CUMMINS | CEDERBERG
Coastal & Marine Engineering

Technical Report
Flushing Analysis

Wong's Marina West Bay Street

Nassau, The Bahamas

October 2024

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1 INTRODUCTION

1.1 General

Cummins Cederberg, Inc. (Cummins Cederberg) was retained by Engineering & Technical Services (ETS) Ltd. to prepare a flushing analysis relative to the proposed site for Wong's Marina on West Bay Street in Nassau, Bahamas (Project).

The proposed Project site is located at latitude 25° 4'47.85"N and longitude 77°21'39.28"W. It is situated on the northern side of West Bay Street and west of the adjacent Arawak Cay Fish Fry of the New Providence mainland, illustrated in **Figure 1** and **Figure 2**. The Project site is located on the New Providence mainland coastline and is separated from the western end of Nassau Harbour by the artificial island Arawak Cay.

The proposed improvements (refer to **Appendix A**) include the development of a commercial complex, which comprises of a 90-slip marina, a dry storage area, parking lot, and two commercial buildings. Proposed dredging requires the basin to be at a minimum 5 feet in water depth at mean low water (MLW).

The proposed Project was evaluated relative to the flushing time criteria within the proposed basin. The flushing time is defined as the time required to reduce the concentration of a conservative pollutant to a desired percentage of its original concentration. Within the Bahamas, the flushing time is typically defined as the time required to reduce the concentration of a pollutant to 10% of the pollutant's original concentration.

FIGURE 1: LOCATION MAP

FIGURE 2: PROPOSED PROJECT SITE

1.2 Scope

The scope of work included the following components:

- **Desktop Flushing Study:** Cummins Cederberg reviewed available documents and data pertinent to the flushing characteristics for the Project. Documents provided by the Client to date include sketches illustrating the marina basin and bathymetry, as well as flow measurements obtained on September 1st and 2nd, 2024.

  Cummins Cederberg performed a flushing analysis utilizing tidal prism desktop calculation methods. The flushing analysis considered the proposed dredged conditions within the proposed marina basin, and the effects of the proposed deepening on the flushing characteristics. Water volume changes were computed based on local bathymetric data and the proposed depths in the marina basin. The flushing time was evaluated and compared to industry standards.

2 SITE CONDITIONS

2.1 Datum Information and Water Levels

2.1.1 Tide

Tidal datums for the Project site was obtained from the nearest National Oceanic and Atmospheric Administration (NOAA) station (9710441) at Settlement Point and are given in **Table 1**. Although Settlement Point is over 150 miles from the project site, tidal signals in Nassau Harbour exhibit similar phasing and amplitude. According to NOAA tide predictions at Nassau (Station ID TEC4623) which is only approximately 0.7 miles from the Project site, the tidal signal phase varies by approximately 8 minutes, and the amplitude varies by about 0.1 feet.

TABLE 1: WATER LEVELS IN MLLW

Datum	Water Level (ft, MLLW)
Mean Higher High Water (MHHW)	3.07
Mean High Water (MHW)	2.83
Mean Sea Level (MSL)	1.47
Mean Low Water (MLW)	0.09
Mean Lower Low Water (MLLW)	0.00

The water levels are characterized by a semidiurnal tide with a mean tidal range of approximately 2.74 feet and a period of approximately 12.2 hours.

2.1.2 Current

The current speed nearby the Project site was measured by a floating object test on September 1-2, 2024. The floating object test measures current speed by releasing a floating object at a marked start point and timing how long it takes to reach a predetermined endpoint. The speed is calculated using the formula: speed = distance/time. The floating object test was performed to the east of the Project site, see **Figure 3**, where measurements could easily be obtained.

FIGURE 3: START AND END LOCATIONS OF FLOATING OBJECT TEST

The current speeds representative of the Project site are presented in **Figure 4** relative to time and cross referenced with the gathered tide prediction. Current speeds ranged from 6.6 to 68.8 ft/min with an average current speed of 29.4 ft/min.

