FLORIDA KEYS

CARRYING CAPACITY STUDY

CANAL IMPACT ASSESSMENT MODULE

Draft

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1 INTRODUCTION

This report describes the development, testing and subsequent integration into the Carrying Capacity Impact Assessment Model (CCIAM) of a comparative analysis tool for evaluating the impacts of wastewater effluents and stormwater discharges into tidally-flushed dead-end canals.

Available literature for the Florida Keys documents water quality problems in dead-end and plugged canals in the FKCCS Study Area (reviewed in Kruczynski and McMannus 2002). Additionally, anecdotal data suggests the presence of a "nutrient aura" in nearshore waters at the mouths of canals. This aura has been attributed to the concentration and discharge of wastewater effluents from on-site wastewater systems to adjacent canals.

Review comments on the Test CCIAM identified the need to develop an additional module of the CCIAM to assess differential impacts of alternative scenarios on canals. The Florida Department of Community Affairs (DCA) is funding a study to identify existing canals, characterize their known physical attributes, identify the availability of existing water quality data, classify the canals based upon a number of characteristics, and suggest generic types of engineering measures for specific classes of canals. At the time of this effort, the canal study was partially developed; its GIS coverage and database were adopted for use in the Canal Impacts Module.

The Canal Module is intended to assess relative impacts of wastewater and stormwater management decisions on nutrient concentrations in representative canals in the Study Area. Pathogens and fecal coliform, while of much human interest, were omitted from the model due to lack of pertinent data. This work included the following:

- Review and assess pertinent physical and water quality data;
- Select representative canals in the Study Area;
- Develop a tidal characteristics database;
- Develop an ambient nearshore water quality database;
- Define canal segments, contributing watersheds and receiving water discharge zone elements;
- Develop and test a simplified canal impacts model;
- Integrate the canal impacts model into CCIAM; and
- Prepare a summary report.

2 DATA COLLECTION, REVIEW & DEVELOPMENT

The Canal Module of the CCIAM is a steady-state, tidal-flushing model that estimates pollutant concentrations in canals based on pollutant loads from stormwater and wastewater and pollutant concentrations in nearshore waters. To develop the model, data acquisition efforts targeted previous canal water quality studies, nearshore water quality data, and tidal fluctuation.

2.1 Previous Canal Water Quality Studies

The following eight studies were identified and reviewed:

- Proposed Designation of the Waters of the Florida Keys as Outstanding Florida Waters. FDER, March 1985. A total of 165 stations were sampled for a few parameters from Key Largo to Key West from January 8, 1985 to February 20, 1985. Background stations at 1/4 mile offshore show no violations of dissolved oxygen standards, while one to seven oceanside stations and one to five bayside stations violated the standard and showed higher levels of nitrogen and phosphorous.

- Water Quality Assessment of Five Selected Pollutant Sources in Marathon, Florida Keys. FDER. Heatwole, July 1987. The study measured 32 water quality parameters at twelve nearshore sites in Marathon during 1984. Five primary sampling sites were located in canals and marina basins with a representative pollution source; five secondary sampling sites were located in areas adjacent to these primary sites to monitor the pollutant dilution, and two stations were located as background stations. Results varied by pollution source, and by seasonal changes in weather and population densities.

- Boot Key Harbor Study. FDER, December 1990. Fourteen stations located in canals and the harbor basin were monitored during a year in Boot Key Harbor. Low dissolved oxygen levels in the canals were attributed to poor flushing characteristics that resulted in them serving as sinks for organic matter.

- Florida Bay Watch Annual Reports. The Nature Conservancy, 1995 –2001. The reports summarized the data collected during the sample year and presented monthly means for certain parameters over the entire data collection history. Data results varied among stations because of the location differences between sampling sites.

- Effects of Installing Flow-Through Culverts on Canal Water Quality and Benthic Communities at Jolly Roger Estates. The Nature Conservancy. Fogarty, Keller & Dye, April 2001. Weekly benthic and water quality data was collected for about ten months before and after culverts were installed at dead end canals on Little Torch Key. Water quality improved after the culverts were installed, and very little change was observed in the benthic community.

- Effects of Stormwater Nutrient Discharges on Eutrophication Processes in Nearshore Waters of the Florida Keys. LaPointe & Matzie, June 1996. Stormwater discharges were characterized by continuously sampling (30 minutes interval) water quality parameters along an offshore eutrophication gradient prior to and following heavy rainfall during the 1992 rainfall season. The gradient included a station in a developed canal system on Big Pine Key (Port Pine Heights).

- Nutrient Inputs from the Watershed and Coastal Eutrophication in the Florida Keys. LaPointe & Clark, December 1992. Thirty stations throughout inner-shelf waters (<10 m depth) were measured for water quality parameters during summer and winter. Sampling at each site was done along an onshore-offshore transect. The authors found a gradient in nutrients from inshore to offshore and concluded that the widespread use of septic tanks increases the nutrient concentrations of limestone groundwaters that discharge into shallow nearshore waters, resulting in coastal eutrophication.

- Water Quality Concerns in the Florida Keys: Sources, Effects and Solutions. USEPA, Kruczynski, 1999. The report reviews several previous published studies and reports in the study area.

2.2 Existing Data Acquisition

The following data sets were acquired and assimilated:

- Monroe County Residential Canal Inventory and Assessment (90% Draft). A total of 480 canals were included in the draft database.

- FKNMS Water Quality Protection Program Data. 155 fixed stations were monitored for water quality parameters for the period of record of March 1995 to December 2001.

- Village of Islamorada, Periodic Water Quality Sampling Program Data. 24 Stations were sampled for the period of record of April 2001 to April 2002.

- The Florida Bay Watch Ambient Water Quality Program Data. The Nature Conservancy. 101 stations were monitored for water quality parameters for the period of record of November 1994 to December 2001. Of these stations 51 were located at canals.

- The Little Venice Canals Water Quality Monitoring Data. USEPA. 9 stations were sampled for the period of record of May 2001 to January 2002.

2.3 Tidal Database

The current NOAA tide gauge network consists of more than 170 tidal stations in the vicinity of the Florida Keys. An inventory of tide stations for the Florida Keys was collected from the Center for Operational Oceanographic Products and Services (CO-OPS) web site (Table 1). The inventory consists of 172 stations from Virginia Key to the Dry Tortugas, and included the latitude and longitude of each station. Location data was input into a GIS coverage for the CCIAM.

TABLE 1
NOAA TIDE STATION INVENTORY – FLORIDA KEYS

Sta. #	Station Name	Mean Tide (feet) Range	Level	Time Difference (hrs) (TD_H/TD_L) High	Low	Height Adjustments (H_{adj}/L_{adj}) High	Low	Ref. Station
1	Bear Cut, Virginia Key	2.05	1.16	0.817	0.867	0.82	0.82	Miami Harbor Entrance
2	Key Biscayne Yacht Club, Biscayne Bay	2.00	1.13	1.117	1.583	0.80	0.81	Miami Harbor Entrance
3	Coral Shoal, Biscayne Channel	2.05	1.15	0.567	0.683	0.82	0.81	Miami Harbor Entrance
4	Cutler, Biscayne Bay	1.98	1.13	1.383	2.000	0.79	0.88	Miami Harbor Entrance
5	Soldier Key	1.90	1.00	0.883	1.333	0.74	0.75	Miami Harbor Entrance
6	Fowey Rocks	2.40	1.40	0.017	0.050	0.97	0.94	Miami Harbor Entrance
7	Ragged Keys, Biscayne Bay	1.65	0.95	1.117	1.417	0.66	0.66	Miami Harbor Entrance
8	Boca Chita Key, Biscayne Bay	1.57	0.94	1.400	1.717	0.63	0.63	Miami Harbor Entrance
9	Sands Key, northwest point, Biscayne Bay	1.46	0.82	1.800	2.500	0.58	0.56	Miami Harbor Entrance
10	Coon Point, Elliott Key, Biscayne Bay	1.44	0.82	2.300	3.000	0.57	0.57	Miami Harbor Entrance
11	Elliott Key Harbor, Elliott Key, Biscayne Bay	1.48	0.83	2.317	3.067	0.59	0.56	Miami Harbor Entrance
12	Turkey Point, Biscayne Bay	1.64	0.94	2.550	3.417	0.65	0.65	Miami Harbor Entrance
13	Billys Point, south of, Elliott Key, Biscayne Bay	1.46	0.82	2.517	3.400	0.58	0.56	Miami Harbor Entrance
14	Sea Grape Point, Elliott Key	2.30	1.39	0.633	0.650	0.92	0.92	Miami Harbor Entrance
15	Christmas Point, Elliott Key	1.82	1.06	0.600	0.683	0.73	0.73	Miami Harbor Entrance
16	Adams Key, south end, Biscayne Bay	1.52	0.90	1.400	1.200	0.61	0.61	Miami Harbor Entrance
17	Totten Key, west side, Biscayne Bay	1.26	0.71	2.700	3.417	0.50	0.50	Miami Harbor Entrance
18	East Arsenicker, Card Sound	0.91	0.54	2.817	3.217	0.36	0.36	Miami Harbor Entrance
19	Card Sound, western side	0.68	0.40	3.233	3.733	0.27	0.27	Miami Harbor Entrance
20	Pumpkin Key, south end, Card Sound	0.63	0.43	2.967	2.933	0.25	0.25	Miami Harbor Entrance
21	Wednesday Point, Key Largo, Card Sound	0.77	0.46	3.017	3.567	0.31	0.31	Miami Harbor Entrance
22	Cormorant Point, Key Largo, Card Sound	0.73	0.43	3.133	3.083	0.29	0.29	Miami Harbor Entrance
23	Little Card Sound bridge	0.53	0.32	3.850	4.267	0.21	0.21	Miami Harbor Entrance
24	Ocean Reef Harbor, Key Largo	2.33	1.37	0.217	0.300	0.93	0.93	Miami Harbor Entrance
25	Main Key, Barnes Sound	0.41	0.26	5.450	6.333	0.16	0.16	Miami Harbor Entrance
26	Manatee Creek, Manatee Bay, Barnes Sound	0.39	0.25	5.617	6.400	0.16	0.16	Miami Harbor Entrance
27	Carysfort Reef	2.34	1.36	0.700	0.717	0.93	0.93	Miami Harbor Entrance
28	Garden Cove, Key Largo	2.16	1.24	0.367	0.483	0.86	0.86	Miami Harbor Entrance
29	Largo Sound, Key Largo	0.80	0.47	2.600	3.117	0.32	0.32	Miami Harbor Entrance
30	Key Largo, South Sound, Key Largo	1.55	0.85	0.767	1.883	0.61	0.56	Miami Harbor Entrance
31	Rock Harbor, Key Largo	2.10	1.23	0.717	0.683	0.84	0.84	Miami Harbor Entrance
32	Rock Harbor, Key Largo	2.14	1.24	0.750	0.667	0.85	0.85	Miami Harbor Entrance
33	Mosquito Bank	2.20	1.20	0.367	0.517	0.85	0.88	Miami Harbor Entrance
34	Molasses Reef	2.20	1.20	0.233	0.200	0.88	0.88	Miami Harbor Entrance
35	Tavernier Harbor, Hawk Channel	2.09	1.23	0.517	0.483	0.83	0.83	Miami Harbor Entrance
36	Tavernier Creek, Hwy. 1 bridge, Hawk Channel	1.32	0.81	0.800	0.933	0.53	0.53	Miami Harbor Entrance
37	Crane Keys, north side, Florida Bay	0.40	0.24	3.317	4.667	0.16	0.16	Miami Harbor Entrance
38	East Key, southern end, Florida Bay	0.52	0.28	3.100	4.167	0.21	0.21	Miami Harbor Entrance
39	Plantation Key, Hawk Channel	2.20	1.27	0.467	0.267	0.88	0.88	Miami Harbor Entrance
40	Yacht Harbor, Cowpens Anchorage, Plantation Key	0.53	0.31	3.133	4.067	0.21	0.21	Miami Harbor Entrance
41	Snake Creek, Hwy. 1 bridge, Windley Key	1.07	0.61	1.200	1.000	0.43	0.43	Miami Harbor Entrance
42	Snake Creek, USCG Station, Plantation Key	0.82	0.48	1.517	2.000	0.33	0.33	Miami Harbor Entrance
43	Whale Harbor, Windley Key, Hawk Channel	1.56	0.83	0.500	0.917	0.62	0.62	Miami Harbor Entrance
44	Whale Harbor Channel, Hwy. 1 bridge, Windley Key	1.36	0.78	0.650	1.067	0.54	0.54	Miami Harbor Entrance
45	Upper Matecumbe Key, Hawk Channel	1.98	1.16	0.950	0.883	0.79	0.79	Miami Harbor Entrance
46	Alligator Reef, Hawk Channel	1.93	1.15	0.517	0.467	0.77	0.77	Miami Harbor Entrance

TABLE 1 (Continued)
NOAA TIDE STATION INVENTORY – FLORIDA KEYS

Sta. #	Station Name	Mean Tide (feet) Range	Level	Time Difference (hrs) (TD_H/TD_L) High	Low	Height Adjustments (H_{adj}/L_{adj}) High	Low	Ref. Station
47	Flamingo, Florida Bay	2.02	1.27	5.467	7.333	1.47	1.08	Key West
48	Upper Matecumbe Key, west end, Hawk Channel	1.44	0.80	-1.000	0.233	0.98	0.33	Key West
49	Indian Key, Hawk Channel	1.84	1.09	-0.300	0.083	1.30	0.71	Key West
50	Shell Key Channel, Florida Bay	1.02	0.58	0.333	0.750	0.78	0.78	Key West
51	Lignumvitae Key, NE side, Florida Bay	0.68	0.37	0.150	1.517	0.52	0.52	Key West
52	Lignumvitae Key, west side, Florida Bay	0.62	0.35	0.533	1.900	0.47	0.47	Key West
53	Little Basin, Upper Matecumbe Key, Florida Bay	0.80	0.40	0.133	1.250	0.61	0.61	Key West
54	Shell Key, northwest side, Lignumvitae Basin	0.60	0.33	0.517	1.950	0.46	0.46	Key West
55	Islamorada, Upper Matecumbe Key, Florida Bay	0.49	0.30	0.650	2.117	0.37	0.37	Key West
56	Indian Key Anchorage, Lower Matecumbe Key	1.94	1.20	-0.783	-0.250	1.40	0.96	Key West
57	Matecumbe Bight, Lower Matecumbe Key, Fla. Bay	0.77	0.48	0.417	0.583	0.55	0.38	Key West
58	Matecumbe Harbor, Lower Matecumbe Key, Fla. Bay	0.83	0.50	0.250	0.383	0.59	0.33	Key West
59	Channel Two, east, Lower Matecumbe Key, Fla. Bay	1.18	0.72	-0.150	-0.033	0.85	0.54	Key West
60	Channel Two, west side, Hawk Channel	1.55	0.96	-0.433	-0.233	1.12	0.75	Key West
61	Channel Five, east side, Hawk Channel	1.25	0.77	-0.233	-0.033	0.90	0.58	Key West
62	Channel Five, west side, Hawk Channel	1.39	0.85	-0.300	-0.017	1.00	0.67	Key West
63	Jewfish Hole, Long Key, Florida Bay	0.56	0.37	0.483	1.533	0.42	0.38	Key West
64	Long Key Bight, Long Key	1.44	0.87	-0.317	-0.050	1.03	0.62	Key West
65	Long Key Lake, Long Key	0.85	0.53	0.550	0.950	0.62	0.46	Key West
66	Long Key, western end	1.19	0.67	-0.350	-0.233	0.82	0.33	Key West
67	Conch Key, eastern end	1.18	0.72	-0.483	-0.083	0.85	0.54	Key West
68	Toms Harbor Cut	0.48	0.33	-0.650	0.167	0.37	0.38	Key West
69	Duck Key, Hawk Channel	1.37	0.81	-0.517	0.000	0.96	0.50	Key West
70	Toms Harbor Channel, Hwy. 1 bridge	0.50	0.45	5.117	4.817	0.38	0.38	Key West
71	Grassy Key, north side, Florida Bay	0.87	0.70	5.683	6.817	0.66	0.66	Key West
72	Grassy Key, south side, Hawk Channel	1.72	1.03	-0.200	0.233	1.22	0.71	Key West
73	Fat Deer Key, Florida Bay	1.14	0.82	5.150	6.433	0.87	0.87	Key West
74	Vaca Key-Fat Deer Key bridge	1.31	0.83	-0.517	0.067	0.95	0.71	Key West
75	Key Colony Beach	1.69	1.05	-0.617	-0.217	1.22	0.83	Key West
76	VACA KEY, USCG STATION, FLORIDA BAY	0.75	0.52	0.000	0.000	1.00	1.00	Vaca Key
77	Boot Key Harbor bridge, Boot Key	1.57	0.96	-0.383	0.050	1.13	0.75	Key West
78	Sombrero Key, Hawk Channel	1.64	1.01	-0.383	0.017	1.18	0.79	Key West
79	Knight Key Channel, Knight Key, Florida Bay	0.72	0.48	0.633	0.367	0.54	0.50	Key West
80	Pigeon Key, south side, Hawk Channel	1.14	0.69	-0.250	0.233	0.81	0.50	Key West
81	Pigeon Key, north side, Florida Bay	0.60	0.44	0.500	0.750	0.46	0.46	Key West
82	Molasses Key Channel, Molasses Keys	1.10	0.67	-0.267	0.400	0.79	0.50	Key West
83	Money Key	0.76	0.54	0.050	1.283	0.58	0.58	Key West
84	Little Duck Key, east end, Hawk Channel	0.88	0.60	-0.150	0.083	0.67	0.67	Key West
85	East Bahia Honda Key, south end, Florida Bay	0.90	0.77	4.067	2.817	0.69	0.69	Key West
86	Cocoanut Key, Florida Bay	0.72	0.66	3.867	2.833	0.55	0.55	Key West
87	West Bahia Honda Key	1.27	0.88	3.983	4.017	0.97	1.00	Key West
88	Horseshoe Keys, south end	1.09	0.79	3.900	3.150	0.86	1.00	Key West
89	Johnson Keys, south end	0.88	0.67	3.600	2.550	0.72	0.96	Key West
90	Johnson Keys, north end	1.70	1.18	3.583	4.367	1.31	1.38	Key West
91	Missouri Key-Little Duck Key Channel	0.98	0.60	-0.200	0.600	0.70	0.46	Key West
92	Missouri Key-Ohio Key Channel, west side	1.08	0.66	-0.117	0.300	0.77	0.50	Key West
93	Ohio Key-Bahia Honda Key Channel, west side	1.10	0.70	-0.283	0.433	0.81	0.62	Key West
94	Bahia Honda Key, Bahia Honda Channel	1.19	0.74	-0.083	0.217	0.86	0.62	Key West
95	Big Pine Key, Spanish Harbor	1.07	0.64	-0.067	0.617	0.75	0.42	Key West
96	Big Pine Key, Doctors Arm, Bogie Channel	0.80	0.57	0.683	1.783	0.63	0.71	Key West
97	Big Pine Key, Bogie Channel Bridge	0.80	0.60	2.167	2.183	0.65	0.83	Key West
98	No Name Key, east side, Bahia Honda Channel	0.70	0.55	1.583	1.550	0.58	0.83	Key West
99	Little Pine Key, south end	0.68	0.53	1.117	1.117	0.56	0.79	Key West
100	Porpoise Key, Big Spanish Channel	0.88	0.68	3.383	2.483	0.72	1.00	Key West
101	Water Key, west end, Big Spanish Channel	1.00	0.75	3.383	2.617	0.81	1.04	Key West
102	Mayo Key, Big Spanish Channel	1.17	0.85	3.583	3.017	0.92	1.08	Key West
103	Little Pine Key, north end	1.33	0.96	3.633	3.467	1.05	1.21	Key West
104	Big Pine Key, northeast shore	1.08	0.80	3.317	2.500	0.86	1.08	Key West
105	Crawl Key, Big Spanish Channel	1.74	1.19	3.567	4.217	1.33	1.33	Key West

