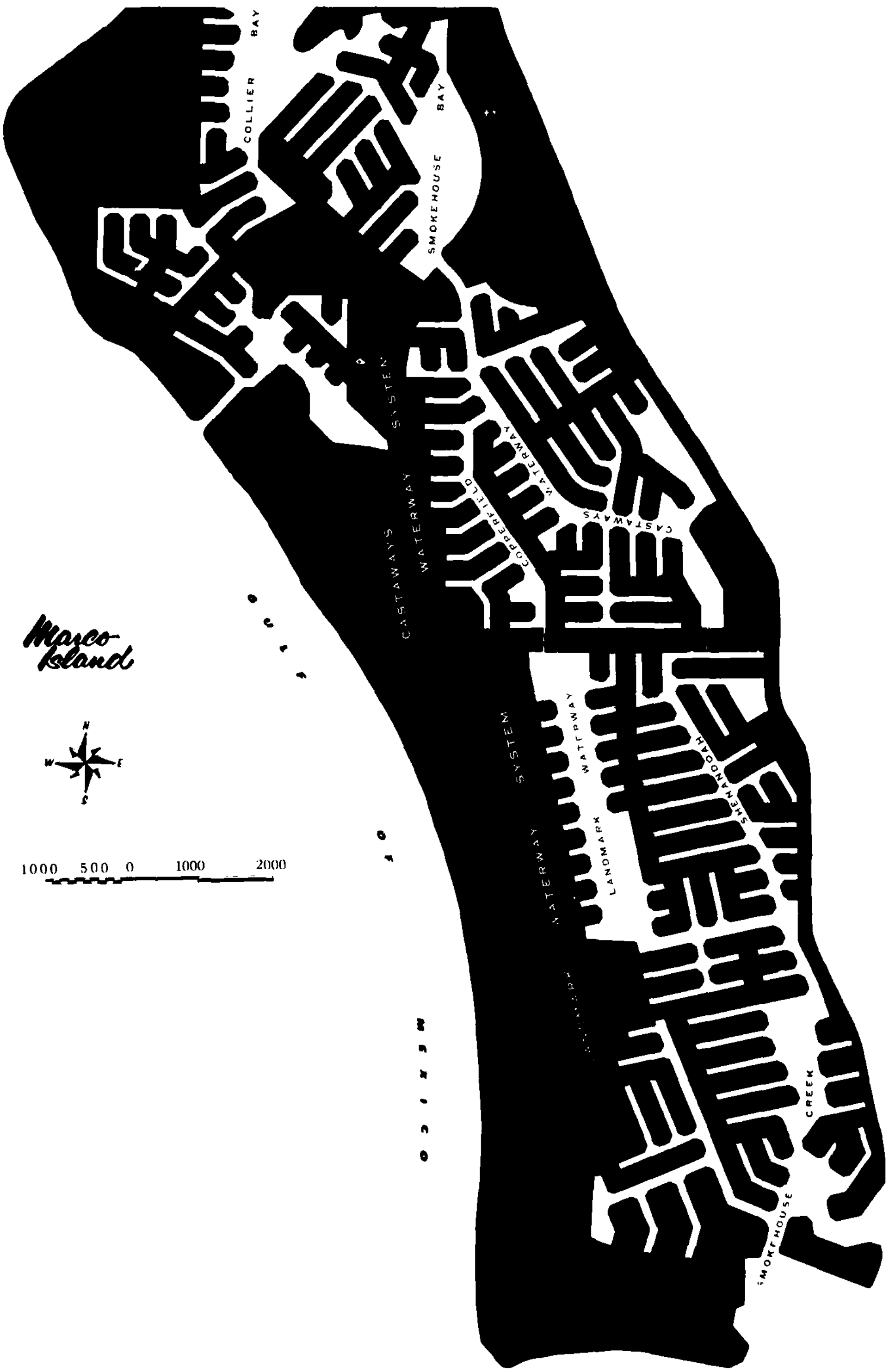


FIGURE 1 - PLAN VIEW OF SYSTEM

Approach to the Problem

In attacking this problem, it was immediately evident that the proximity of the landward ends of the waterways might be used to advantage by connecting them at one or more points. A quick study of the records of tide gauges located near the mouths of the system showed a phase difference. This indicated that a differential head would exist across State Road 92. This head would be available to promote interchange between the two systems. The actual extent of the interchange could be predicted by means of a numerical model.