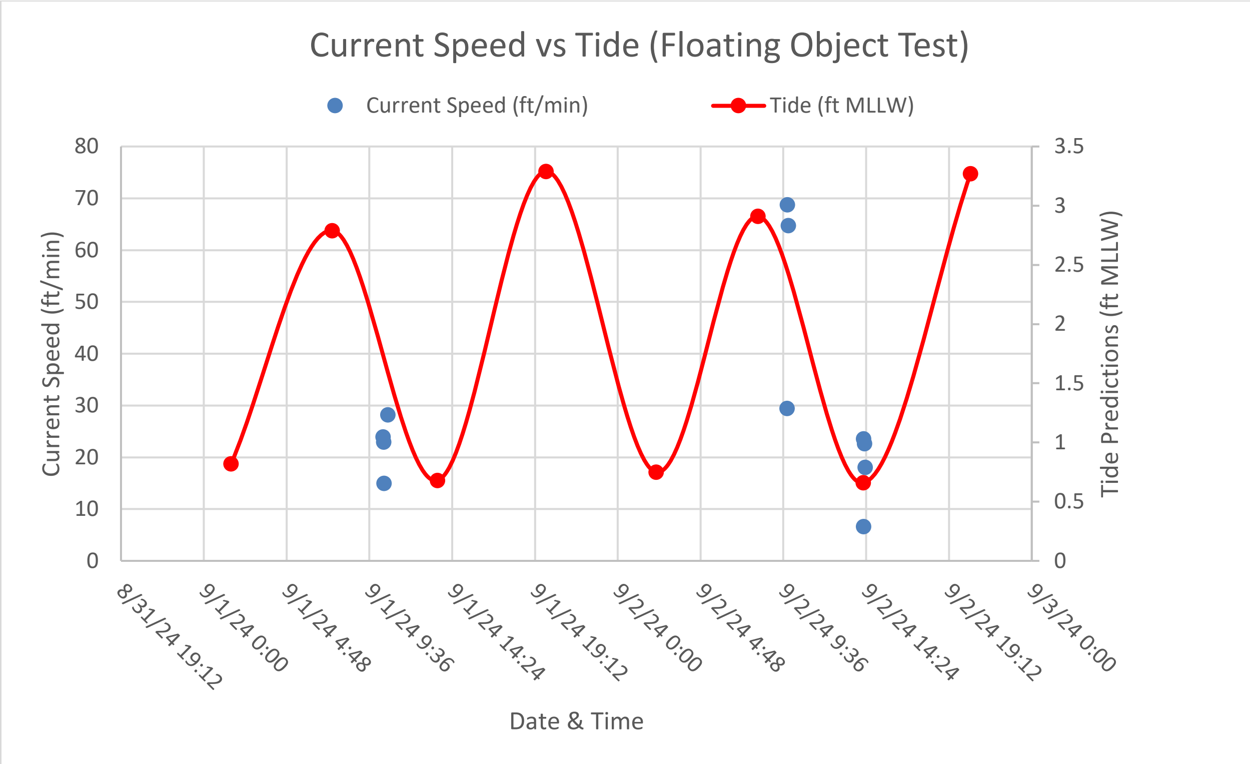


FIGURE 4: CURRENT SPEED VS TIDE PREDICTION

2.2 Water Depths

Bathymetric data of the Project site was received from the Client on August 8, 2024 (refer to **Appendix B** – Bathymetric Survey). Based on the bathymetric data, the present water depth in the basin ranges from 3 to 7 feet. The proposed basin is designed to dredge to a minimum water depth of 5 feet at MLW, the water depth would most likely average close to 5 feet in the proposed basin. This value was used in the **Flushing Analysis** to determine basin volumes.