TABLE 1 (Continued)
NOAA TIDE STATION INVENTORY – FLORIDA KEYS

Sta. #	Station Name	Mean Tide (feet) Range	Mean Tide (feet) Level	Time Difference (hrs) (TD_H/TD_L) High	Time Difference (hrs) (TD_H/TD_L) Low	Height Adjustments (H_{adj}/L_{adj}) High	Height Adjustments (H_{adj}/L_{adj}) Low	Ref. Station
106	Big Pine Key, north end	1.29	0.85	4.400	5.933	0.96	0.83	Key West
107	Annette Key, north end, Big Spanish Channel	1.92	1.27	3.500	4.550	1.44	1.29	Key West
108	Little Spanish Key, Spanish Banks	2.30	1.54	3.417	4.500	1.74	1.62	Key West
109	Big Spanish Key	2.69	1.71	3.317	4.483	1.97	1.50	Key West
110	Munson Island, Newfound Harbor Channel	1.36	0.84	0.000	0.467	0.98	0.67	Key West
111	Ramrod Key, Newfound Harbor	1.28	0.76	-0.017	0.083	0.90	0.50	Key West
112	Middle Torch Key, Torch Ramrod Channel	0.98	0.58	0.400	1.483	0.69	0.38	Key West
113	Little Torch Key, Torch Channel	0.80	0.48	0.183	1.750	0.57	0.33	Key West
114	Big Pine Key, Newfound Harbor Channel	1.16	0.69	0.517	0.733	0.82	0.46	Key West
115	Big Pine Key, Coupon Bight	1.22	0.74	0.333	0.817	0.87	0.54	Key West
116	Little Torch Key, Pine Channel Bridge, south side	0.97	0.56	0.417	0.950	0.68	0.33	Key West
117	Little Torch Key, Pine Channel Bridge, south side	0.98	0.58	0.450	0.900	0.69	0.38	Key West
118	Big Pine Key, Pine Channel Bridge, south side	0.96	0.56	0.450	1.050	0.67	0.33	Key West
119	Big Pine Key, Pine Channel Bridge, north side	0.81	0.49	0.050	1.733	0.57	0.33	Key West
120	Big Pine Key, west side, Pine Channel	0.71	0.45	0.350	1.867	0.52	0.42	Key West
121	Howe Key, south end, Harbor Channel	0.96	0.63	4.717	4.817	0.72	0.62	Key West
122	Big Torch Key, Harbor Channel	2.14	1.38	3.783	5.850	1.58	1.29	Key West
123	Water Keys, south end, Harbor Channel	2.11	1.29	3.700	5.683	1.52	1.00	Key West
124	Howe Key, northwest end	2.28	1.46	3.483	5.367	1.68	1.33	Key West
125	Summerland Key, Niles Channel South	1.14	0.74	0.067	0.183	0.85	0.71	Key West
126	Summerland Key, Niles Channel Bridge	0.90	0.59	0.500	0.933	0.67	0.58	Key West
127	Ramrod Key, Niles Channel Bridge	0.93	0.58	0.450	1.200	0.67	0.46	Key West
128	Big Torch Key, Niles Channel	0.77	0.56	3.250	2.083	0.61	0.71	Key West
129	Knockemdown Key, north end	1.80	1.19	3.500	4.900	1.35	1.21	Key West
130	Raccoon Key, east side	2.04	1.31	3.333	5.150	1.50	1.21	Key West
131	Content Keys, Content Passage	2.86	1.87	2.783	3.833	2.13	1.83	Key West
132	Key Lois, southeast end	1.46	0.91	-0.583	-0.083	1.06	0.75	Key West
133	Sugarloaf Key, east side, Tarpon Creek	1.24	0.76	-0.017	0.250	0.89	0.58	Key West
134	Gopher Key, Cudjoe Bay	1.22	0.78	-0.100	0.283	0.90	0.71	Key West
135	Sugarloaf Key, Pirates Cove	0.74	0.55	-0.133	1.683	0.59	0.75	Key West
136	Cudjoe Key, Cudjoe Bay	1.18	0.76	0.033	0.683	0.87	0.71	Key West
137	Summerland Key, southwest side, Kemp Channel	1.12	0.69	0.233	0.833	0.81	0.54	Key West
138	Cudjoe Key, north end, Kemp Channel	2.17	1.43	3.533	4.667	1.63	1.46	Key West
139	Sugarloaf Key, northeast side, Bow Channel	1.40	0.87	3.783	3.400	1.01	0.71	Key West
140	Cudjoe Key, Pirates Cove	1.01	0.69	3.833	2.917	0.77	0.79	Key West
141	Sugarloaf Key, north end, Bow Channel	1.82	1.09	3.617	5.333	1.29	0.75	Key West
142	Pumpkin Key, Bow Channel	2.14	1.35	3.283	4.650	1.56	1.17	Key West
143	Sawyer Key, outside, Cudjoe Channel	2.32	1.28	2.750	5.400	1.57	0.50	Key West
144	Sawyer Key, inside, Cudjoe Channel	2.10	1.17	2.617	5.317	1.43	0.50	Key West
145	Johnston Key, southwest end, Turkey Basin	1.59	0.92	3.433	5.633	1.10	0.50	Key West
146	Upper Sugarloaf Sound – Perky	0.42	0.23	5.617	8.417	0.28	0.08	Key West
147	Upper Sugarloaf Sound - Park Channel Bridge	0.34	0.24	5.783	8.550	0.26	0.29	Key West
148	Upper Sugarloaf Sound - North Harris Channel	0.33	0.22	5.533	8.067	0.25	0.25	Key West
149	Upper Sugarloaf Sound - Tarpon Creek	0.46	0.32	0.183	0.283	0.35	0.38	Key West
150	Snipe Keys, southeast end, Inner Narrows	1.79	1.10	3.417	5.650	1.28	0.83	Key West
151	Snipe Keys, Middle Narrows	1.42	0.87	3.733	5.900	1.02	0.67	Key West
152	Snipe Keys, Snipe Point	2.31	1.47	2.250	3.550	1.69	1.29	Key West
153	Waltz Key, Waltz Key Basin	1.36	0.91	3.883	5.550	1.03	0.96	Key West
154	Duck Key Point, Duck Key, Waltz Key Basin	1.61	1.03	3.450	4.950	1.19	0.96	Key West
155	O'Hara Key, north end, Waltz Key Basin	1.40	0.90	3.883	5.650	1.03	0.83	Key West
156	Saddlebunch Keys, Channel No. 5	0.76	0.65	4.533	6.967	0.66	1.12	Key West
157	Saddlebunch Keys, Channel No. 4	0.76	0.45	4.583	5.600	0.54	0.29	Key West
158	Saddlebunch Keys, Channel No. 3	0.62	0.36	1.733	0.500	0.43	0.21	Key West
159	Bird Key, Similar Sound	0.82	0.51	0.317	1.050	0.59	0.42	Key West
160	Shark Key, southeast end, Similar Sound	0.70	0.46	0.300	1.850	0.52	0.46	Key West
161	Saddlebunch Keys, Similar Sound	0.52	0.31	0.650	2.683	0.37	0.21	Key West
162	Big Coppitt Key, northeast side, Waltz Key Basin	1.22	0.69	4.350	6.900	0.84	0.33	Key West
163	Rockland Key, Rockland Channel Bridge	0.97	0.69	5.033	6.100	0.76	0.88	Key West
164	Boca Chica Key, Long Point	1.28	0.81	3.900	5.367	0.94	0.71	Key West

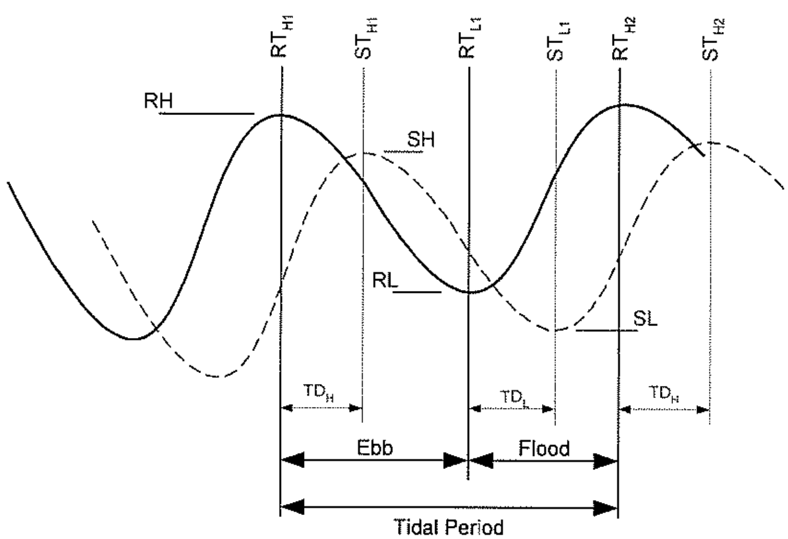
TABLE 1 (Continued)
NOAA TIDE STATION INVENTORY – FLORIDA KEYS

Sta. #	Station Name	Mean Tide (feet) Range	Mean Tide (feet) Level	Time Difference (hrs) (TD_H/TD_L) High	Time Difference (hrs) (TD_H/TD_L) Low	Height Adjustments (H_{adj}/L_{adj}) High	Height Adjustments (H_{adj}/L_{adj}) Low	Ref. Station
165	Channel Key, west side	0.91	0.62	3.150	3.117	0.70	0.71	Key West
166	Boca Chica Channel Bridge	0.72	0.52	1.383	1.483	0.57	0.67	Key West
167	Key Haven - Stock Island Channel	0.94	0.66	2.417	2.950	0.73	0.79	Key West
168	Sigsbee Park, Garrison Bight Channel	1.04	0.73	1.983	2.100	0.81	0.88	Key West
169	Key West, south side, Hawk Channel	1.44	0.94	-0.200	0.167	1.07	0.92	Key West
170	KEY WEST	1.31	0.90	0.000	0.000	1.00	1.00	Key West
171	Sand Key Lighthouse, Sand Key Channel	1.26	0.82	-0.383	0.017	0.94	0.79	Key West
172	Garden Key, Dry Tortugas	1.14	0.89	0.483	0.550	0.94	1.33	Key West

Source: http://www.co-ops.nos.noaa.gov/tides

The time and height adjustment factors for the high and low tides (Table 1) with respect to the reference station are used to determine the tidal characteristics of each tide station (Figure 1).

FIGURE 1
SECONDARY TIDAL STATION ADJUSTMENTS



2.3.1 Reference Stations

The time and height adjustments are applied to the reference station to predict the time and height of the high and low tides at the selected subordinate station. Of the 172 tide stations in the Keys, only three are reference stations (Miami Harbor Entrance, Vaca Key, and Key West). The remaining 169 are subordinate stations that rely on one of the reference stations for tidal predictions. The Miami Harbor Entrance station is the reference station for 45 stations and Key West is the reference for 124 stations. Vaca Key is not used as a reference by any subordinate station.

2.3.2 High/Low Tide Time Adjustments

To determine the time of high tide (ST_H) or low tide (ST_L) at a subordinate station, the appropriate time adjustment value (TD_H or TD_L) is added to the time of the high (RT_H) or low tide (RT_L) for the reference station. The equations used to compute these time values at a secondary station are as follows:

$$ST_H = RT_H + TD_H \quad \text{(Time of high tide at secondary station)}$$

or: $$ST_L = RT_L + TD_L \quad \text{(Time of low tide at secondary station)}$$

Positive time adjustment values indicate that the tide at the subordinate station occurs later than at the reference station, negative values indicate that the tide occurs earlier.

2.3.3 High/Low Tide Height Adjustments

To calculate the high (SH) or low tide (SL) elevations at a subordinate station, the high (RH) or low (RL) tide elevation at the reference station is multiplied by the appropriate adjustment factor (H_{adj}/L_{adj}), as follows:

$$SH = RH \times H_{adj} \quad \text{(High tide elevation at secondary station)}$$

or: $$SL = RL \times L_{adj} \quad \text{(Low tide elevation at secondary station)}$$

2.3.4 Tide Cycle Durations

The ebb tide cycle (Ebb) is the time required to move from high tide to low tide; the flood tide cycle (Flood) is the time required to move from low tide to high tide. A tidal period (Period) is the duration of any two consecutive tide cycles. The equations used to compute these durations, expressed in hours, at a reference station, are as follows:

$$Ebb_{ref} = RT_{L1} - RT_{H1} \quad \text{(Duration from high to low tide)}$$

$$Flood_{ref} = RT_{H2} - RT_{L1} \quad \text{(Duration from low to high tide)}$$

$$Period = RT_{H2} - RT_{H1} \quad \text{(Duration from high to high tide)}$$

or: $$Period = RT_{L2} - RT_{L1} \quad \text{(Duration from low to low tide)}$$

or: $$Period = Ebb_{ref} + Flood_{ref}$$

At secondary stations, the Ebb and Flood durations can be calculated directly from the adjustment factors in Table 1, as follows:

$$Ebb_{sec} = Ebb_{ref} + TD_L - TD_H \quad \text{(Duration from high to low tide)}$$

$$Flood_{sec} = Flood_{ref} + TD_H - TD_L \quad \text{(Duration from low to high tide)}$$

$$Period_{sec} = Ebb_{sec} + Flood_{sec} \quad \text{(Duration from high to high or low to low tide)}$$

Data regarding the tidal periods and the duration of ebb and flood tides was not available on the CO-OPs site. To estimate these values, a year of daily predicted tidal data values were downloaded for each of the three reference stations. These values were assessed to determine the range and average duration for the tidal period ebb tide, and flood tide (Table 2).

TABLE 2
REFERENCE STATION TIDE CYCLE DURATIONS

	Miami Harbor Ent.			Vaca Key			Key West		
	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.
Ebb Tide (hrs)	5.4	6.5	6.2	0.8	12.3	4.7	3.2	7.9	5.8
Flood Tide (hrs)	5.8	6.9	6.2	2.3	19.1	8.7	5.8	7.4	6.7
Tidal Period (hrs)	11.9	13.1	12.4	3.4	27.7	13.3	10.2	15.3	12.4

2.4 Nearshore Water Quality Database

Two main data sources were used to compile the ambient nearshore water quality to reflect the tidal input into the canals during flood tides, the FKNMS Water Quality Protection Program (WQPP) and Baywatch. The geometric means of the TN and TP data were interpolated to obtain representative TN and TP ambient concentrations at 250 feet offshore from the mouth of each canal. This distance was selected as the edge of the mixing zone (the nutrient aura) for the mdel.

Little analytical data regarding biochemical oxygen demand (BOD) or total suspended solids (TSS) was available to characterize the spatial variation of these two parameters. The only information found came from a study published in July of 1987 for the Marathon area called the *Water Quality Assessment of Five Selected Pollutant Sources in Marathon, Florida Keys*. The limited information from that study was used to develop standardized values of BOD and TSS to represent the nearshore water quality data for the flushing model. Geometric means were developed for each secondary station and the average value of the geometric means of these stations were calculated for TSS (5.6 mg/l) and BOD (0.7 mg/l). These values were used to represent the nearshore water quality for all canals, regardless of their distance from Marathon.