The Numerical Model

This model was based on the application of Manning's formula to a series of separate reaches in the system. Reaches are selected so that their geometry can be considered to be uniform throughout. For each reach, a storage area and a resistance coefficient is determined.

The following relationships will then hold for the nth reach for continuity and energy loss:

$$\left(\frac{Q_n - Q_{n+1}}{A_n}\right) = \frac{\Delta\eta}{\Delta t} \qquad (1)$$

where:

Q_n = flow into the reach (ft^3/s)

Q_n+1 = flow out of the reach (ft^3/s)

A_n = storage area (ft^2)

$\Delta\eta$ = increase in surface elevation (ft)

Δt = interval of time (s)

The head loss in the reach is related to the flow by

$$\eta_n - \eta_{n+1} = k_n \left(\frac{Q_n^2 + Q_{n+1}^2}{2} \right) \quad (2)$$

where:

η_n = water surface elevation at entrance (ft)

η_{n+1} = water surface elevation at exit (ft)

k_n = resistance coefficient for the reach (s/ft^2)

where: k_n is derived from Manning s formula

$$u_n = \frac{1.486}{n} R_n^{2/3} S_n^{1/2} \quad (3)$$

and:

$$\bar{Q}_n = \left(\frac{Q_n^2 + Q_{n+1}^2}{2} \right)^{1/2} = u_n a_n \quad (4)$$

where:

$\bar{Q}_n$ = the root mean square discharge in the reach(ft^3/s)

u_n = velocity averaged vertically and horizontally (ft/s)

1.486 = a conversion factor from metric to English units. $(3.281 \text{ ft/m})^{1/3}$

n = Manning's roughness coefficient$(ft)^{1/6}$

R_n = the hydraulic radius (ft) which is the cross sectional area of the channel, $a_n(ft^2)$divided by the wetted perimeter, p_n(ft)

S = the hydraulic gradient(ft/ft)

which for uniform flow

= $\Delta\eta \div L_n$ where L_n = the length of the reach(ft)

Substituting in Equation (4) and squaring we have

$$\bar{Q}_n^2 = \left(\frac{1.486}{n} \right)^2 \frac{a_n^{10/3}}{p_n^{4/3}} \frac{\Delta\eta}{L_n} \tag{5}$$

which gives:

$$k_n = \frac{n^2 \; p_n^{4/3} \; L_n}{2,208 \; a_n^{10/3}} \tag{6}$$

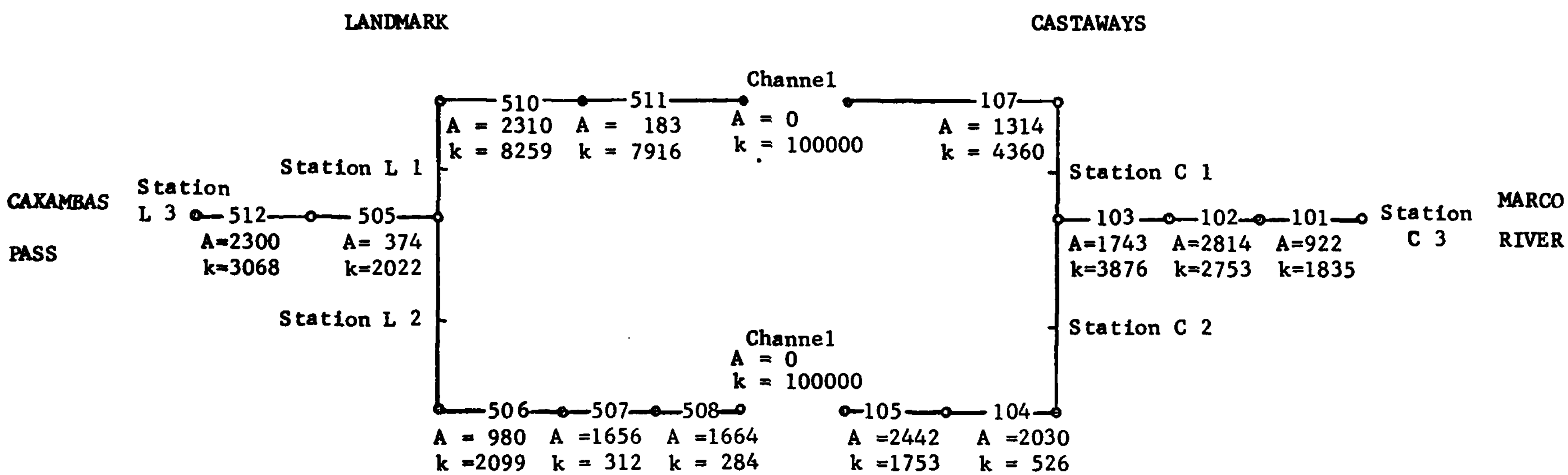
Obviously in an area affected by tide k_n will vary with time as p_n and a_n vary with the water surface elevation. In the present model, this variation was found to be insignificant due to the large depth (20 ft) of the canals; so it was ignored.