3 FLUSHING ANALYSIS

3.1 US EPA Method

To evaluate the flushing time for the Project, a Tidal Prism Analysis (TPA) for a semi-enclosed basin was utilized. The Project site could be considered open due to the basin accessibility from the west, north, and east borders. However, the basin was analyzed as a semi-enclosed basin because this designation provides for a more conservative analysis than an open basin, which the EPA defines as "…directly located on rivers, bays or estuaries and are not entirely enclosed by protective barriers [that] would have flushing characteristics generally similar to those for the water body" (US EPA, 1985). The TPA considers the basin depth at low tide and high tide, surface area of the basin, tidal cycle, and nontidal freshwater inflow. Utilizing these basin characteristics, it is possible to estimate the flushing time based on a dilution factor (i.e., reduction percentage of original concentration) and return flow factor (i.e., the percentage of discharged water returning to the basin during the following tidal cycle). The flushing time can be estimated with the following equation (US EPA, 1985):

$$Tf = \frac{Tc \log D}{\log\left(\frac{VL+bVP}{VH}\right)}$$

where:
T_f= Flushing time
T_c = Tidal cycle time
D = Dilution factor
b = Return flow factor
V_L = Volume of marina basin at low tide
V_H = Volume of marina basin at high tideV_p= Volume of marina basin tidal prism ($V_H - V_L$)

The tide exhibits a semi-diurnal signal with an approximate 12.2-hour period. The volume of the basin was calculated through a volumetric-analyzing software using the proposed basin configurations following the dredging described in **Section 1**, and the MHW and MLW levels presented in **Table 1**.

The target dilution factor was set as 10% to evaluate the flushing time based on the published standards. The return flow factor is based on the percentage of the water previously flushed that returns to the marina and expressed as a percentage. The return flow factor was set at 5%, which means 5% of the outgoing water would return to the basin. This flushing time is based on conservative conditions and represents an upper limit for the flushing time estimate since the TPA does not consider varying currents or wind effects within basin which would further reduce the flushing time. **Table 2** presents the necessary inputs used in the US EPA method.

TABLE 2: INPUTS FOR US EPA METHOD

Input	Value
Dilution Factor (D)	10%
Tidal Cycle Time (T_c)	12.2 hrs
Return Flow Factor	5%
Non-Tidal Freshwater Inflow (I)	0 CY/hr
Volume of Basin at MLW (V_L)	31,111 CY
Volume of Basin at MHW (V_H)	48,160 CY
Volume of Basin Tidal Prism (V_p)	17,049 CY

Referring to the inputs provided in **Table 2**, the flushing time for the existing basin was calculated as follows:

$$Tf = \frac{(12.2\ h)\log(0.1)}{\log\left(\frac{(31111\ cy) + \left(0.05(170449\ cy)\right) - (0)(12.2\ h)}{48160\ cy}\right)}$$

$$Tf = 69\ hours = 2\ days,\ 21\ hours$$

3.2 Christensen Method

With the Christensen Method (Christensen), the flushing time may also be determined through the following equation:

$$p = \left(1 + \beta\,\frac{Vp}{Vo}\right)^{-N}$$

where:
p = Relative concentration after N tidal cycles
β = Mixing coefficient
Vp= Volume of tidal prism
Vo = Volume below MLW
N = Number of tidal cycles

This equation can be rearranged to solve for the flushing time directly:

$$ln(p) = -N \times ln\left(1 + \beta\,\frac{Vp}{Vo}\right)$$

$$N = -\frac{ln(p)}{ln(1+\beta\frac{Vp}{Vo})})$$

$$Tf = N \times Tc$$

A mixing coefficient (β) of 1.0 is normally a sound approximation for small and relatively short basins; thus, this value was adopted. The number of tidal cycles (N) is multiplied by the tidal cycle time (T_c) to yield the flushing time (T_f).