3 DEVELOPMENT OF THE CANAL IMPACTS ASSESSMENT MODULE (CIAM)

3.1 Objectives and Assumptions of the CIAM

The CIAM simulates the dilution of stormwater and wastewater pollutant loads discharged into canals and, subsequently, from canals into the nearshore waters. The module was developed as a spreadsheet model with appropriate macros to aid in calculating a pollutant concentration for each canal segment and discharge zone under a specific land use or development scenario. The module includes tidal fluctuation, nearshore water quality, stormwater loads (affected by land use or development), and wastewater loads (affected by the type of wastewater treatment).

The CIAT uses a two-step (flood and ebb) tidal flushing model, based upon the following concepts:

- Fully mixed exchange between the defined segments of both the canal and the discharge zone segments;
- Interconnected canal segments;
- One-dimensional, bi-directional flow within the canal segments and discharge zone segments; and
- Defined interface elements in the adjacent nearshore waters that interact with the canal.

To develop a tool that reflects the impacts of various land use and wastewater treatment scenarios, within the constraints of a spreadsheet model, the Technical Contractor made several enabling assumptions. These included:

- Tidal flows are idealized as a single time-step from low tide directly to high tide and vice-versa;
- Flows and their associated pollutant loads passed between canal segments are assumed to be completely mixed with the fluid volume and pollutant load of the receiving segment prior to being passed to subsequent canal/discharge zone segments;
- The selected pollutants (TN, TP, BOD, and TSS) are idealized as conservative, uniformly mixed, neutrally buoyant particles that do not volatilize or settle out of the water column;
- The volume of stormwater or wastewater discharged into each segment is negligible and will not affect the tidal volume entering or exiting the canal;

- Parcels with offsite wastewater treatment types do not contribute wastewater loads or flows to the canal;
- The only forcing function recognized is tidal fluctuation. Wind, temperature, stormwater flow, wastewater flow and other potential driving factors are not considered;
- Utilize a steady-state approach (i.e., annual or monthly averages for input values), rather than event simulations; and
- Model is a comparative tool (i.e., results compared between two scenarios) rather than predictive

3.2 Selection of Representative Canals

Ten representative canals were selected for model development and testing. Along with USACE and DCA, the EPA (Dr. Bill Kruczynski), FDEP (Mr. Gus Rios) and Monroe County (Mr. George Garrett) collaborated with the Technical Contractor to select the 10 canals. The most important selection criteria were the availability of water quality data and the presence of representative sources of wastewater and stormwater pollutant loadings, including residential and commercial sources.

Only canals with one opening were considered. Therefore, 44 canals in the *Monroe County Residential Canal Inventory* were removed from further consideration because they had no openings (20 canals) or had multiple openings (24 canals).

Water quality data was obtained from previous studies for 41 canals. Additional characteristics (Table 3) were documented for each canal to assist in the selection (Table 4). In general, the 10 selected canals represent the diversity of canal length, complexity, and location of canals in the Keys (Table 5, Figure 2a,b). The review group added an additional canal, Canal #246 in Marathon.

TABLE 3
CANDIDATE CANAL DATA FIELDS

Database Field	Description
Land Use (1) – Residential	Developed from the parcels GIS coverage intersected with the wastesheds coverage. Included four (4) subcategories: high-density residential, low-density residential, medium-density residential, and vacant residential.
Land Use (1) – Commercial	Developed from the parcels GIS coverage intersected with the wastesheds coverage. Included seven (7) subcategories: hotel/ motel, institutional, office, public facilities & services, retail, service, and vacant commercial
Land Use (1) – Industrial	Developed from the parcels GIS coverage intersected with the wastesheds coverage. Included two (2) subcategories: light industrial and marinas.
Land Use (1) – Other	Developed from the parcels GIS coverage intersected with the wastesheds coverage. Included two (2) subcategories: open space & recreation and submerged lands.

TABLE 3 (CONTINUED)
CANDIDATE CANAL DATA FIELDS

Database Field	Description
Wastewater Plants [2] – Permit #	Developed with GIS using 150' offset from canal boundaries. Permit numbers taken from previously developed GIS coverage.
WQ Stations [3]	Locations from various sources. Assigned visually since locations are approximate and don't always fall within the canal boundary.
Degree of Convolution [4]	Numerical value assigned (visually) based on the number of 90-degree turns. A full 90° turn has a value of 1.
Key Segment [2]	Developed using GIS. Canals north of US-I were assigned a bay side attribute, canals south of US-1 were assigned an ocean side attribute. Assignment to upper, middle or lower Keys done using previously developed GIS coverage of those boundaries.

Data Source: (1) Monroe County Property Appraiser's Tax Roll Data, July 2001.
(2) GIS operation/selection using previously developed GIS coverages.
(3) Nature Conservancy's Baywatch program, the Village of Islamorada, and the Little Venice Canals water quality investigation.
(4) Monroe County Residential Canal Inventory and Assessment 90% GIS Deliverable, March 22, 2002.

TABLE 4
CANDIDATE CANALS

Canal No.	Key Name	Land Use Residential	Land Use Commercial	Land Use Industrial	Land Use Other	WW Plants (Permit #)	WQ Stations	Degree of Convolution	Key Segment
31	Key Largo	94.8%	5.2%	0.0%	0.0%		BW-85	1.5	Upper-Bayside
44	Key Largo	85.8%	4.6%	0.0%	9.6%		BW-48	0.3	Upper-Bayside
47	Key Largo	88.1%	4.9%	0.0%	7.1%		BW-32	5.0	Upper-Bayside
50	Key Largo	17.7%	0.0%	0.0%	82.3%		BW-62	4.0	Upper-Oceanside
59	Key Largo	100.0%	0.0%	0.0%	0.0%		BW-83	1.0	Upper-Bayside
60	Key Largo	79.9%	11.0%	3.3%	5.9%	FLA014746, FLA014811, FLA014865	BW-131	11.0	Upper-Oceanside
61	Key Largo	99.5%	0.4%	0.0%	0.1%		BW-95	0.0	Upper-Oceanside
69	Rock Harbor	99.2%	0.0%	0.0%	0.8%		BW-12	4.0	Upper-Oceanside
70	Rock Harbor	96.6%	2.6%	0.0%	0.8%		BW-22	0.0	Upper-Bayside
114	Plantation Key	81.2%	16.8%	0.0%	2.0%	FLA014881	VI-1	0.6	Upper-Oceanside
117	Plantation Key	98.5%	0.0%	0.0%	1.5%		BW-6	0.0	Upper-Bayside
120	Plantation Key	86.1%	4.0%	0.0%	9.9%	FLA014787	BW-17,VI-3	9.0	Upper-Bayside
135	Plantation Key	100.0%	0.0%	0.0%	0.0%		VI-5,VI-30	0.0	Upper-Bayside
136	Plantation Key	100.0%	0.0%	0.0%	0.0%		BW-44	0.0	Upper-Bayside
140	Plantation Key	84.7%	0.0%	0.0%	15.3%		VI-19	0.0	Upper-Bayside
145	Lower Matecumbe Key	92.7%	2.1%	0.0%	5.2%		VI-26	1.0	Upper-Oceanside
148	Lower Matecumbe Key	97.9%	0.0%	0.0%	2.1%		VI-25	0.0	Upper-Oceanside
150	Lower Matecumbe Key	76.8%	1.2%	0.0%	22.0%		VI-28,VI-32	16.0	Upper-Bayside
152	Lower Matecumbe Key	96.2%	0.2%	0.0%	3.6%		VI-12	4.0	Upper-Bayside
157	Lower Matecumbe Key	69.8%	21.2%	0.3%	8.8%		VI-11,VI-14	1.5	Upper-Oceanside
171	Marathon	100.0%	0.0%	0.0%	0.0%		BW-126	2.0	Middle-Bayside
185	Marathon	81.4%	3.1%	0.0%	15.5%		BW-129	0.0	Middle-Oceanside
204	Marathon	58.4%	36.7%	0.0%	4.9%	FLA014738	LV-2,LV-4,LV-5	2.0	Middle-Oceanside
208	Marathon	93.3%	5.9%	0.0%	0.9%		LV-6,LV-7	0.0	Middle-Oceanside
224	Marathon	75.2%	4.5%	0.0%	20.4%		LV-8,LV-9	0.0	Middle-Oceanside
229	Big Pine Key	66.7%	0.0%	0.0%	33.3%		BW-87	11.0	Lower-Bayside
278	Big Pine Key	86.7%	0.1%	0.0%	13.2%	FLA014843, FLA014844, FLA014816	BW-43,BW-68,BW-76	25.0	Lower-Bayside
281	Little Torch Key	100.0%	0.0%	0.0%	0.0%		BW-3	1.0	Lower-Bayside
285	Little Torch Key	100.0%	0.0%	0.0%	0.0%		BW-2	2.0	Lower-Bayside
288	Big Pine Key	81.5%	1.3%	0.0%	17.2%		BW-74	0.0	Lower-Bayside
292	Little Torch Key	98.3%	0.3%	0.0%	1.3%		BW-42	9.0	Lower-Bayside
296	Big Pine Key	98.0%	0.0%	0.0%	2.0%		BW-75	0.0	Lower-Bayside
309	Big Pine Key	63.9%	5.2%	1.9%	29.0%		BW-120,BW-121	12.0	Lower-Oceanside
324	Cudjoe Key	83.2%	9.7%	0.0%	7.2%		BW-92	0.0	Lower-Oceanside
329	Cudjoe Key	91.6%	4.1%	0.0%	4.3%		BW-71	8.0	Lower-Oceanside
332	Cudjoe Key	100.0%	0.0%	0.0%	0.0%		BW-72	0.0	Lower-Oceanside

TABLE 6 (CONTINUED)
CANDIDATE CANALS

Canal No.	Key Name	Land Use Residential	Land Use Commercial	Land Use Industrial	Land Use Other	WW Plants (Permit #)	WQ Stations	Degree of Convolution	Key Segment
335	Cudjoe Key	96.8%	3.2%	0.0%	0.0%	FLA014946	BW-21	5.0	Lower-Oceanside
339	Little Torch Key	90.3%	3.6%	0.0%	6.2%		BW-111	7.0	Lower-Oceanside
340	Cudjoe Key	100.0%	0.0%	0.0%	0.0%		BW-94	0.0	Lower-Oceanside
344	Cudjoe Key	96.8%	1.5%	1.7%	0.0%		BW-93	2.0	Lower-Oceanside
350	Ramrod Key	77.1%	3.9%	0.0%	19.1%	FLA014808	BW-51,BW-84,BW-139	18.0	Lower-Oceanside

TABLE 5
SELECTED CANALS

Canal No.	Key Name	WQ Stations	Key Segment
50	Key Largo	BW-62	Upper-Oceanside
69	Rock Harbor	BW-12	Upper-Oceanside
70	Rock Harbor	BW-22	Upper-Bayside
117	Plantation Key	BW-6	Upper-Bayside
152	Lower Matecumbe Key	VI-12	Upper-Bayside
204	Marathon	LV-2, LV-4, LV-5	Middle-Oceanside
208	Marathon	LV-6, LV-7	Middle-Oceanside
246	Marathon		Middle-Oceanside
288	Big Pine Key	BW-74	Lower-Bayside
339	Little Torch Key	BW-111	Lower-Oceanside

3.3 Definition of Canal Segments, Contributing Basins and Discharge Zones

For each canal, the Technical Contractor delineated canal segments, drainage boundaries and receiving water discharge zone segments, and defined the spatial relationships between these elements. This mapping process provided the basis for estimating pollutant loads into each canal segment.

3.3.1 Definition of Canal Segments

Canal segments were defined for each of the 10 representative canals based upon geometry, connectivity, and tidal connection. Where possible, segments were of equal length (approximately 150 feet); but segment lengths were varied to accommodate canal geometry, branches, and turns (see Appendix C-A for canal figures).

FIGURE 2A
UPPER KEYS SELECTED CANALS

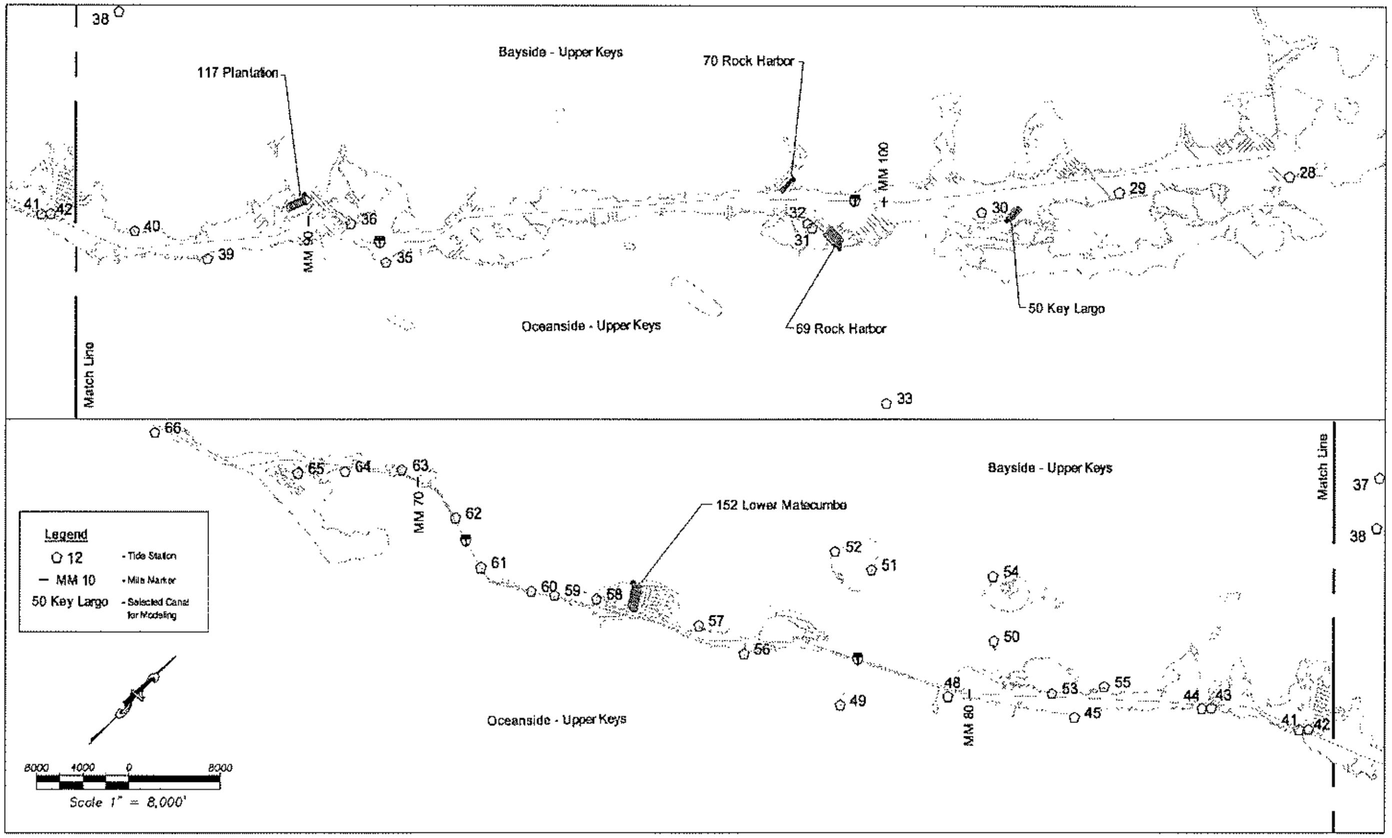
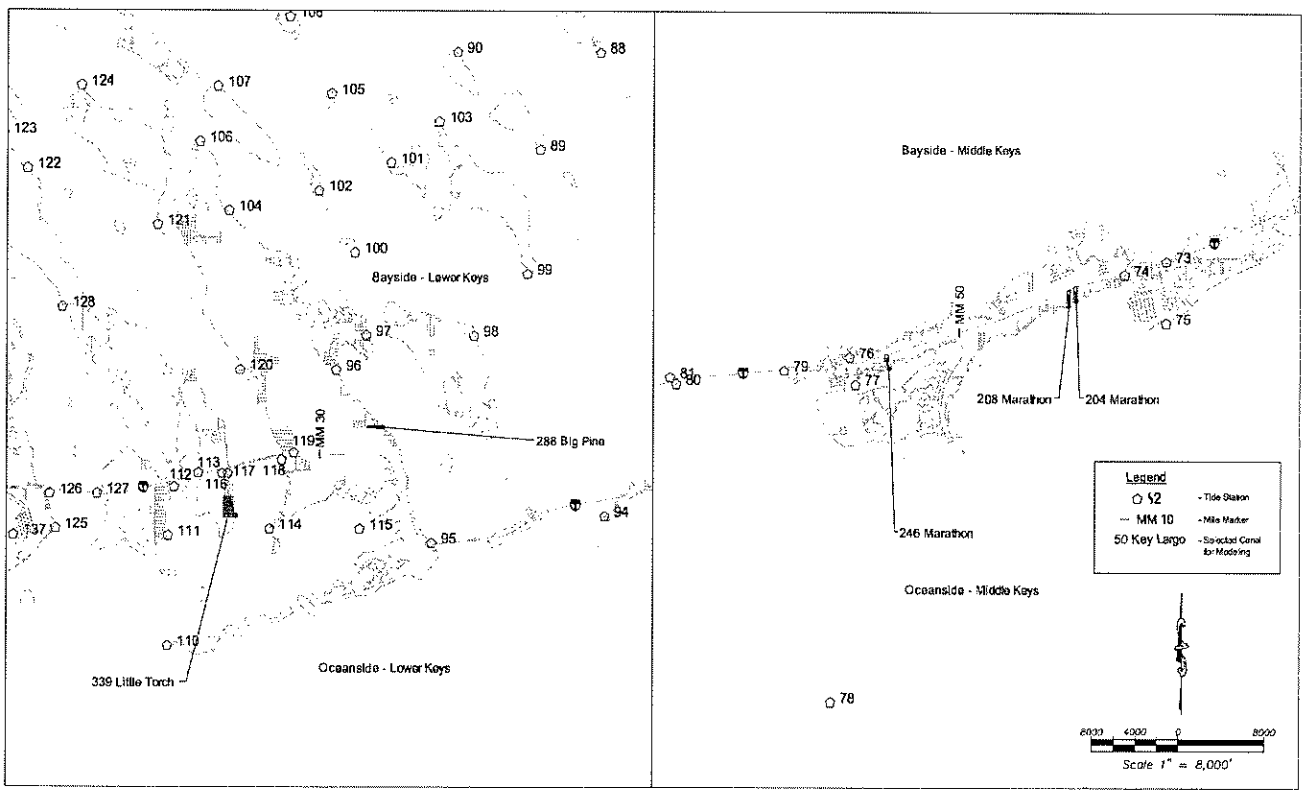


Figure 2B

MIDDLE AND LOWER KEYS SELECTED CANALS



3.3.2 Canal Segment Drainage Areas

Canal segment drainage areas were delineated based on 1999 digital orthographic quarter-quads (DOQQs) aerials available for the Study Area (Appendix C-A). Roads were typically used to delineate drainage divides. The proximity of adjacent canals or other water bodies were often used to estimate split areas between the canal of interest and the adjacent canal/water body.