Figure 2 shows a schematic diagram of the waterways systems as modelled.

The boundary conditions are prescribed by the water surface elevations at the mouth and the geometry.

In analyzing these elevations, the raw data from tide gauges is smoothed to eliminate transient effects such as wind set up by utilizing a tidal component analysis involving a least squares fit to isolate the mean tide level and sine and cosine coefficients for the four principal frequencies of tide producing forces according to the formula:

$$\eta = \eta_o + \sum_{n=1}^{4} (S_n \sin \sigma_n t + C_n \cos \sigma_n t)$$



NOTE: A is in $ft^2 x10^3$
k is in $(S/ft^2)x10^{-12}$

FIGURE 2.

SCHEMATIC DIAGRAM OF NUMERICAL MODEL

where:

η = tide level at time t

η_o = mean tide level

S_n = coefficient for the sine term for the nth frequency

C_n = coefficient for the cosine term for the nth frequency

σ_n = frequency or $2\pi/T_n$ where T_n is the period of the nth frequency

For this study the analysis included components having periods as shown: M2-12.42 hours, S2-12.00 hours, K1-23.93 hours and 01-25.82 hours.

The components are used to compute typical spring and neap tides to be used in the model. In the case of this study hourly values were computed for 26 hour periods at spring and neap tide.

In operating the model, the first approximation for discharges is based on a frictionless condition. The head loss and storage volume is then recomputed by Equations (1) and (2) on the basis of these flows to determine a second approximation. This is averaged with the preceeding value and the process is repeated until a reasonable tolerance is obtained.

Application of the Model

On the basis of using the tidal differences in the two waterway systems to increase flushing, the model as shown on Figure 2 was revised to provide a channel 20 feet wide and 10 feet deep connecting Reach No. 105 (Castaways Waterway) of the Castaways system with Reach No. 510 (Shenandoah Waterway) of the Landmark system. A similar channel was provided to connect Reach No. 107 (Copperfield Waterway) with Reach No. 508 (Landmark Waterway). These connections are shown by dotted lines on Figure 2. These channels were found to have a resistance coefficient, $k = 100{,}000 \times 10^{-12}$, considerably more than the total resistance of all channels in the network.

Operation of the revised model utilizing existing data from the David Key and Yacht Club tide gauges and allowing 25% of the velocity head for entrance and exit losses showed that the discharge through the canals would be more than trebled on both spring and neap tides.

The situation was further improved by simulating gates at the channels to allow flow only to the north. Under these conditions, it was shown that the net rate of exchange per 24 hour period would exceed 130×10^6 cubic feet on a spring tide and 90×10^6 cubic feet on a neap tide.

Since the tidal data used could not be assumed to reflect the exact conditions in the waterways, two recording gauges were installed in the waterways themselves and operated during the period 1-26 April 1973. These gauges were accurately referenced to each other and to Sea Level Datum, 1929, by differential leveling.