TABLE 3: INPUTS FOR CHRISTENSEN METHOD

Input	Value
Relative concentration after N tidal cycles (p)	10%
Mixing Coefficient (β)	1.0
Volume of Tidal Prism (V_p)	17,049 CY
Volume Below MLW (V_o)	31,111 CY
Tidal Cycle Time (T_c)	12.2 hours

Referring to the inputs provided in **Table 3**, the flushing time for the existing basin was calculated as follows:

$$N = -\frac{ln(0.1)}{\ln\left(1 + (1)\frac{17049\ cy}{31111\ cy}\right)}$$

$$N = 5.27$$

$$T_f = 5.27 \times 12.2h$$

$$T_f = 64\ hours = 2\ days,\ 16\ hours$$

3.3 Dilution Based on Flow

The above described were deemed conservative due to the open configuration of the proposed basin in relation to the surrounding water, however, they establish an upper limit for potential flushing time. In an effort to establish the potential lower limit of the flushing time, a direct calculation based on the open configuration of the basin was utilized with the current measurements. With an affected volume of the basin being approximately 32% and using a current speed of 6.6 ft/min which represents the lowest speed recorded during the floating object test, the total time it would take to flush out the volume of the basin would be approximately 2.3 hours, which is within duration of either flood or ebb tide prior to reversal. The lowest speed recorded was used in order to represent a conservative estimate of this method, with the understanding that greater velocities would decrease the flushing time.

4 CONCLUSIONS

Three methods were utilized to estimate the flushing time for the Project site. A summary of the flushing times estimated for the proposed marina basin is provided in **Table 4**.

TABLE 4: RESULTS OF FLUSHING ANALYSIS METHODS

Analysis	Flushing Times
US EPA Method	69 $hours$
Christensen Method	64 $hours$
Flux Calculations Using Current Speed Data	2.3 $hours$

The calculated flushing time based on various methods ranges from 2.3 hours to 69 hours. The US EPA and Dr. Christensen's methods were generally developed for marina basins with semi-enclosed geometry; however, the proposed marina basin is relatively open with tidal flow passing through the theoretical outline of the docks uninhibited, rather than entering an enclosed basin through a single, constricted entrance channel. These simplified methods are useful in determining the theoretical limits of flushing but are not truly applicable to the proposed Project. All the above methods are desktop calculations, and therefore have their limitations, however, the actual flushing time within the identified range is anticipated to occur closer to the flux calculation method.

If the channel openings to the east and the west of the project site remain open and allow tidal flow freely through the proposed basin, **the flushing time is anticipated to be within 24 hours.** Twenty-four (24) hours is the typical target for semi-enclosed docking basins within the Bahamas, even though the proposed basin is open as discussed above. All methods resulted in flushing times within the standard guidelines established by the South Florida Water Management District (SFWMD) Basis of Review Section 4.2.4.3, which states a flushing time of less than or equal to four (4) days is the maximum time that is desirable for docking facilities. In addition, **the proposed docking facility is not anticipated to have significant adverse impacts on the adjacent businesses, attributed to potential changes in coastal processes.**

5 REFERENCES

1. Christensen, B. A. 1989. *Canal and Marina Flushing Characteristics*. University of Florida, Gainesville, Florida.

2. National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products Station TEC4623

3. United States Environmental Protection Agency (US EPA). 1985. *Coastal Marinas Assessment Handbook.* Section 4.2.1.

Appendix A – Proposed Conceptual Plans

Wong’s Marina structures

The Marina profile (Figure 2 A1.0 2014) as seen from the sea and site plan (Figure 3 A0.0 of March 2024) prepared by the project architect Winston Jones and Associated, of the proposed Wong’s Marina is provided illustrating its relative location along West Bay Street and proposed footprint on the seabed between New Providence and Arawak Cay.