3.3.3 Canal Segment Discharge Zone Segments

For the model, the Technical Contractor assumed a 250-foot-wide discharge zone (mixing zone or nutrient aura). Receiving water segments were defined for each of the 10 canals using a 250-foot radial distance from the canal's mouth (Appendix C-A). This radial line represents the boundary between the nearshore water and the end of the discharge zone associated with the canal (i.e., the canal would not affect water quality beyond 250 feet from its outlet). The water quality at this boundary was used to characterize the quality of the source water (i.e., nearshore water) during flood tides. The nearshore values for TN and TP (Table 6) were obtained through interpolation (see Section 2.4).

TABLE 6
TN AND TP VALUES AT THE 250-FOOT
CANAL DISCHARGE ZONE BOUNDARIES

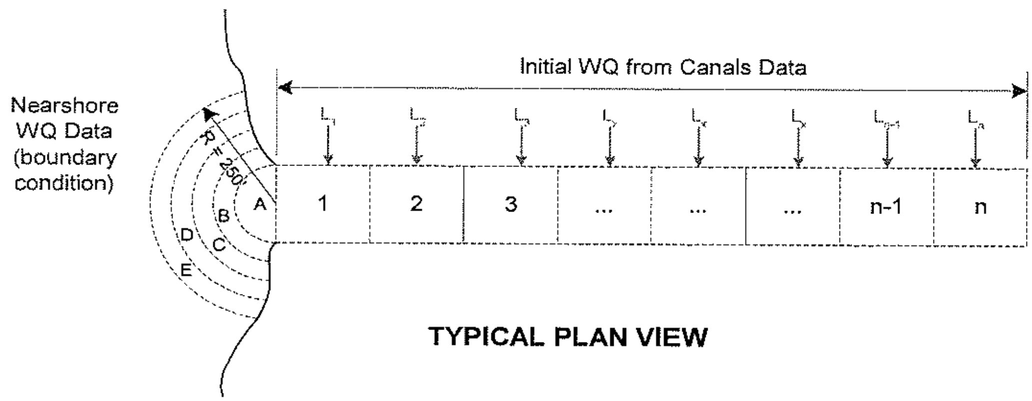
		Total Nitrogen (TN)			Total Phosphorous (TP)		
Canal #	Key Name	Min (mg/l)	Max (mg/l)	Avg (mg/l)	Min (mg/l)	Max (mg/l)	Avg (mg/l)
50	Key Largo	0.3336	0.3336	0.3336	0.0090	0.0090	0.0090
70	Rock Harbor	0.4190	0.4190	0.4190	0.0094	0.0095	0.0094
69	Rock Harbor	0.4285	0.4285	0.4285	0.0093	0.0094	0.0093
117	Plantation Key	0.3435	0.3435	0.3435	0.0088	0.0088	0.0088
152	Lower Matecumbe Key	0.1965	0.1965	0.1965	0.0068	0.0068	0.0068
204	Marathon	0.2132	0.2132	0.2132	0.0097	0.0097	0.0097
208	Marathon	0.2132	0.2132	0.2132	0.0096	0.0096	0.0096
246	Marathon	0.2447	0.2447	0.2447	0.0086	0.0087	0.0087
288	Big Pine Key	0.3030	0.3030	0.3030	0.0100	0.0101	0.0100
339	Little Torch Key	0.3007	0.3007	0.3007	0.0101	0.0101	0.0101

3.4 Module Algorithms

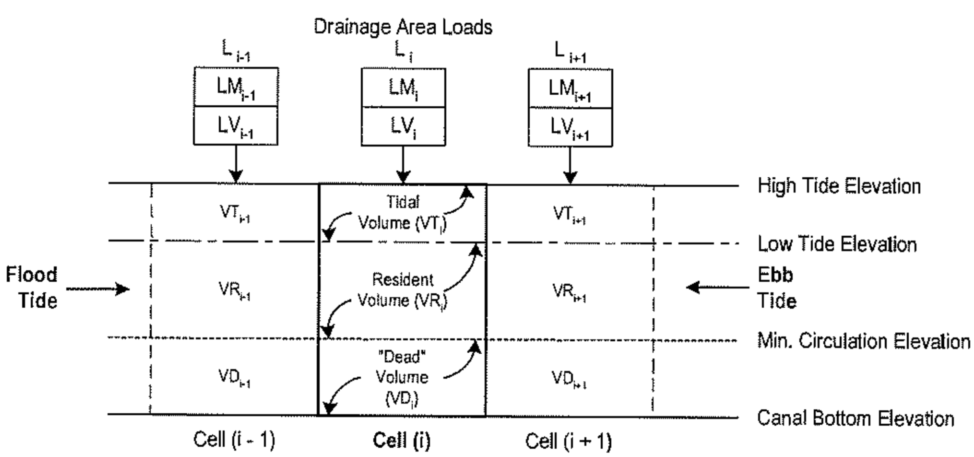
3.4.1 Variables

Initial conditions include the pollutant concentration at the edge of the discharge zone and an initial water quality for each segment, taken from the water quality monitoring data discussed previously (Figure 3). Each segment receives a drainage area load (L).

FIGURE 3
MODEL ELEMENTS



TYPICAL PLAN VIEW



PROFILE ILLUSTRATION

A typical canal segment (i) is associated with receiving and discharge segments to either side of it (i+1 and i-1; Figure 3). A minimum circulation elevation is assumed, since it has been suggested that deeper canals will stratify due to the presence of a shallow entrance into the canal and water will not circulate throughout the entire volume. A minimum circulation elevation of negative five (-5) feet was adopted for each canal. For all the selected canals – the depth of the canal (bottom elevation) is unknown and was assumed to be –15 feet.

Loads (L) from canal segment drainage areas are comprised of two parts: the mass of pollutants (LM) and the volume of water (LV) carrying LM into the canal segment (Figure 3). The tidal volume (VT) is the volume in the canal segment between low and high tide. The resident volume (VR) is the volume in the canal segment between low tide and the minimum circulation elevation. VT and VR are the only volumes considered by the model for mixing, or for computing pollutant mass/concentration in a segment at any time.

Canal segments are numbered in an upstream order (i.e., canal segment 1 is located at the canal entrance, segment n is located at the canal terminus). Flood tides enter the canal segment (i) from the downstream segment (i-1) and are discharged into the upstream segment (i+1). Ebb tides enter the canal segment (i) from the upstream segment (i+1) and are discharged into the downstream segment (i-1).

3.4.2 Model Time Steps and Iterations

The model uses one tide period as the time step. With the exception of the Vaca Key tide station at 13.32 hours, tidal periods in the Keys average 12.42 hours at all tide stations. There is however, substantial variation in the durations of average flood and ebb tides among the Keys tide stations. Average flood tide durations range from 3.87 hours (Upper Sugarloaf Sound - Perky) to 8.65 hours (Vaca Key, USCG Station, Florida Bay). Average ebb tide durations range from 4.50 hours (East Bahia Honda Key, south end, Florida Bay) to 8.55 hours (Upper Sugarloaf Sound - Perky). The model calculates flood tides and ebb tides separately in each tidal period.

Although the CCIAM provides a daily average load, this daily load is reduced to an average hourly rate to address tide cycle duration. Thus, different loads (L, LV and LM) are used by the model for ebb and flood tides.

3.4.3 Flood Tide Algorithms

To simulate a flood tide, the initial volume (IV in cubic feet, cft) in a canal segment is set as the volume at low tide. This is calculated as the resident volume (VR) plus the dead volume (VD):

$$IV(f)_i = VR_i + VD_i$$

Where (f) indicates a flood tide value.

The volume of water (VI) that flows into a canal segment is equal to the tidal volume (VT) of the canal segment plus that of all upstream segments. It also includes the load volume (LV) that flows into the segment over the flood tide duration:

$$VI(f)_i = \sum_{i}^{n} VT_i + LV(f)_i$$

The volume of water that flows out of a canal segment (VO) is equal to the tidal volume (VT) of all the upstream segments:

$$VO(f)_i = \sum_{i+1}^{n} VT_i$$

The final volume (FV) in a canal segment is computed as the initial volume (IV) plus the volume in (VI) minus the volume out (VO). The equation used to compute this value at each canal segment (i) is as follows:

$$FV(f)_i = IV(f)_i + VI(f)_i - VO(f)_i$$

The total volume used in the mixing calculation (MV) for a canal segment is the initial volume (IV) minus the dead volume (VD) plus the volume in (VI):

$$MV(f)_i = IV(f)_i - VD_i + VI(f)_i$$

The initial mass of a pollutant in a canal segment is computed as the resident volume (VR) of the cell times the concentration (Conc in mg/l) of the pollutant. The model tracks mass in units of pounds (lbs.) and concentration in units of milligrams per liter (mg/l). Note that the dead volume (VD) is not included in the mass calculations. The equation used to compute this value at each canal segment (i) is as follows:

$$IM(f)_i = VR_i \times Conc_i \times (28.317\ l/cft \div 453{,}592\ mg/lb)$$

The mass of a pollutant discharged into a canal segment (MI) is computed as the mass out of the downstream cell (MO_{i-1}) plus the load mass (LM) discharged by the segment drainage area. Flood tide calculations are performed in an upstream order, so MO_{i-1} is computed prior to MI_i. The equation used to compute this value at each canal segment (i) is as follows:

$$MI(f)_i = MO(f)_{i-1} + LM(f)_i$$

alternately:

$$MI(f)_i = \left[VO(f)_{i-1} \times Conc_{i-1} \times (28.317\ l/cft \div 453{,}592\ mg/lb)\right] + LM(f)_i$$

The mass used in the mixing calculation (MM) is the initial mass (IM) plus the mass in (MI):

$$MM(f)_i = IM(f)_i + MI(f)_i$$

The mixed pollutant concentration (MC) is the mixed mass (MM) divided by the mixing volume (MV):

$$MC(f)_i = MM(f)_i \div MV(f)_i \times (453{,}592\ mg/lb \div 28.317\ l/cft)$$

The mass discharged out (MO) is the mixed concentration (MC) times the volume out (VO):

$$MO(f)_i = MC(f)_i \times VO(f)_i \times (28.317\ l/cft \div 453{,}592\ mg/lb)$$

The final mass (FM) in a canal segment is computed as the initial mass (IM) plus the mass in (MI) minus the mass out (MO):

$$FM(f)_i = IM(f)_i + MI(f)_i - MO(f)_i$$

3.4.4 Ebb Tide Algorithms

Ebb tide algorithms are the same as those for flood tide, but the flow direction is reversed. To simulate an ebb tide, the initial volume (IV) in a canal segment is set as the volume at high tide. This was calculated in the flood tide computations as the Final Volume (FV_f); this value is carried down to represent the initial volume for the ebb tide computations. Thus:

$$IV(e)_i = FV(f)_i$$

Where (e) indicates an ebb tide value.

3.5 Inputs from CCIAM

The canal segment drainage areas were entered into the CCIAM to calculate the stormwater and wastewater loads for each canal segment drainage area. Load volumes are computed by the CCIAM in units of gallons per day (gpd). This is converted to cubic-feet per day (cfd) by dividing by 7.48 gallons per cubic-foot for use in the canal model. On the other hand, load mass is computed by the CCIAM in units of pounds per day (lbs/day). This requires no unit conversion for use as model input. Stormwater loads included both surface runoff and groundwater runoff components, while wastewater volume and loads included only a groundwater flow component.

The CCIAM outputs the stormwater and wastewater loads by canal segment drainage area to a loading spreadsheet for use as input data in the canal model spreadsheets. The loading spreadsheet contains the pollutant loading data for any particular scenario in the CCIAM. Changes to it are reflected in the canal models when they are next opened in Excel.

3.6 Description of the CIAM

Each canal model consists of a single spreadsheet with three calculation tabs: Setup, Model, and Results. Five additional tabs in the spreadsheet are used to display and assess the results. These are: Schematic, TN Profile, TP Profile, BOD Profile, and TSS Profile.

A second spreadsheet is common to all the canal models. It contains the database of tide stations along with their associated values. The tide database is linked to the canal model through the Setup tab, which links in the tide station data when the user selects a station name from a pull-down selection box.

A third spreadsheet common to all the canal models is the loading spreadsheet. The CCIAM interfaces with the CIAT through the loading spreadsheet. Separate loading spreadsheets can be created and stored to simulate various scenarios. The appropriate loading spreadsheet is specified in the Setup tab.

The final common spreadsheet is the Model Results Summary spreadsheet. This file has multiple tabs, one for each scenario along with the Active Model tab. The Active Model tab has links to the canal models to pull in and summarize the results for each canal segment. The other tabs are copies of the values from the Active Model tab for previously run scenarios. They are used for comparison purposes and are the source of the comparison data for the Profile tabs. Additional scenario tabs can be created at any time by copying the Active Model tab and pasting over the references with their values (Paste Special – Values).

3.6.1 Setup Tab

The Setup tab of the model contains all the information that describes the canal to be modeled. User input cells are shaded gray and, in addition to the tide database link described above, they also include:

- The identification number of the canal and the name of the scenario. These are used as interface keys with the CCIAM. The scenario entry is used to identify the loading file, which contains the pollutant load data for the canal segment drainage areas as generated by the CCIAM. The identification number of the canal enables the model to search through the loading file for the appropriate canal segment drainage area loads.

- The sector angle and radial increments to be used for the five discharge zone segments in the model. The discharge zone segments are idealized as semi-circular bands described by an inner and outer radius, along with a sector angle to define the surface area of each segment.

- Water quality settings (mg/l) for the nearshore water and the initial canal water. Parameters included in the model are currently limited to TN, TP, BOD, and TSS. The nearshore water quality is used to characterize the incoming load of pollutants during a flood tide and will have a substantial effect on the model results. The initial water quality is only used as a starting point for calculations and has no effect on the final result.

- Canal and discharge zone segment geometry is described using four input lines: Bottom Elevation, Cell Width, Cell Length and Minimum Circulation Elevation, all expressed in feet (ft). Canal segments require entries in all four lines, while discharge zone segments only require a Bottom Elevation entry.

3.6.2 Model Tab

The Model tab contains the algorithms and macros used to compute the model results. There is only one user input on this tab, Tolerance, which is expressed in mg/l. This is the precision to which the computations will be run. Once a model iteration fails to have any parameter change by more than the Tolerance value, the model assumes steady-state has been reached and ends the run.

The Model tab also includes all the linkage information for the segments. The user must take care to be sure that the equations with in the cells, particularly at branch junctions, are properly linked to the appropriate downstream/upstream cells. This represents the most challenging part of developing a specific canal model.

Finally, the Model tab has two buttons located at the top-left portion of the sheet. These two buttons (Reset and Run) are linked to macros that either reset the model to the initial conditions, or run the model algorithms until the Tolerance value has been reached. These macros must be modified slightly for different canals, based on the number of columns (segments) in the Model tab. An example of each of these macros is shown in Figure 4 and 5. The ending column in the range statement on line 31 of the Flushing Model Macro and line 13 of the Reset Macro must be modified to reflect the number of columns in the Model tab.