These data were then reduced and tides were reconstructed for 10 April 1973 to produce a neap tide and for 17 April to produce a spring tide. Plots of these are shown on Figures 3 and 4.

The model was then operated utilizing the reconstructed tides. Conditions with and without gates were assumed and volumes of net flow toward the north were computed. From these volumes and the total volume of the waterway systems: Castaways - $145 \times 10^6 ft^3$, Landmark - $131 \times 10^6 ft^3$, the exchange time for the total volumes was computed.

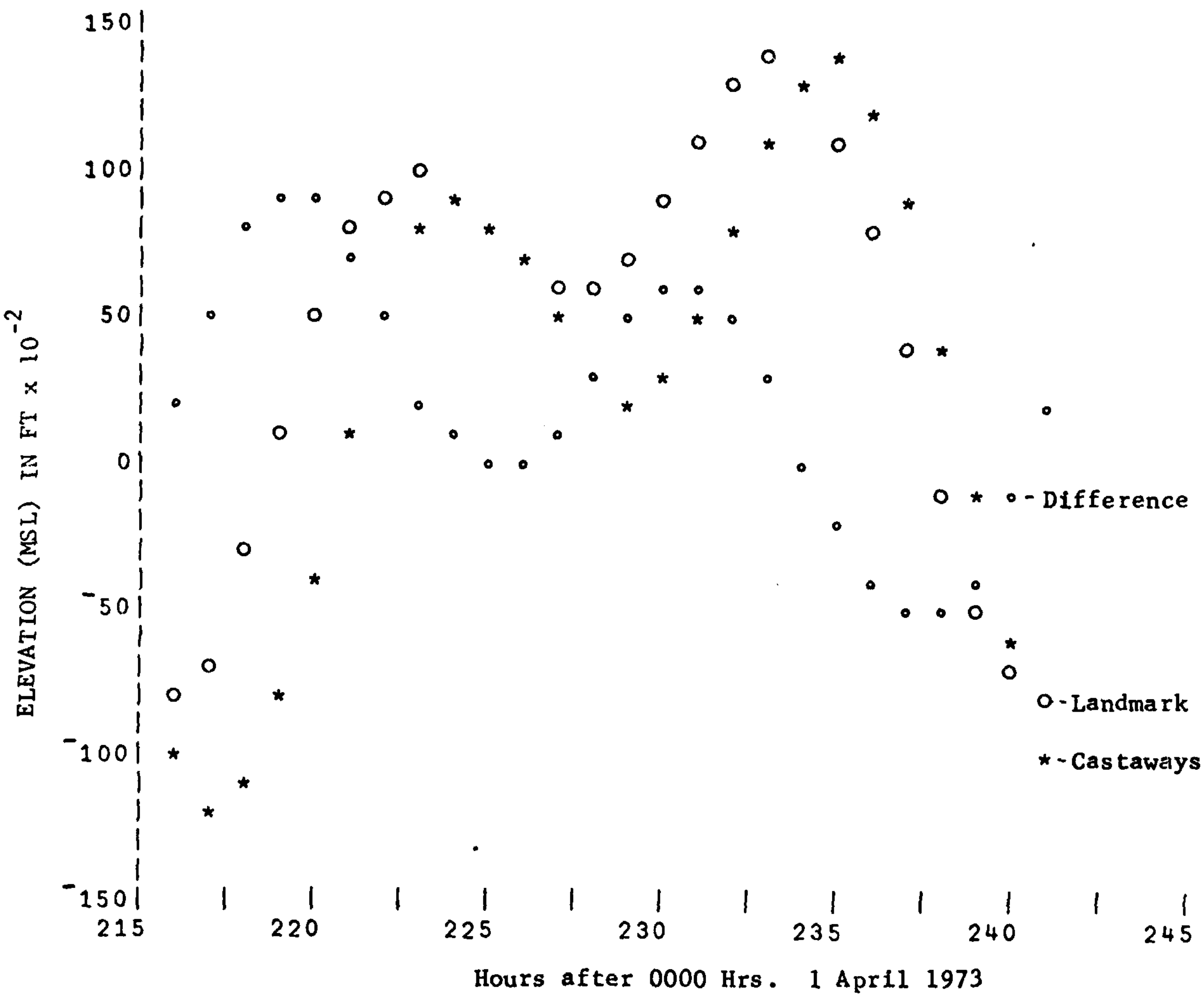


FIGURE 3 - TIDAL RELATIONS FOR LANDMARK AND CASTAWAYS WATERWAYS FOR NEAP TIDE

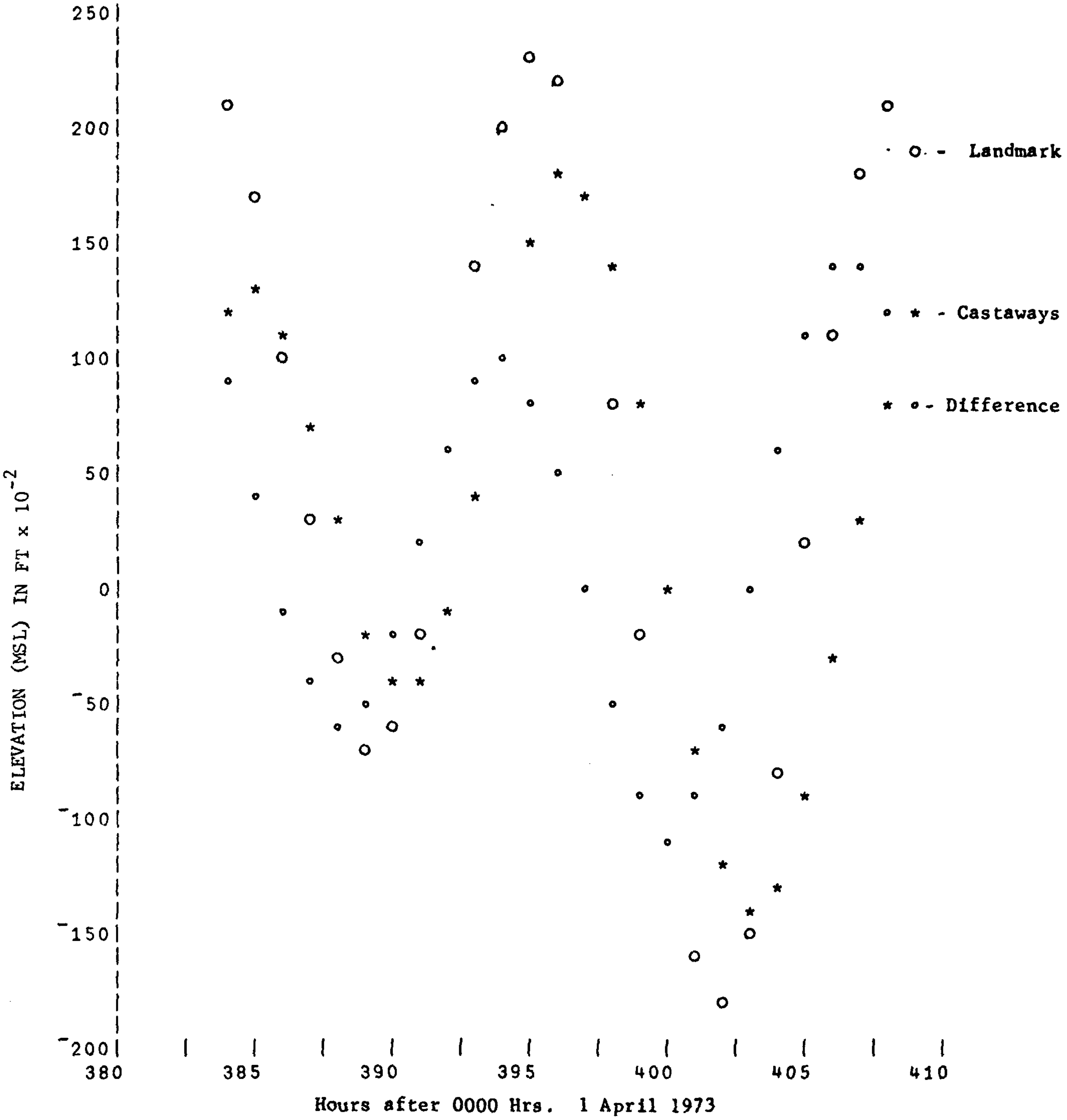


FIGURE 4 - TIDAL RELATION FOR LANDMARK AND CASTAWAYS WATERWAYS FOR SPRING TIDE

The results of operating the model are shown in detail in the Appendix. A summary is shown on Table 1.