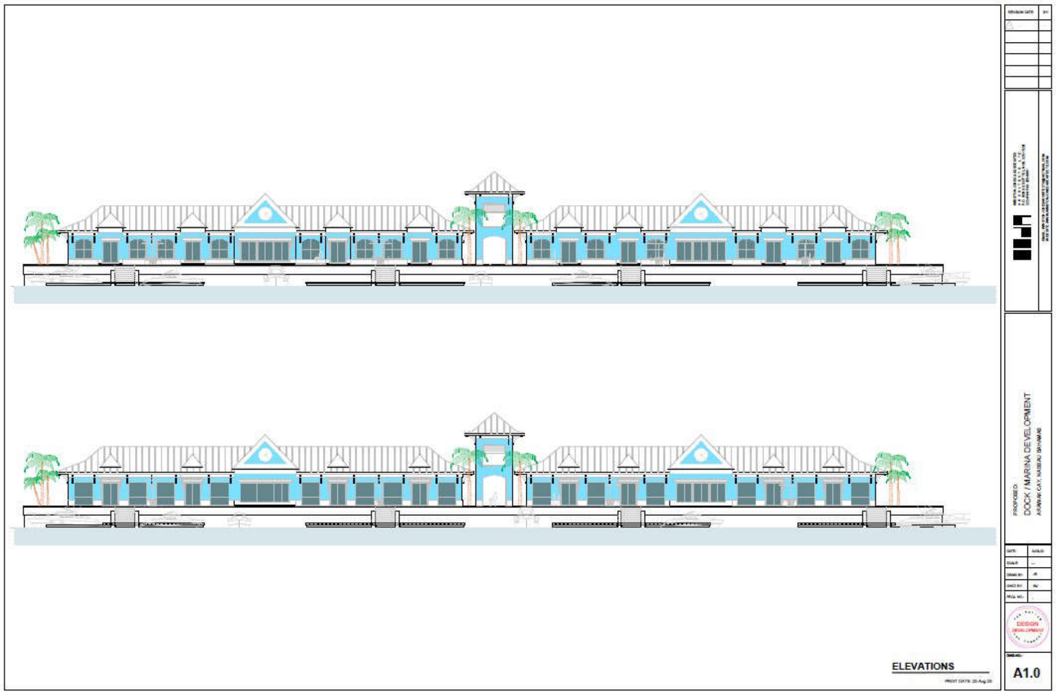


Figure 2 - Wong's Marina commercial building and proposed elevation as seen from the sea based on submission considered by the Department of Physical Planning 2014.