FIGURE 4
EXAMPLE OF FLUSHING MODEL MACRO

```
Sub Flush_Model()
'
' Flush_Model Macro

' Turn off screen updates to speed up model run
Application.ScreenUpdating = False
'Set cursor to hourglass to indicate busy status
Application.Cursor = xlWait
   Dim counter As Integer
   Dim tolerance As Double
   Dim test As Double
   tolerance = Worksheets("Model").Cells(5, 1).Value
   test = Worksheets("Results").Cells(5, 2).Value
   counter = 0
'==========================================================
' Start Model Iterations
'==========================================================
While test > tolerance
'==========================================================
' Update Counter Value on Results Sheet
' Update test value to the maximum change in results matrix
' When test < tolerance, the model will stop iterations
'==========================================================
   Worksheets("Results").Cells(2, 2).Value = counter
   counter = counter + 1
   test = Worksheets("Results").Cells(5, 2).Value
'==========================================================
' Update Model Inputs for Next Iteration (Tide Period)
'==========================================================
   Sheets("Model").Select
   Range("C111:W114").Select
   Application.CutCopyMode = False
   Selection.Copy
'Paste Flood Result Values into Ebb Input Values
   Range("C16").Select
   Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
      False, Transpose:=False
   Application.CutCopyMode = False
Wend
'==========================================================
' Run Finished - Alert User and Reset Application Settings
'==========================================================
Application.ScreenUpdating = True
Application.Cursor = xlDefault
Beep
Beep
End Sub
```

FIGURE 5
EXAMPLE OF RESET MACRO

```
Sub Model_Reset()
'
' Model_Reset Macro

'Set Model Display to Hide Reset Process
   Sheets("Model").Select
   Application.ScreenUpdating = False
   Application.Cursor = xlWait
'=====================================================
' Copy Initial WQ Conditions from the Setup Sheet
'=====================================================
   Sheets("Setup").Select
   Range("E12:Y15").Select
   Selection.Copy
   Sheets("Model").Select
   Range("C16").Select
   Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
      False, Transpose:=False
   Application.CutCopyMode = False
' Reset Model Iteration to 0
   Sheets("Results").Select
   Range("B2").Select
   Selection.ClearContents
'Reset Model Display to default conditions
   Sheets("Model").Select
   Application.ScreenUpdating = True
   Application.Cursor = xlDefault

End Sub
```

3.6.3 Results Tab

The Results tab is used to hold the interim results at each iteration. The Flushing Model Macro compares the maximum change at each iteration in the Results tab with the Tolerance value to identify when calculations can cease. Once this occurs, the interim results stored in the Results tab are considered to be the final results.

The top of the Results tab contains the stationing values for the Profile tabs, as well as charting data for any water quality monitoring station associated with the canal. The Number of Columns value is used by the CCIAM to retrieve the results data from the canal model.

The bottom of the Results tab contains the references to the comparison scenario. Cell C31 is a user input for the name of the scenario tab in the Model Results Summary spreadsheet. Once a valid entry is made here, the scenario results are pulled in and plotted on the Profile tabs. This allows the user to make rapid visual assessments of different scenarios in comparison to the scenario currently modeled.

3.6.4 Schematic Tab

The Schematic tab allows a quick look at the results of the model run in a schematic layout similar to the geometric configuration of the canal being modeled. The user can select, using radio buttons, one of the four parameters for display under either high or low tide conditions. Figure 6 shows an example of the Schematic tab.

3.6.5 Profile Tabs

There is at least one Profile tab for each parameter included in the model: TN, TP, BOD, and TSS. There may be additional Profile tabs in a model if there are too many branches to show on a single Profile tab. Any water quality monitoring station associated with the canal can be included in the profile plot along with the basic statistics from the data collected for that station (minimum, maximum and average).

The Profile tabs chart the change in the computed steady-state concentration of a parameter along the length of the canal and through the discharge zones. If the user has entered a valid scenario name for comparison on the Results tab, the profile for that scenario will also be included in the chart. Figure 7 shows an example of a Profile tab.

3.7 Application of CIAM to Selected Canals

A canal model spreadsheet was developed for each of the ten (10) canals selected for modeling. The drainage area segments were digitized into GIS to estimate the stormwater/ wastewater loads and volumes input data for each canal segment. The digital delineations were then shifted to best match the parcels coverage.

The Setup tab, Model tab, and Results tab in each model were developed to include a column for each defined canal segment and discharge zone segment with corresponding changes made to the range values in the macros.

The geometry of the canal segments (length and width) was measured from the 1999 DOQQ maps. Depths could not be determined from any source, including the *Monroe County Residential Canal Inventory* and the canal bottom elevation for all segments was set at –15 feet. Observation of the canals using the recent DOQQ maps showed that the entrance to the canals in the discharge zone appeared to be substantially shallower. The discharge zone bottom elevation was set at –5 feet for all canals and all segments. Based on this assumption, the minimum circulation elevation was also set at –5 feet for all canal segments. Volumes below this elevation were not included in the mixing calculations of the model.

FIGURE 6
EXAMPLE OF SCHEMATIC TAB

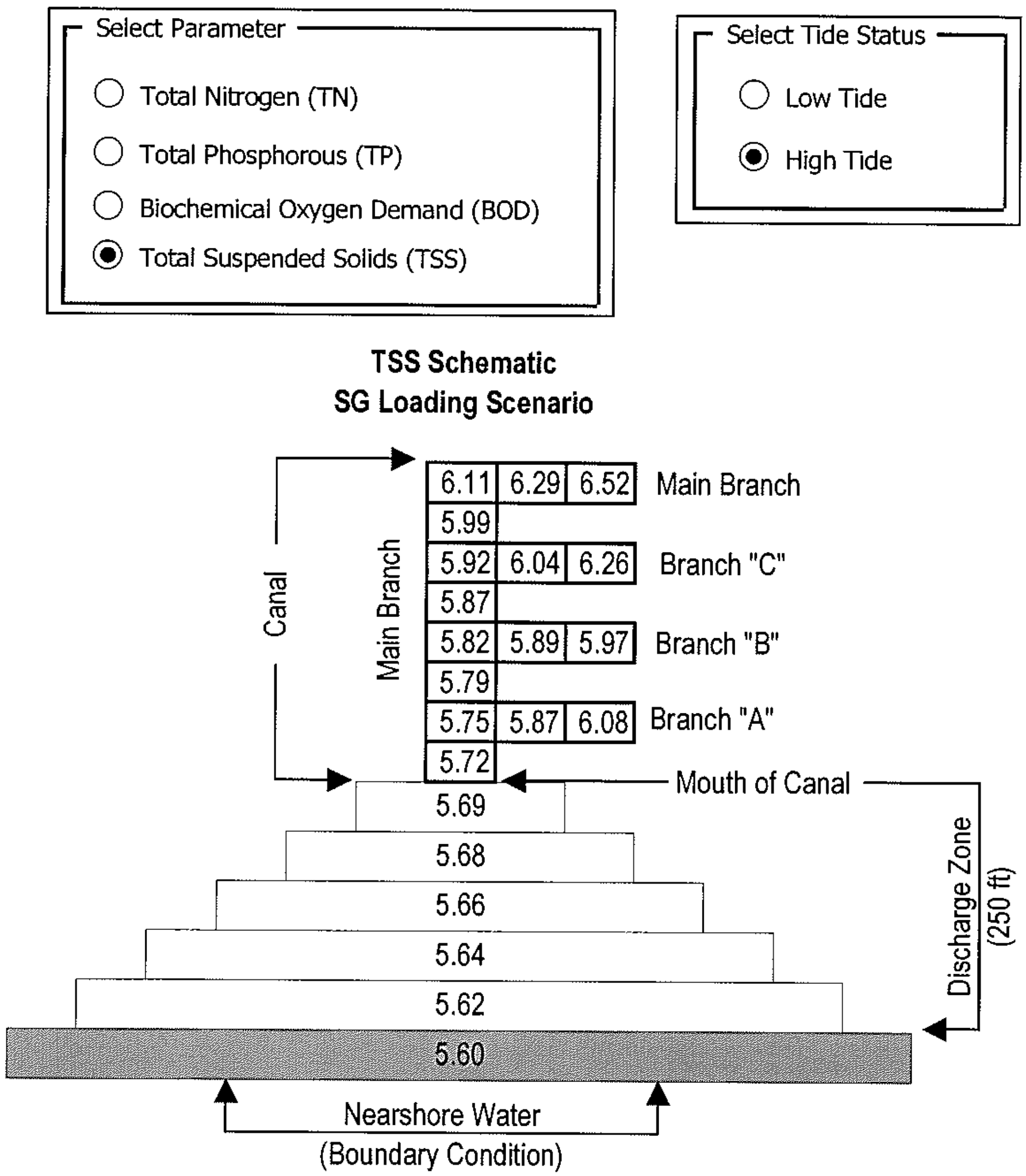
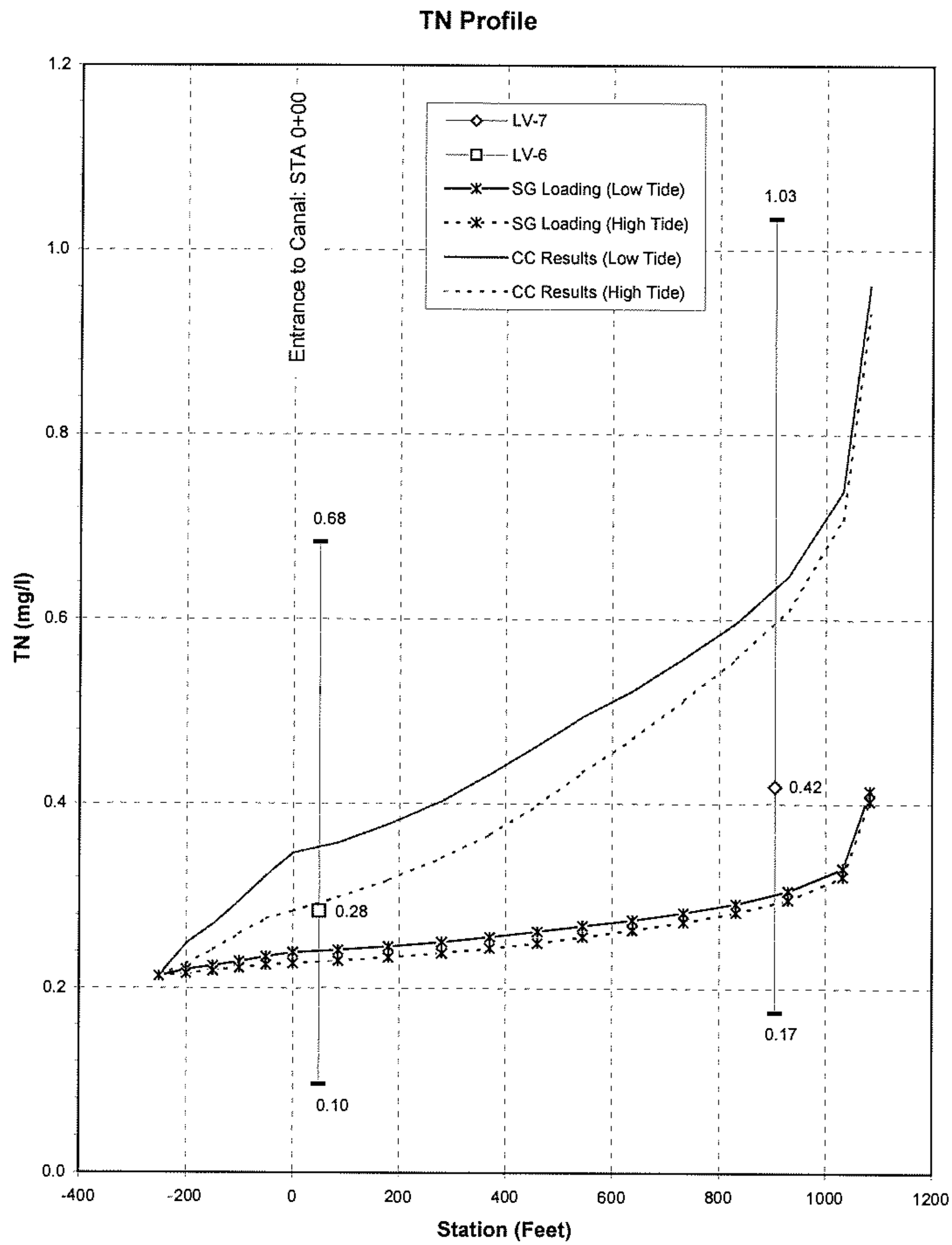


FIGURE 7
EXAMPLE OF A PROFILE TAB



The ambient water quality in the canals was taken from the associated water quality monitoring stations. The geometric mean of the data was selected for input, but the maximum and minimum values were included for charting on the Profile tabs.

The ambient water quality in the nearshore waters (source water under flood tide) was taken from Table 6. The BOD and TSS values were taken from geometric means of the data presented in the 1987 Marathon study (5.6 mg/l for TSS and 0.7 mg/l for BOD). Table 7 shows a brief set up summary for each of the ten canals.

TABLE 7
SELECTED CANALS SET UP SUMMARY

Canal ID		No. of Seg.	Total Length of Seg. (ft)	Canal Splits	Longest Distance (ft)	Nearshore Water Quality			
						TN (mg/l)	TP (mg/l)	BOD (mg/l)	TSS (mg/l)
50	Key Largo	16	2,250	3	1,590	0.334	0.009	0.7	5.6
69	Rock Harbor	27	4,930	2	1,920	0.429	0.009	0.7	5.6
70	Rock Harbor	12	1,330	0	1,330	0.419	0.009	0.7	5.6
117	Plantation Key	14	1,923	0	1,923	0.344	0.009	0.7	5.6
152	Lower Matecumbe Key	30	6,214	2	3,244	0.197	0.007	0.7	5.6
204	Marathon	6	795	0	795	0.213	0.010	0.7	5.6
208	Marathon	12	1,083	0	1,083	0.213	0.010	0.7	5.6
246	Marathon	8	1,150	1	1,030	0.245	0.009	0.7	5.6
288	Big Pine Key	12	1,314	0	1,314	0.303	0.010	0.7	5.6
339	Little Torch Key	44	6,185	6	2,580	0.301	0.010	0.7	5.6

The connectivity of each canal was incorporated into the Model tab, with the appropriate algorithms and connections made between each upstream and down stream segment. A tolerance value of 0.001 mg/l was adopted for application to all canal models.

3.8 CIAM Constraints and Limitations

The CIAM is set up as a canal-specific spreadsheet model. It assumes a long-term steady-state influx of pollutant loads and volumes. It does not include or account for a number of variables that may have a significant impact on observed canal water quality. Some of these potential factors include:

- Sea level rise;
- Water column stratification;
- Wind effects;
- Thermal gradients;

- Surge tides associated with tropical storms or hurricanes;
- Interactions between the benthic/sediment zone and the active water column;
- nutrient uptake/release by marine plants
- Washed in seagrasses and similar sources;
- Direct input of water volumes and pollutant loads attributable to precipitation or atmospheric dryfall deposition;
- Water volume losses attributable to evaporation or transpiration; and
- Direct pollutant inputs related to marine vessel discharges and illicit discharges.

4 RESULTS AND DISCUSSION

Stormwater loads remain essentially unchanged, while the wastewater loads are dramatically reduced under the Smart Growth scenario (Table 8). Stormwater pollutants were reduced by about 1% on average, while wastewater pollutants averaged 90% reductions.

Under the Current Conditions scenario, wastewater is the source of about 80% of the nutrient load (TN and TP), half of the BOD, and about a quarter of the TSS (Table 9). As a volume, it comprises about a quarter of the flow. The remainder comes from stormwater.