TABLE 1

	Net North Flow ($ft^3/day \times 10^{-6}$)	Time to Exchange Total Waterway Volume (days)
1. Without Gates		
a. Castaways System		
(1) Neap Tide	81	1.80
(2) Spring Tide	33	4.39
b. Landmark System		
(1) Neap Tide	87	1.51
(2) Spring Tide	21	4.49
2. With Gates		
a. Castaways System		
(1) Neap Tide	112	1.31
(2) Spring Tide	96	1.53
b. Landmark System		
(1) Neap Tide	117	1.12
(2) Spring Tide	92	1.43

Conclusions

As a result of this study, we conclude that the circulation of the Castaways and Landmark Waterway systems can be greatly improved by the construction of two concrete channels 20 ft. wide by 10 ft. deep by 350 feet long under State Road 92. These channels will provide total exchange in one to three days which will provide exceptionally good water quality as compared to the configuration as currently planned.

The installation of gates that will alow flow only to the north will further improve the circulation, but the cost of constructing, maintaining and operating these gates will outweigh the benefits gained.

Recommendations

We recommend as follows:

1. That the westernmost channel connecting the existing Landmark and Copperfield Waterways be constructed as soon as practicable.

2. That after this is construqted the flows in the existing system be analyzed in detail to check the authenticity of the model.

3. That a channel connecting Shenandoah Waterway with Castaways Waterway be included in future plans for developing the Collier Bay Tract.

4. That the design of both channels be modified on the basis of results of the analysis recommended in Paragraph 2 above. At this stage it may be considered desirable to add tide gates.

APPENDIX

RESULTS OF MODEL RUNS

CONTENTS

Explanation of Format

These tables show flow conditions for neap and spring tides. The columns are as follows:

Column	
1 & 7	Time in hours after 0000 hrs. on 1 April 1973
2 & 8	Tide height above MSL 1929 datum at mouth of system
3 & 9	Flow in ft^3/s through the channel. Flow to the north is positive.
4 & 10	Flow past Station 1 marked C 1 and L 1 on Figure 2 for Castaways and Landmark respectively
5 & 11	Flow past Station 2
6 & 12	Flow past Station 3

CPN.CPS

216	¯102	757	757	757	1514	384	121	1916	1916	1916	3832
217	¯117	1311	1468	1365	3062	385	130	1109	1014	1076	2053
218	¯110	1611	1537	1585	3014	386	110	¯1060	¯811	¯836	¯1472
219	¯82	1732	1437	1629	2641	387	73	¯1900	¯1496	¯1758	¯2654
220	¯41	1703	1271	1556	2201	388	25	¯2126	¯1622	¯1911	¯2842
221	5	1547	1063	1379	1742	389	¯17	¯1955	¯1514	¯1802	¯2670
222	47	1259	817	1105	1283	390	¯39	¯1339	¯1108	¯1253	¯2032
223	75	900	605	797	977	391	¯36	778	746	767	1467
224	88	450	313	402	517	392	¯6	1655	1339	1545	2428
225	84	¯318	¯276	¯304	¯519	393	44	2217	1691	2034	2964
226	68	0	168	58	470	394	101	2249	1649	2040	2822
227	47	636	856	712	1889	395	150	1918	1402	1730	2396
228	30	989	1167	1051	2477	396	176	1336	1062	1241	1907
229	22	1259	1343	1288	2753	397	173	¯673	¯642	¯663	¯1258
230	29	1398	1324	1372	2590	398	137	¯1969	¯1591	¯1838	¯2881
231	49	1410	1199	1337	2232	399	76	¯2475	¯1834	¯2253	¯3158
232	77	1298	1003	1195	1773	400	1	¯2620	¯1832	¯2347	¯3037
233	107	989	673	879	1096	401	¯70	¯2415	¯1669	¯2156	¯2744
234	129	318	86	237	¯11	402	¯122	¯1785	¯1239	¯1596	¯2042
235	136	¯881	¯955	¯907	¯1968	403	¯145	¯121	120	¯38	433
236	123	¯1219	¯1083	¯1172	¯2056	404	¯134	1987	1871	1946	3650
237	91	¯1362	¯1026	¯1246	¯1784	405	¯94	2666	2245	2520	4156
238	44	¯1337	¯843	¯1166	¯1293	406	¯34	2972	2341	2753	4180
239	¯10	¯1132	¯565	¯935	¯678	407	31	2954	2270	2716	3997
240	¯60	¯663	¯138	¯481	143	408	84	2623	2065	2429	3688
241	¯96	711	1089	842	2479	409	116	1814	1477	1697	2687