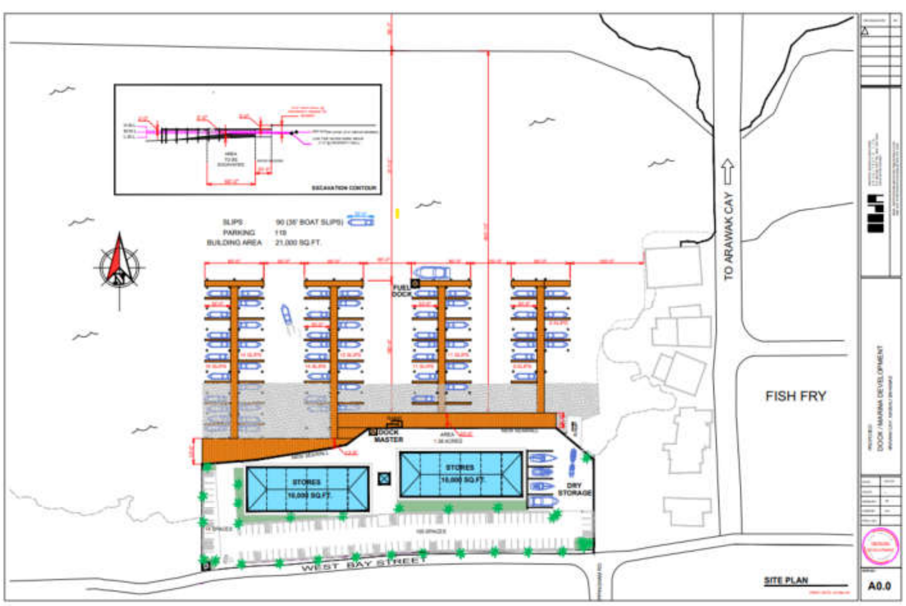
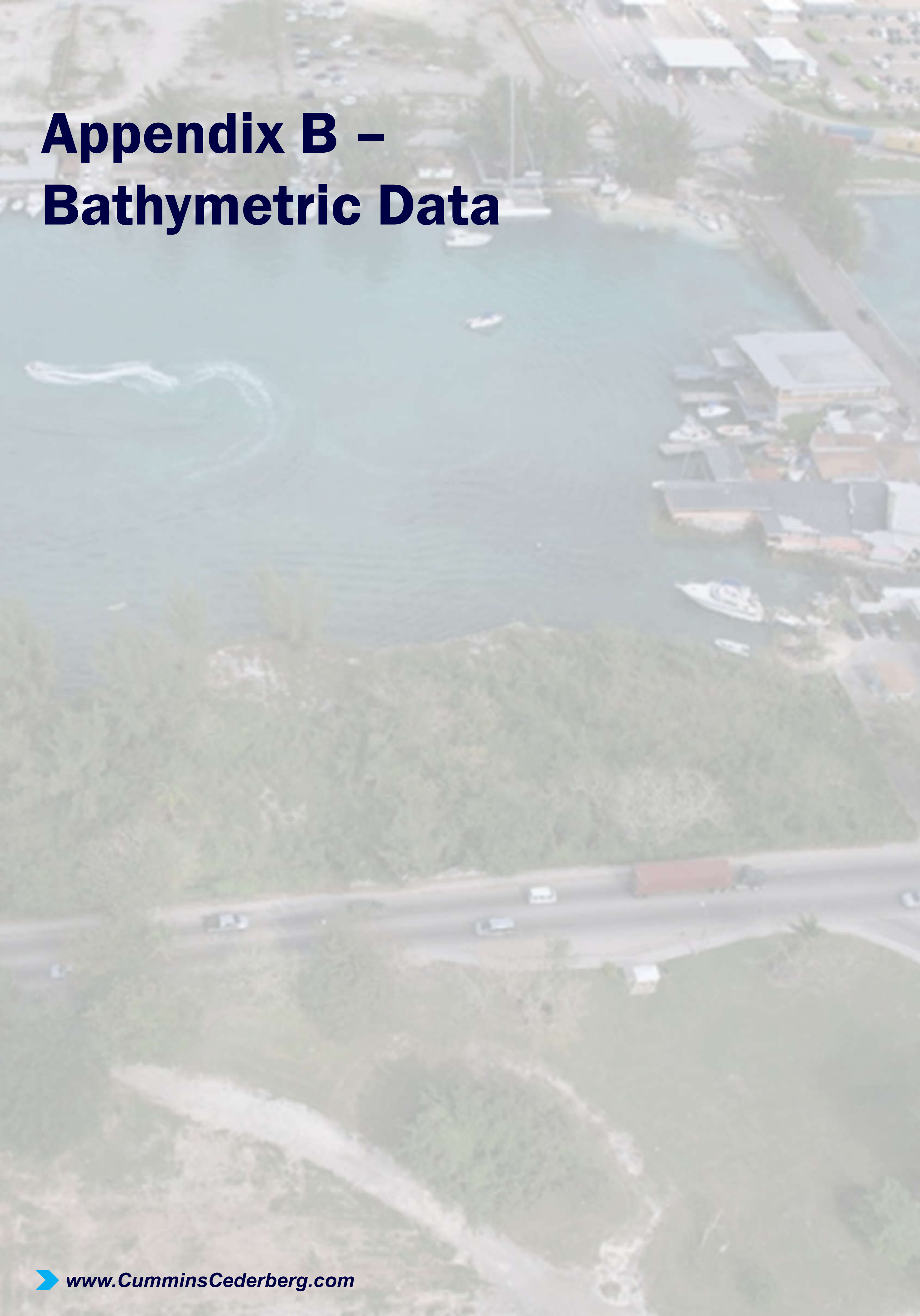


Figure 3 - Wong's Marina proposed marina configuration as proposed March 2024



Appendix B – Bathymetric Data


0.6 m / 2 ft
1 m / 3 ft
2 m / 7 ft
3 m / 10 ft
4 m / 13 ft
5 m / 16 ft
6 m / 20 ft
8 m / 26 ft
10 m / 33 ft
12 m / 39 ft
16 m / 52 ft
20 m / 66 ft
25 m / 82 ft
30 m / 98 ft
35 m / 115 ft
40 m / 131 ft
50 m / 164 ft
70 m / 230 ft
80 m / 262 ft
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