TABLE 8
POLLUTANT LOADS FROM STORMWATER AND WASTEWATER

Canal		Daily SW Load					Daily WW Load				
		TN (lbs)	TP (lbs)	BOD (lbs)	TSS (lbs)	Flow (cft)	TN (lbs)	TP (lbs)	BOD (lbs)	TSS (lbs)	Flow (cft)
50	Key Largo										
	Current Conditions Scenario:	0.19	0.04	1.19	3.26	2,125	1.09	0.11	0.44	0.44	698
	Smart Growth Scenario:	0.18	0.03	1.10	2.99	2,314	0.60	0.03	0.60	0.60	966
	Percent Change:	-6%	-5%	-8%	-8%	9%	-45%	-72%	39%	39%	39%
69	Rock Harbor										
	Current Conditions Scenario:	0.38	0.08	2.48	6.89	4,655	2.68	0.27	1.07	1.07	1,714
	Smart Growth Scenario:	0.38	0.08	2.48	6.90	4,666	0.00	0.00	0.00	0.00	0
	Percent Change:	0%	0%	0%	0%	0%	-100%	-100%	-100%	-100%	-100%
70	Rock Harbor										
	Current Conditions Scenario:	0.14	0.02	1.03	1.99	1,362	1.07	0.11	0.43	0.43	683
	Smart Growth Scenario:	0.14	0.02	1.01	1.95	1,391	0.00	0.00	0.00	0.00	0
	Percent Change:	-1%	-1%	-1%	-2%	2%	-100%	-100%	-100%	-100%	-100%
117	Plantation Key										
	Current Conditions Scenario:	0.49	0.09	3.50	8.04	4,582	3.38	0.33	5.45	5.23	2,024
	Smart Growth Scenario:	0.48	0.09	3.43	7.85	4,715	0.00	0.00	0.00	0.00	0
	Percent Change:	-2%	-1%	-2%	-2%	3%	-100%	-100%	-100%	-100%	-100%
152	Lower Matecumbe Key										
	Current Conditions Scenario:	0.37	0.07	2.22	5.82	5,489	3.03	0.30	1.53	1.39	1,931
	Smart Growth Scenario:	0.37	0.07	2.22	5.82	5,489	0.00	0.00	0.00	0.00	0
	Percent Change:	0%	0%	0%	0%	0%	-100%	-100%	-100%	-100%	-100%
204	Marathon										
	Current Conditions Scenario:	0.12	0.02	1.01	2.18	1,150	0.83	0.08	2.58	2.58	469
	Smart Growth Scenario:	0.12	0.02	1.00	2.16	1,166	0.00	0.00	0.00	0.00	0
	Percent Change:	-1%	-1%	-1%	-1%	1%	-100%	-100%	-100%	-100%	-100%
208	Marathon										
	Current Conditions Scenario:	0.11	0.02	0.62	1.53	1,025	0.82	0.08	2.06	2.06	463
	Smart Growth Scenario:	0.11	0.02	0.62	1.53	1,025	0.00	0.00	0.00	0.00	0
	Percent Change:	0%	0%	0%	0%	0%	-100%	-100%	-100%	-100%	-100%
246	Marathon										
	Current Conditions Scenario:	0.16	0.03	1.62	3.75	1,515	0.56	0.05	2.44	2.44	282
	Smart Growth Scenario:	0.16	0.03	1.62	3.75	1,515	0.18	0.01	0.18	0.18	282
	Percent Change:	0%	0%	0%	0%	0%	-69%	-82%	-93%	-93%	0%
288	Big Pine Key										
	Current Conditions Scenario:	0.11	0.02	0.83	1.99	1,118	0.57	0.06	0.23	0.23	365

TABLE 8 (CONTINUED)
POLLUTANT LOADS FROM STORMWATER AND WASTEWATER

Smart Growth Scenario:	0.11	0.02	0.82	1.97	1,133	0.00	0.00	0.00	0.00	0
Percent Change:	-1%	-1%	-1%	-1%	1%	-100%	-100%	-100%	-100%	-100%
339 Little Torch Key										
Current Conditions Scenario:	0.38	0.08	2.74	7.40	4,439	2.31	0.23	0.94	0.94	1,512
Smart Growth Scenario:	0.38	0.08	2.74	7.40	4,439	0.00	0.00	0.00	0.00	0
Percent Change:	0%	0%	0%	0%	0%	-100%	-100%	-100%	-100%	-100%
Minimum % Change:	-6.4%	-5.1%	-7.8%	-8.4%	0.0%	-100%	-100%	-100%	-100%	-100%
Maximum % Change:	0.1%	0.1%	0.3%	0.0%	8.9%	-45%	-72%	39%	39%	39%
Average % Change:	-1.1%	-0.9%	-1.2%	-1.5%	1.7%	-91%	-96%	-85%	-85%	-76%

TABLE 9
CONTRIBUTION OF WASTEWATER TOTAL LOADS

	WW Portion of Total Load				
	TN	**TP**	**BOD**	**TSS**	**Flow**
CURRENT CONDITIONS SCENARIO					
Maximum:	89%	82%	77%	57%	33%
Minimum:	78%	66%	22%	10%	16%
Average:	86%	77%	44%	27%	27%
SMART GROWTH SCENARIO					
Maximum:	77%	47%	35%	17%	29%
Minimum:	0%	0%	0%	0%	0%
Average:	13%	7%	5%	2%	5%

In the Smart Growth scenario, much of the onsite wastewater sources are eliminated and the bulk of the pollutant loads to the canals become stormwater based, although the actual stormwater loads remain relatively unchanged between the two scenarios. The wastewater portion of the load for nutrients falls to about 10% of the total, while BOD, TSS, and flow are reduced to 5% or less of the load.

For all canals, model results show pollutant concentrations increase with distance from the canal mouth (see Appendix C-B for profiles for each canal and each pollutant). On the average, nutrient concentrations (TN and TP) were approximately 50% lower in Smart Growth (Table 10). BOD concentrations were reduced by about a quarter and TSS concentrations showed a minor reduction (6%). This is in line with the reductions and proportions of wastewater and stormwater loads. Discharged loads (pounds) were also reduced similarly, but to a slightly lesser extent. Nutrients fell by about 45%, BOD by about 20%, and TSS less than 5%.

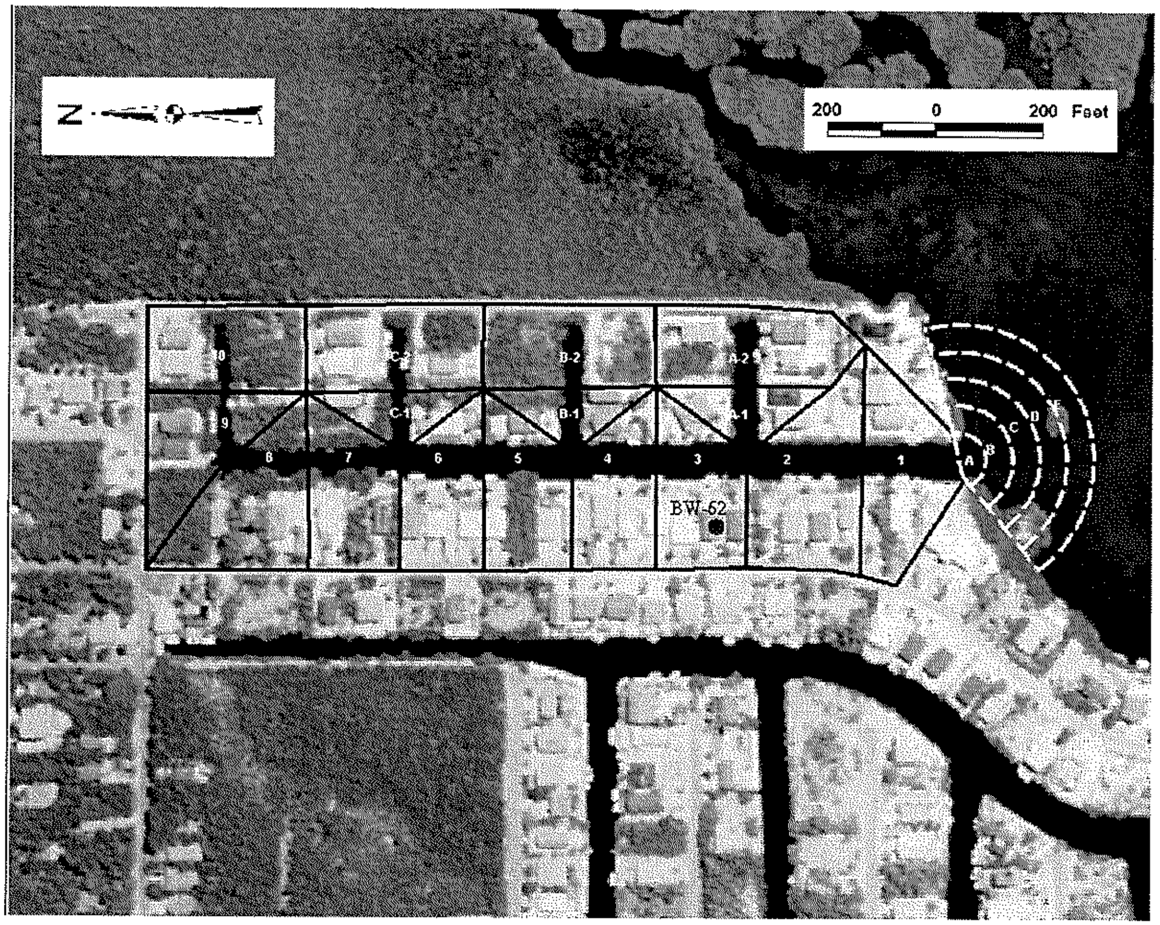
TABLE 10
SCENARIO RESULTS COMPARISON

Canal	Average Canal Concentration (mg/l)				Canal Discharge (lbs/day)			
	TN	TP	BOD	TSS	TN	TP	BOD	TSS
50 Key Largo								
Current Conditions Scenario:	0.51	0.030	0.95	6.06	9.94	0.471	18.88	133.84
Smart Growth Scenario:	0.45	0.019	0.96	6.00	9.01	0.322	19.00	133.50
Percent Change:	-12.4%	-37.3%	1.1%	-1.0%	-9.3%	-31.7%	0.6%	-0.3%
69 Rock Harbor								
Current Conditions Scenario:	0.51	0.019	0.79	5.76	38.34	1.248	60.48	453.27
Smart Growth Scenario:	0.44	0.011	0.77	5.75	34.36	0.847	58.92	451.96
Percent Change:	-14.8%	-40.2%	-3.6%	-0.2%	-10.4%	-32.1%	-2.6%	-0.3%
70 Rock Harbor								
Current Conditions Scenario:	1.28	0.105	1.73	6.92	5.85	0.409	8.20	40.77
Smart Growth Scenario:	0.51	0.027	1.44	6.75	3.00	0.121	7.07	39.91
Percent Change:	-60.4%	-74.6%	-17.1%	-2.4%	-48.8%	-70.5%	-13.9%	-2.1%
117 Plantation Key								
Current Conditions Scenario:	2.53	0.250	5.64	11.76	12.76	1.081	28.51	89.86
Smart Growth Scenario:	0.57	0.059	2.57	9.15	4.79	0.304	15.59	77.99
Percent Change:	-77.5%	-76.4%	-54.4%	-22.2%	-62.5%	-71.9%	-45.3%	-13.2%
152 Lower Matecumbe Key								
Current Conditions Scenario:	0.62	0.054	1.13	6.19	13.2	0.9	31.0	204.3
Smart Growth Scenario:	0.24	0.016	0.96	6.11	7.42	0.366	28.12	202.26
Percent Change:	-62.0%	-71.1%	-15.5%	-1.3%	-43.6%	-61.1%	-9.2%	-1.0%
204 Marathon								
Current Conditions Scenario:	0.55	0.043	2.05	7.26	3.5	0.3	12.4	51.6
Smart Growth Scenario:	0.25	0.016	1.08	6.33	1.85	0.108	7.27	46.58
Percent Change:	-53.4%	-62.1%	-47.2%	-12.8%	-47.2%	-58.5%	-41.4%	-9.7%
208 Marathon								
Current Conditions Scenario:	0.51	0.040	1.52	6.61	4.3	0.3	13.5	73.7
Smart Growth Scenario:	0.25	0.015	0.90	6.05	2.76	0.147	9.55	69.80
Percent Change:	-50.8%	-61.4%	-40.4%	-8.6%	-36.2%	-50.3%	-29.4%	-5.2%
246 Marathon								
Current Conditions Scenario:	0.62	0.050	2.96	8.73	2.98	0.207	12.60	47.24
Smart Growth Scenario:	0.41	0.028	1.76	7.54	2.20	0.123	7.99	42.63
Percent Change:	-33.1%	-44.0%	-40.5%	-13.7%	-26.2%	-40.6%	-36.6%	-9.8%
288 Big Pine Key								
Current Conditions Scenario:	0.86	0.077	1.63	7.18	3.19	0.244	6.06	33.11
Smart Growth Scenario:	0.39	0.029	1.45	7.07	1.80	0.104	5.51	32.68
Percent Change:	-54.4%	-61.7%	-11.1%	-1.5%	-43.6%	-57.5%	-9.1%	-1.3%
339 Little Torch Key								
Current Conditions Scenario:	0.55	0.040	1.04	6.23	16.20	0.942	33.06	226.34
Smart Growth Scenario:	0.33	0.018	0.96	6.20	12.05	0.529	31.41	225.07
Percent Change:	-40.3%	-55.2%	-8.1%	-0.6%	-25.6%	-43.9%	-5.0%	-0.6%
Minimum % Change:	-77.5%	-76.4%	-54.4%	-22.2%	-62.5%	-71.9%	-45.3%	-13.2%
Maximum % Change:	-12.4%	-37.3%	1.1%	-0.2%	-9.3%	-31.7%	0.6%	-0.3%
Average % Change:	-45.9%	-58.4%	-23.7%	-6.4%	-35.4%	-51.8%	-19.2%	-4.3%

CANAL IMPACTS ASSESSMENT TOOL

APPENDIX C-A
CANAL FIGURES

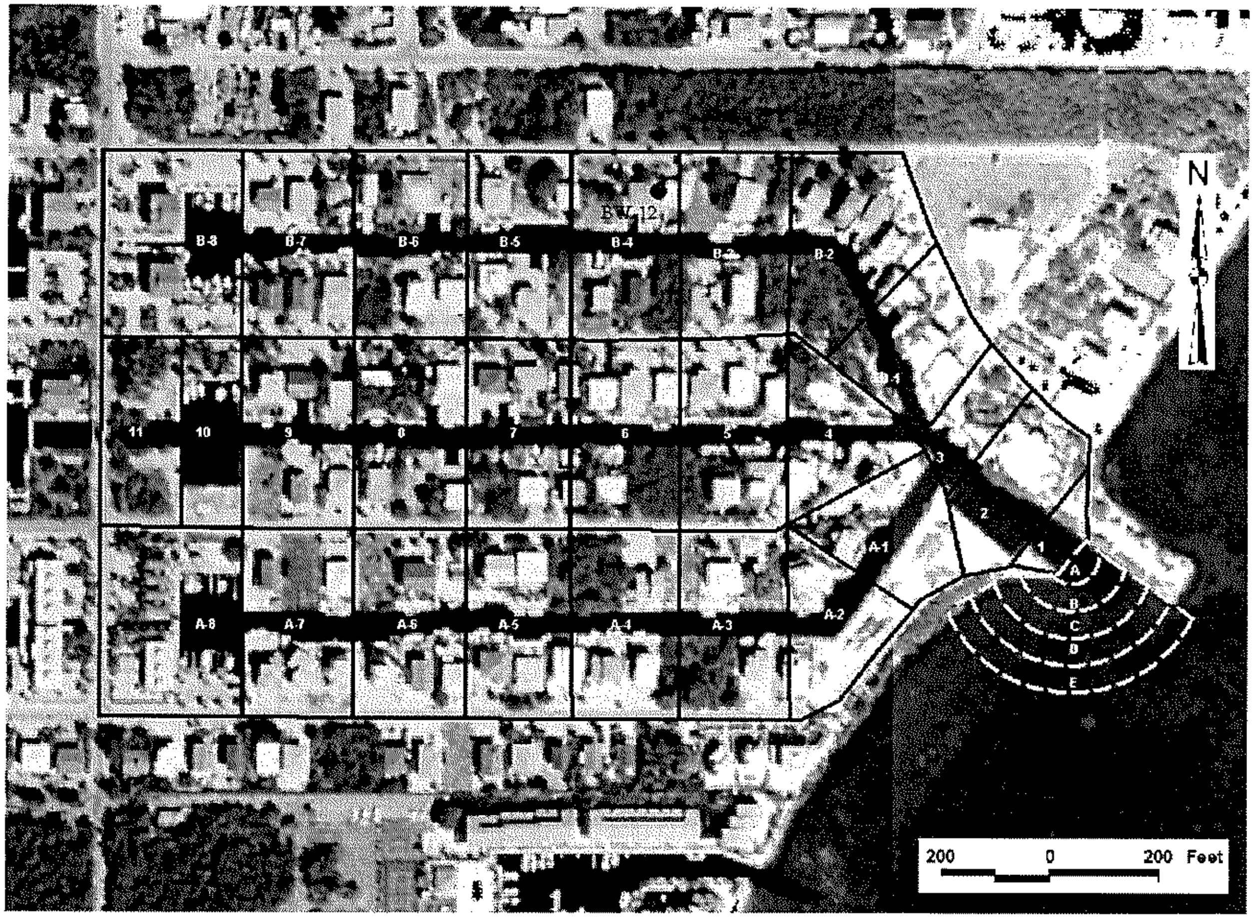
CANAL 50: KEY LARGO



Legend

—	Canal Segment Boundary
1	Canal Segment ID
— —	Discharge Zone Boundary
A	Discharge Zone ID
●	Water Quality Station
BW-10	Water Quality Station ID