TABLE A - CASTAWAYS WATERWAY WITHOUT TIDE GATE

II

LMN,LMS

216	¯85	757	757	757	1514	384	207	1916	1916	1916	3832
217	¯66	1311	1442	1537	3121	385	169	1109	845	655	1218
218	¯33	1611	1839	2005	4089	386	104	¯1000	¯1451	¯1777	¯3710
219	7	1732	2009	2209	4515	387	28	¯1900	¯2427	¯2808	¯5799
220	45	1703	1966	2156	4405	388	¯35	¯2126	¯2563	¯2879	¯5909
221	76	1547	1761	1917	3909	389	¯68	¯1955	¯2184	¯2350	¯4778
222	94	1259	1383	1474	2991	390	¯61	¯1339	¯1291	¯1256	¯2494
223	99	900	934	959	1931	391	¯17	778	1082	1303	2713
224	94	450	415	390	768	392	55	1655	2153	2515	5203
225	81	¯318	¯409	¯474	¯978	393	135	2217	2771	3172	6537
226	68	0	¯91	¯156	¯342	394	201	2249	2706	3037	6233
227	59	636	573	528	1035	395	234	1918	2146	2312	4703
228	59	989	989	989	1978	396	224	1336	1266	1216	2409
229	69	1259	1328	1378	2780	397	170.	¯673	¯1047	¯1316	¯2767
230	87	1398	1522	1613	3269	398	83	¯1969	¯2572	¯3009	¯6226
231	108	1410	1555	1660	3372	399	¯16	¯2475	¯3161	¯3658	¯7554
232	127	1298	1429	1524	3095	400	¯106	¯2620	¯3244	¯3695	¯7607
233	136	989	1051	1096	2214	401	¯165	¯2415	¯2824	¯3120	¯6382
234	132	318	290	270	530	402	¯180	¯1785	¯1889	¯1965	¯3965
235	113	¯881	¯1013	¯1108	¯2262	403	¯147	¯121	107	273	625
236	79	¯1219	¯1455	¯1626	¯3333	404	¯76	1987	2478	2835	5841
237	36	¯1362	¯1660	¯1876	¯3855	405	16	2666	3303	3764	7751
238	¯9	¯1337	¯1649	¯1875	¯3858	406	107	2972	3602	4058	8337
239	¯48	¯1132	¯1403	¯1598	¯3290	407	175	2954	3424	3766	7696
240	¯73	¯663	¯837	¯962	¯1984	408	205	2623	2830	2981	6034
241	¯81	711	655	615	1211	409	193	1814	1730	1670	3312

TABLE B - LANDMARK WATERWAY WITHOUT TIDE GATE

III

CPN1,CPS1

216	¯102	757	757	757	1514	384	121	1916	1916	1916	3832
217	¯117	1311	1468	1365	3062	385	130	1109	1014	1076	1953
218	¯110	1611	1537	1585	3016	386	112	0	¯174	¯298	¯835
219	¯82	1732	1437	1629	2641	387	73	0	20	¯248	¯1144
220	¯41	1703	1271	1553	2201	388	25	0	121	¯208	¯1099
221	5	1547	1063	1379	1742	389	¯17	0	93	¯195	¯1069
222	47	1259	817	1105	1283	390	¯39	0	¯52	¯203	¯976
223	75	900	605	797	977	391	¯36	778	746	767	1467
224	88	450	313	402	517	392	¯6	1655	1339	1545	2428
225	84	0	114	86	¯129	393	44	2217	1691	2034	2964
226	68	0	168	58	470	394	101	2249	1649	2040	2822
227	47	636	856	712	1889	395	150	1918	1402	1739	2396
228	30	989	1167	1051	2477	396	176	1336	1062	1241	1907
229	22	1259	1343	1288	2753	397	173	0	¯252	¯273	¯868
230	29	1398	1324	1372	2590	398	137	0	63	¯184	¯1227
231	49	1410	1199	1337	2232	399	76	0	324	¯95	¯1000
232	77	1298	1003	1195	1773	400	1	0	496	¯19	¯709
233	107	989	673	879	1096	401	¯70	0	524	37	¯551
234	129	318	86	237	¯11	402	¯122	0	475	118	¯328
235	136	0	124	172	¯889	403	¯145	0	439	281	752
236	123	0	410	321	¯563	404	¯134	1987	1871	1946	3650
237	91	0	643	423	¯115	405	¯94	2666	2245	2520	4156
238	44	0	795	472	345	406	¯34	2972	2341	2753	4180
239	¯10	0	822	452	709	407	31	2954	2270	2716	3997
240	¯60	0	674	331	955	408	84	2623	2065	2429	3688
241	¯96	711	1089	842	2479	409	116	1814	1477	1697	2687

TABLE C - CASTAWAYS WATERWAY WITH TIDE GATE

LMN1,LMS1

216	¯85	757	757	757	1514	384	207	1916	1916	1916	3832
217	¯66	1311	1442	1537	3121	385	169	1109	845	655	1218
218	¯33	1611	1839	2005	4089	386	104	0	¯814	¯1140	¯3073
219	7	1732	2009	2209	4515	387	28	0	¯917	¯1298	¯4289
220	45	1703	1966	2156	4405	388	¯35	0	¯820	¯1136	¯4166
221	76	1547	1761	1917	3909	389	¯68	0	¯577	¯743	¯3171
222	94	1259	1383	1474	2991	390	¯61	0	¯235	¯200	¯1438
223	99	900	934	959	1931	391	¯17	778	1082	1303	2713
224	94	450	415	390	768	392	55	1655	2153	2515	5203
225	81	0	¯19	¯84	¯588	393	135	2217	2771	3172	6537
226	68	0	¯91	¯156	¯342	394	201	2249	2706	3037	6233
227	59	636	573	528	1035	395	234	1918	2146	2312	4703
228	59	989	989	989	1978	396	224	1336	1266	1216	2409
229	69	1259	1328	1378	2780	397	170	0	¯657	¯928	¯2377
230	87	1398	1522	1613	3269	398	83	0	¯918	¯1355	¯4572
231	108	1410	1555	1660	3372	399	¯16	0	¯1003	¯1500	¯5396
232	127	1298	1429	1524	3095	400	¯106	0	¯916	¯1367	¯5279
233	136	989	1051	1096	2214	401	¯165	0	¯631	¯927	¯4189
234	132	318	290	270	530	402	¯180	0	¯175	¯251	¯2251
235	113	0	66	¯29	¯1183	403	¯147	0	426	592	944
236	79	0	38	¯133	¯1840	404	¯76	1987	2478	2835	5841
237	36	0	9	¯207	¯2186	405	16	2666	3303	3764	7751
238	¯9	0	¯11	¯237	¯2220	406	107	2972	3602	4058	8337
239	¯48	0	¯16	¯211	¯1903	407	175	2954	3424	3766	7696
240	¯73	0	¯25	¯150	¯1172	408	205	2623	2830	2981	6034
241	¯81	711	655	615	1211	409	193	1814	1730	1670	3312

TABLE D - LANDMARK WATERWAY WITH TIDE GATE

V