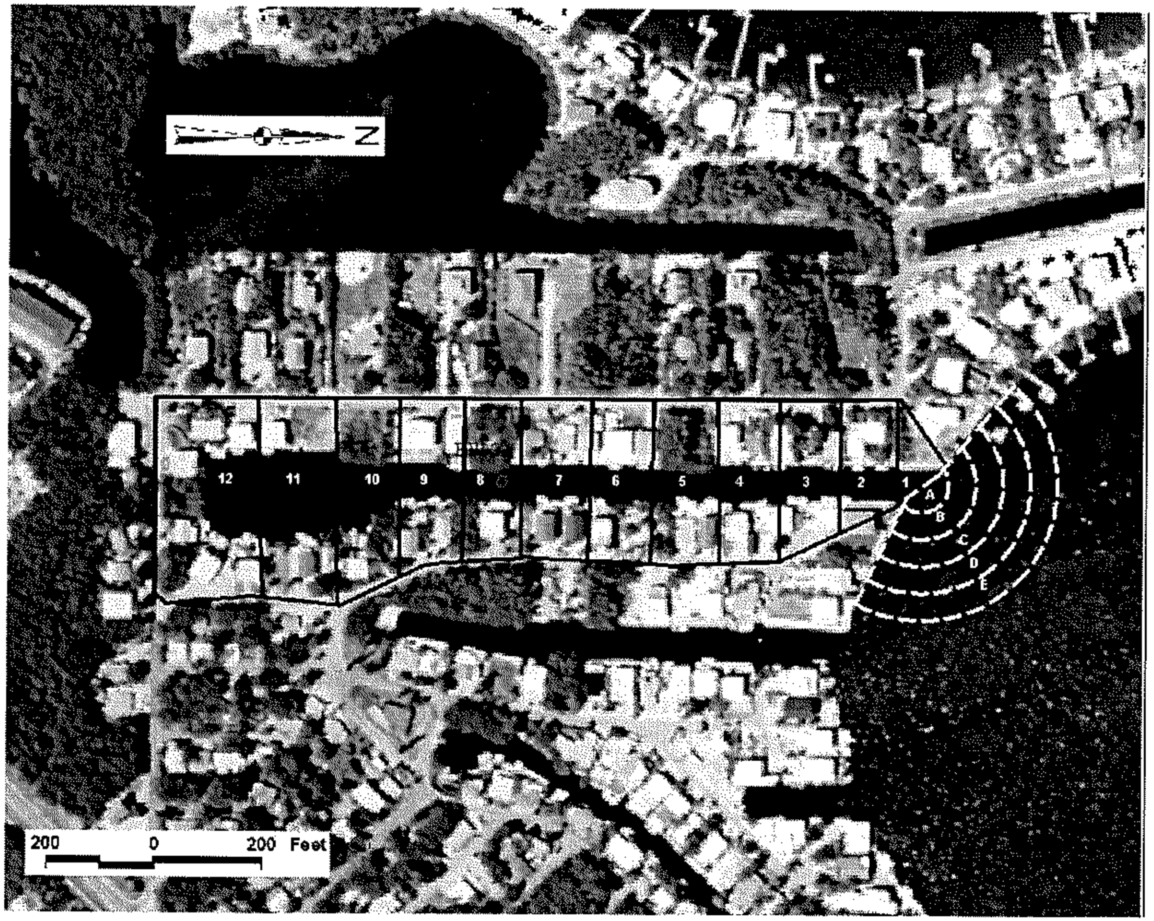
CANAL 69: ROCK HARBOR



Legend

—	Canal Segment Boundary
5	Canal Segment ID
- -	Discharge Zone Boundary
A	Discharge Zone ID
●	Water Quality Station
BW-10	Water Quality Station ID

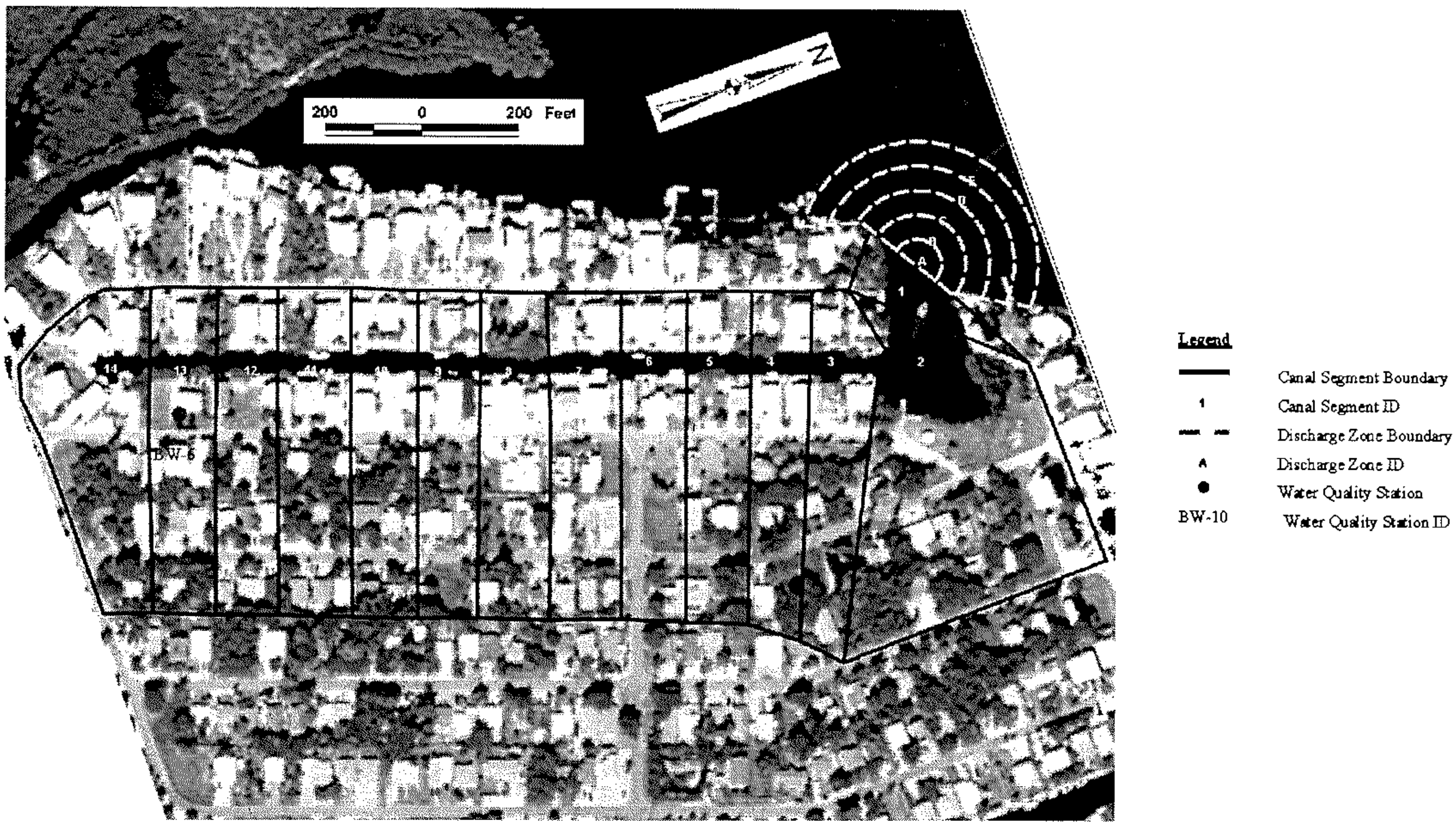
CANAL 70: ROCK HARBOR



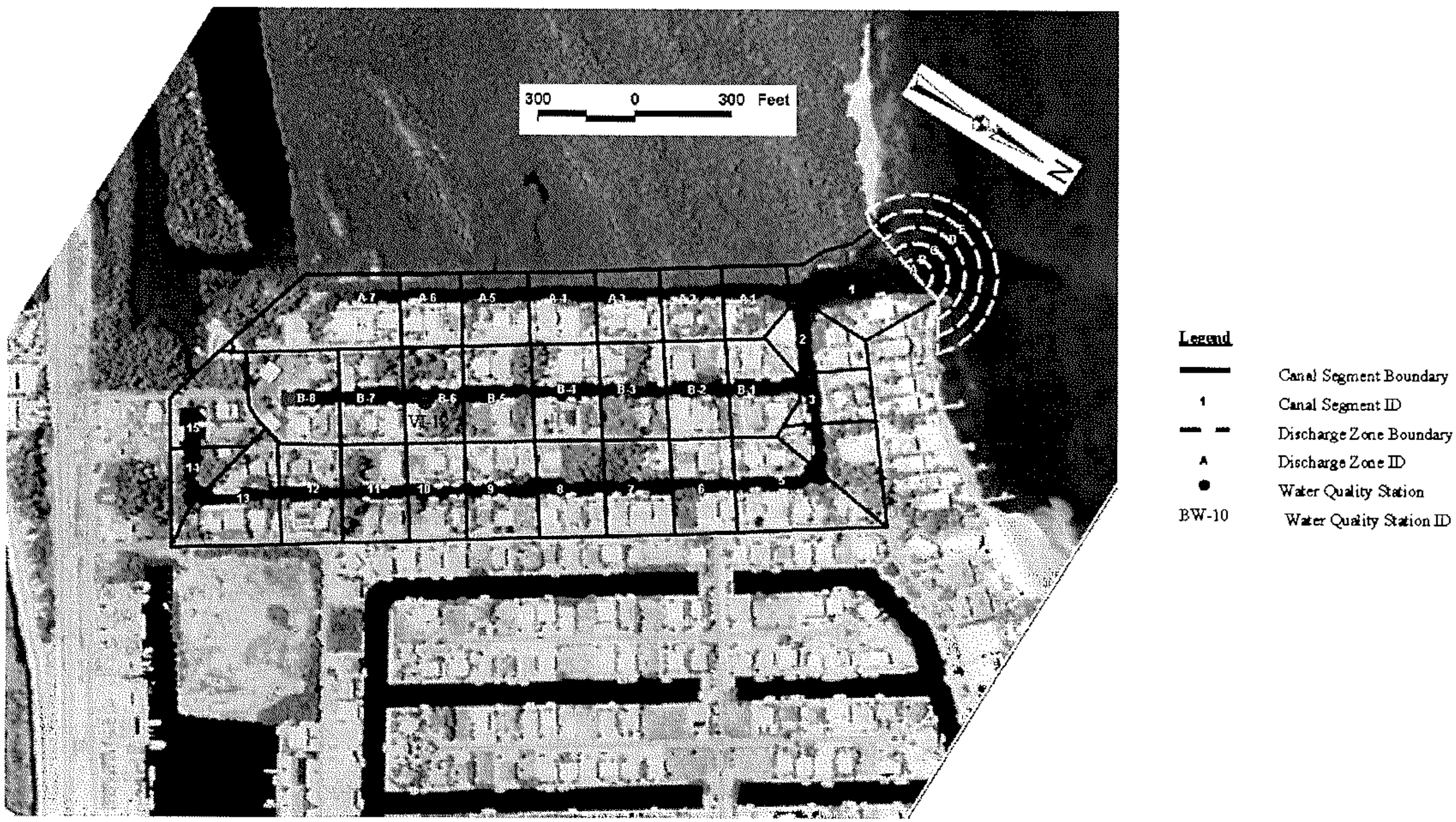
Legend

	Canal Segment Boundary
1	Canal Segment ID
	Discharge Zone Boundary
A	Discharge Zone ID
	Water Quality Station
BW-10	Water Quality Station ID

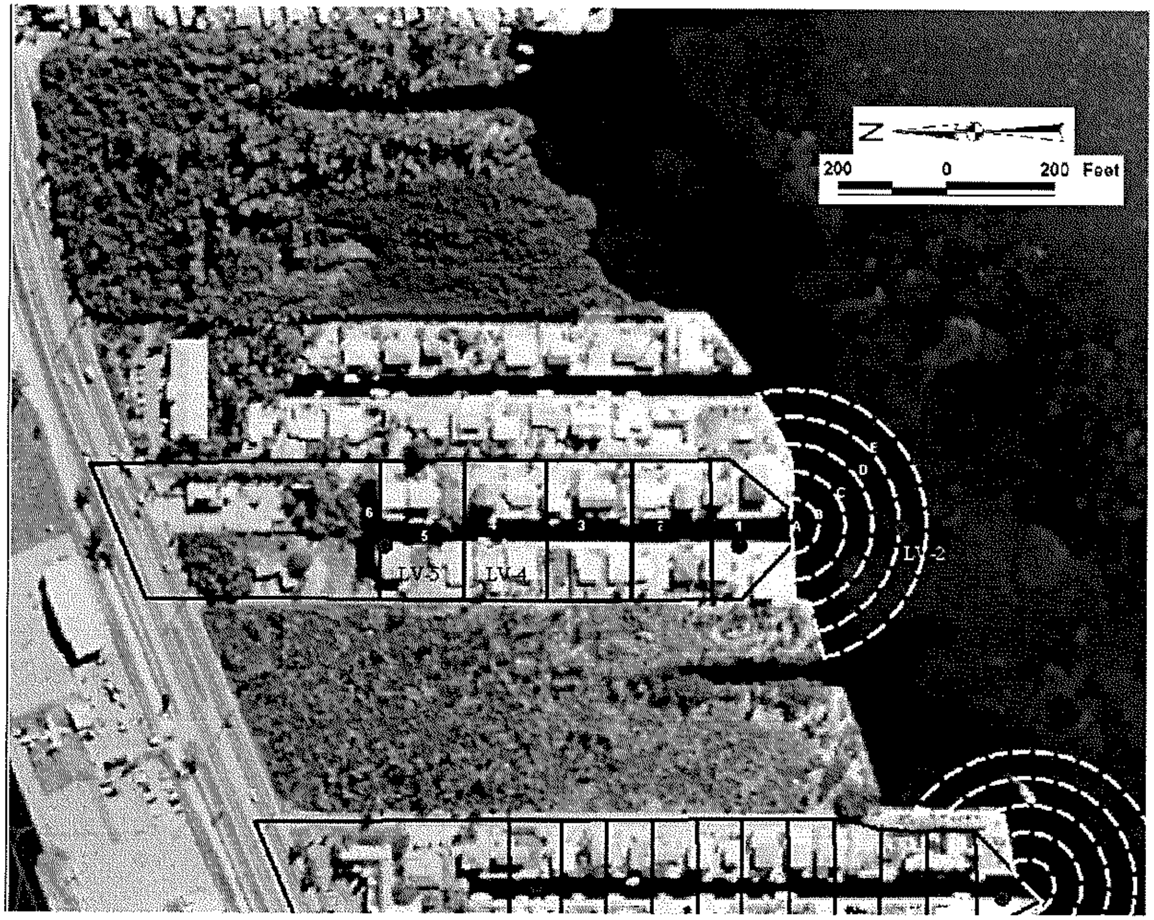
CANAL 117: PLANTATION KEY



CANAL 152: LOWER MATECUMBE KEY



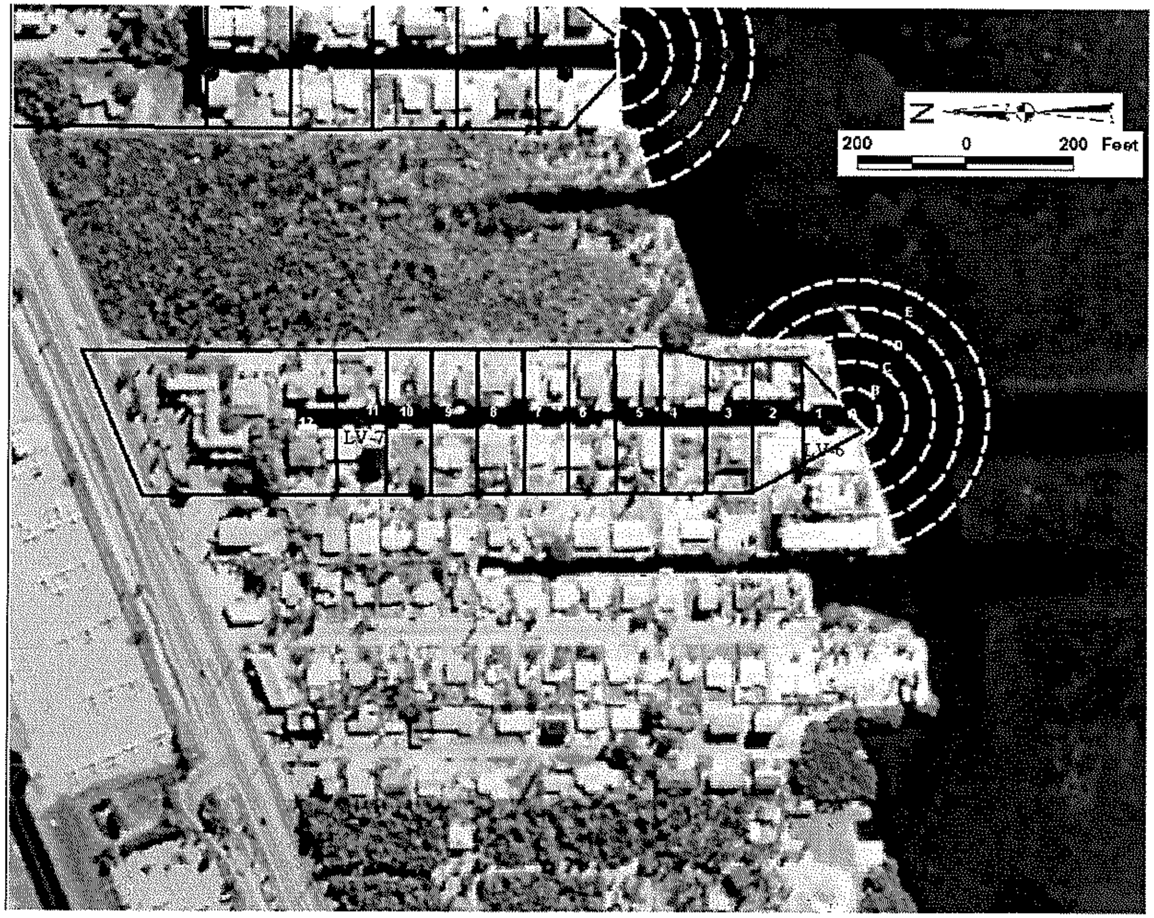
CANAL 204: MARATHON



Legend

▬	Canal Segment Boundary
1	Canal Segment ID
‒ ‒	Discharge Zone Boundary
A	Discharge Zone ID
●	Water Quality Station
BW-10	Water Quality Station ID

CANAL 208: MARATHON



Legend

Canal Segment Boundary

Canal Segment ID

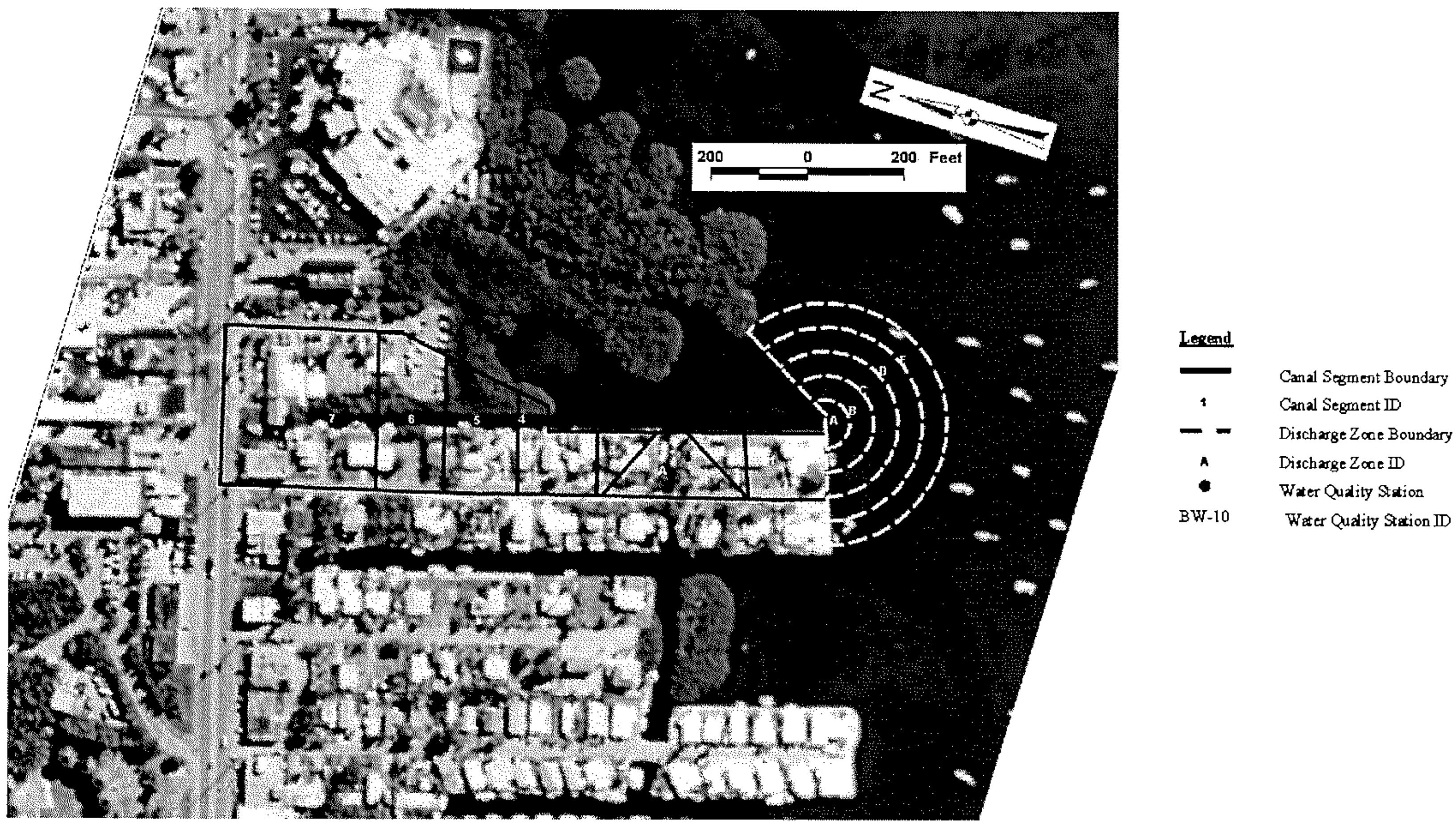
Discharge Zone Boundary

Discharge Zone ID

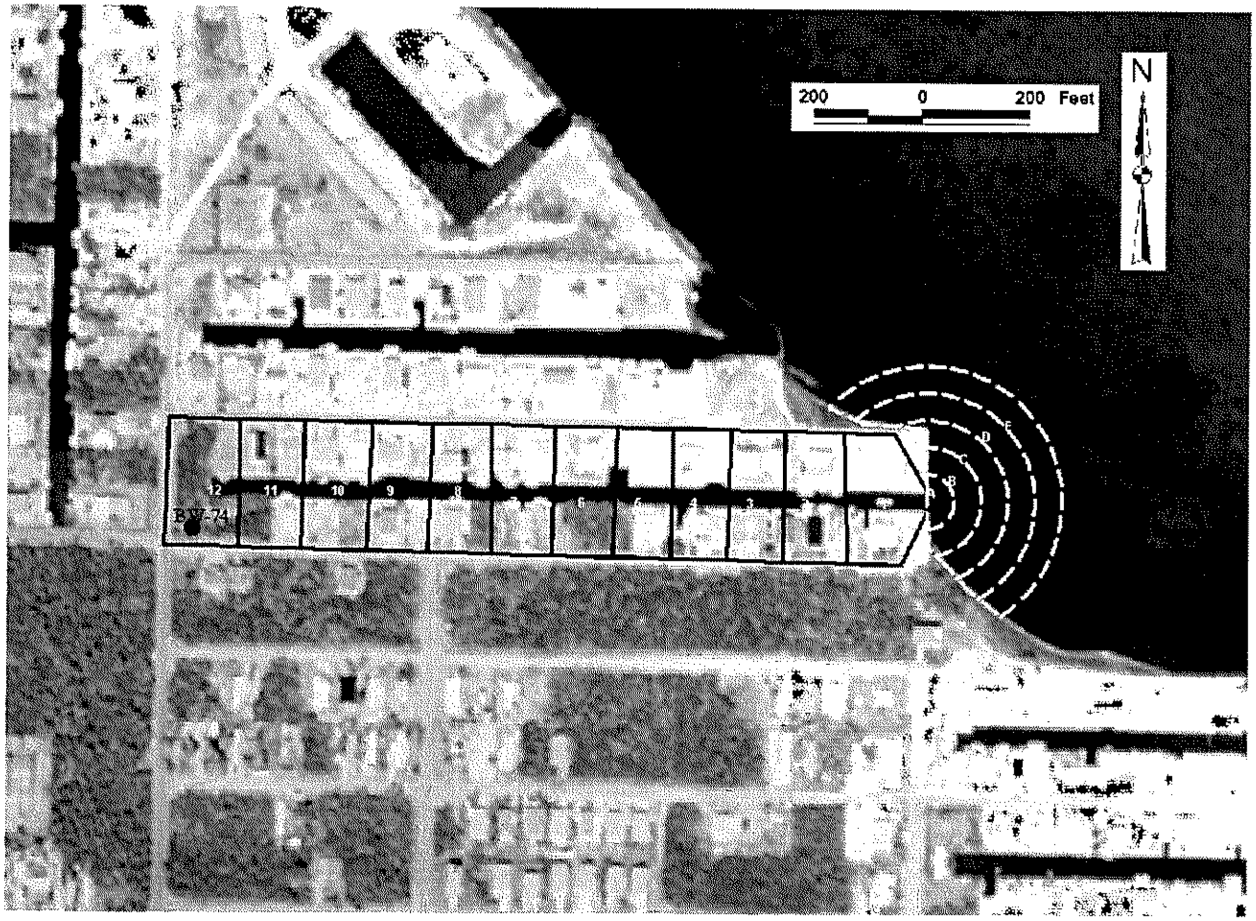
Water Quality Station

BW-10 Water Quality Station ID

CANAL 246: MARATHON



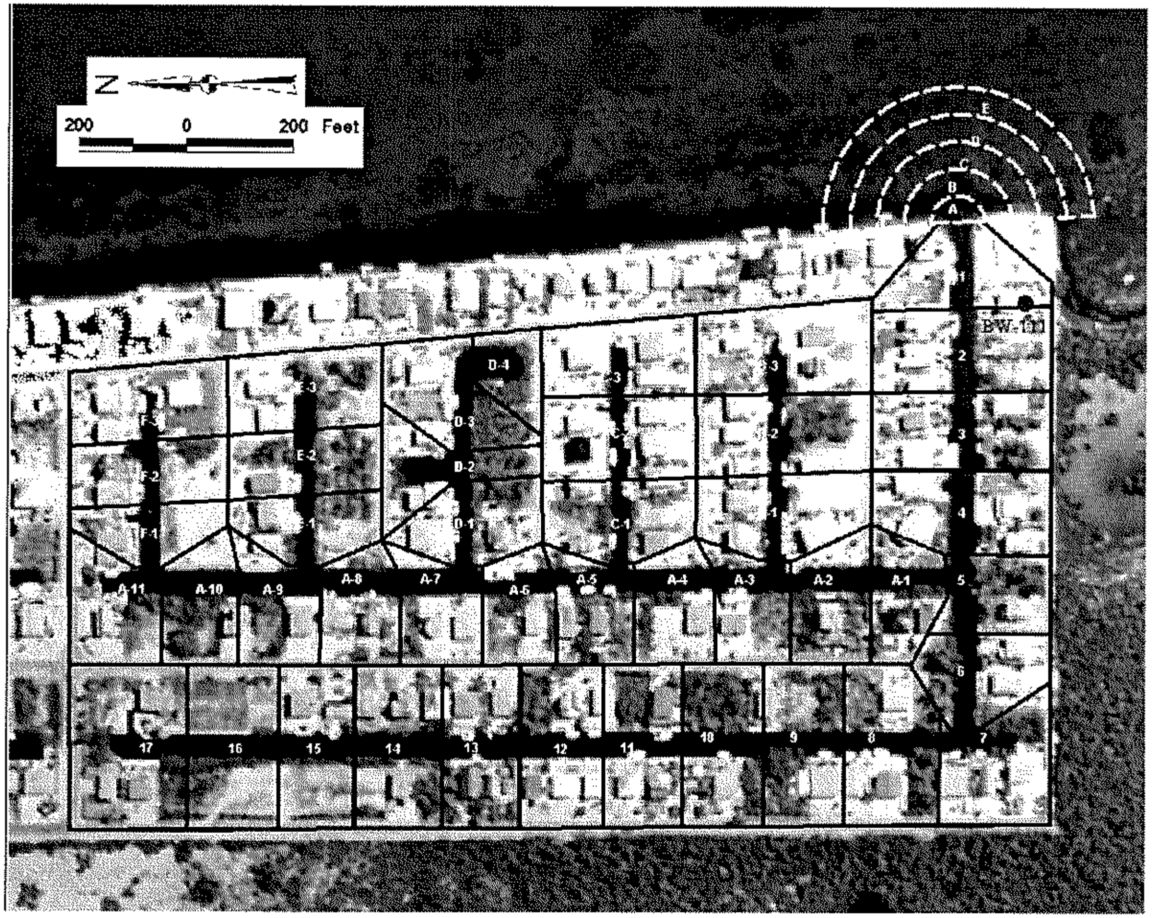
CANAL 288: BIG PINE KEY



Legend

(line)	Canal Segment Boundary
1	Canal Segment ID
(dashed line)	Discharge Zone Boundary
A	Discharge Zone ID
●	Water Quality Station
BW-10	Water Quality Station ID

CANAL 339: LITTLE TORCH KEY

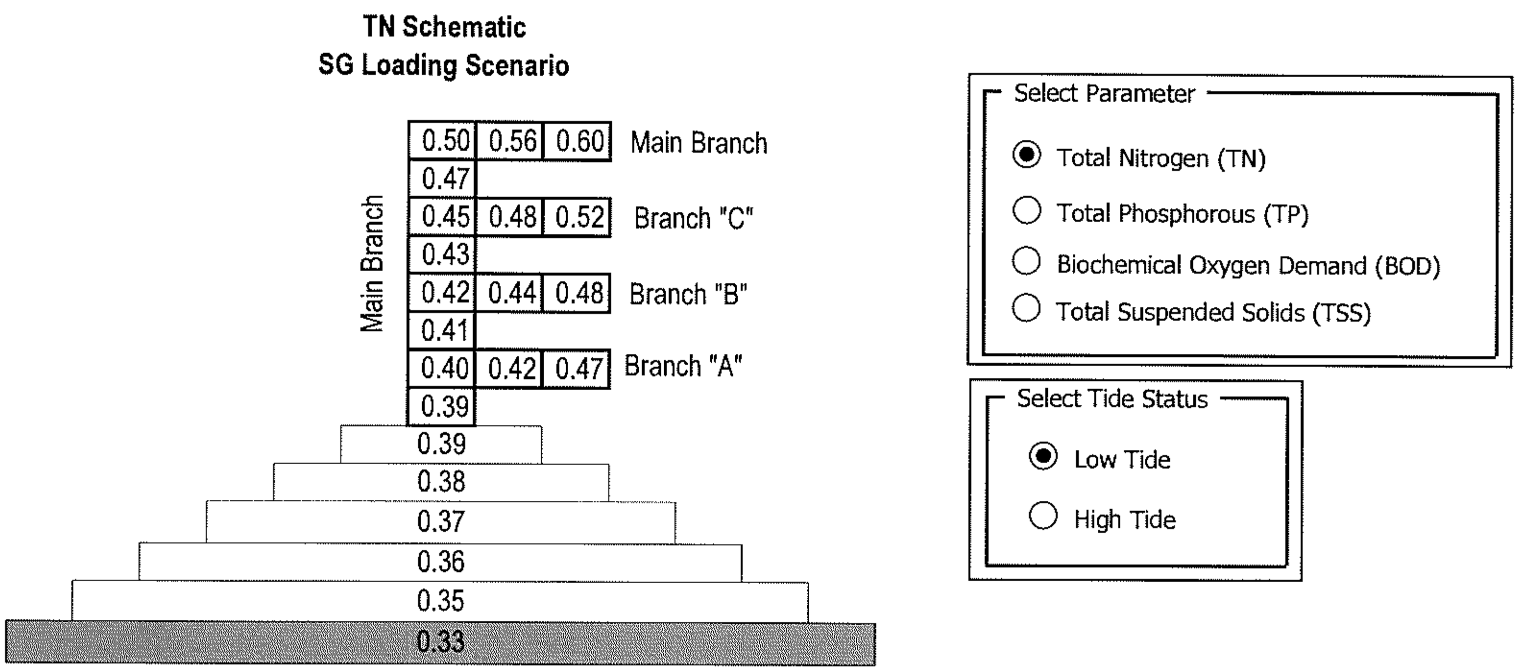


Legend

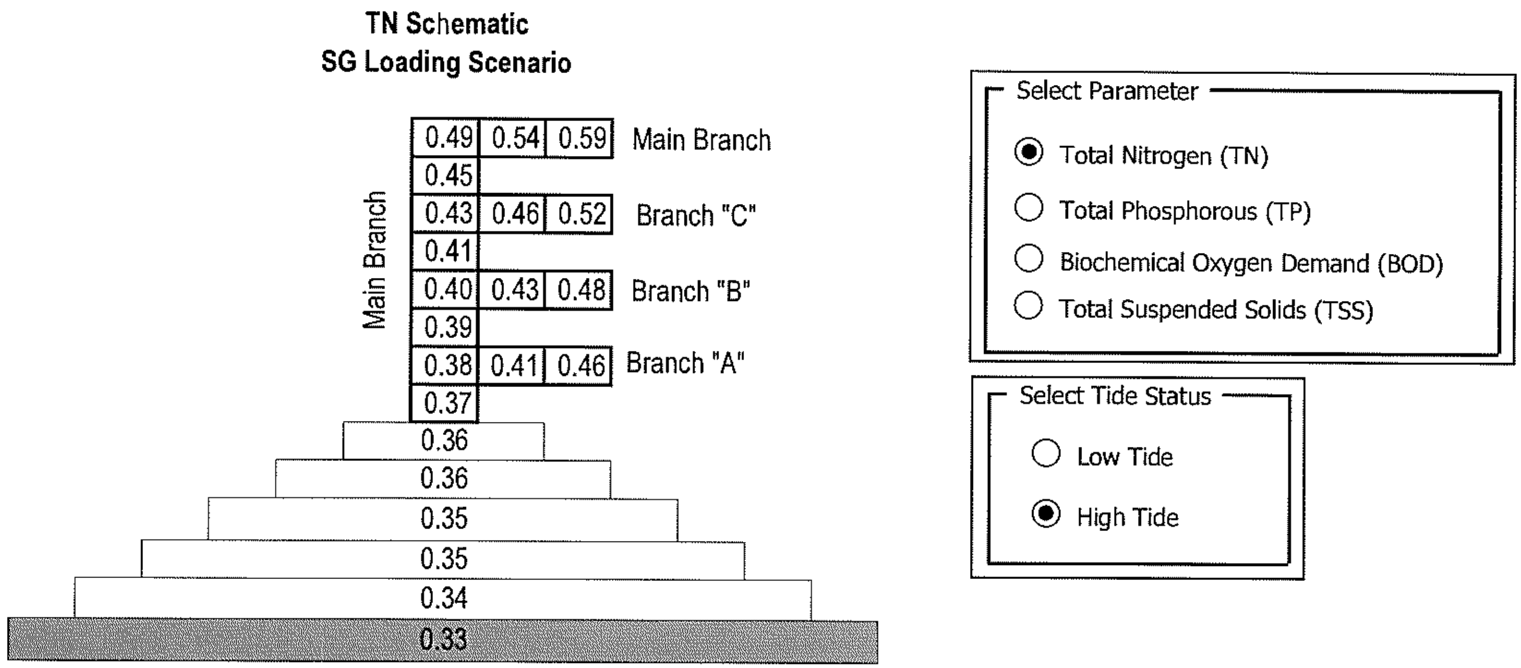
	Canal Segment Boundary
1	Canal Segment ID
	Discharge Zone Boundary
A	Discharge Zone ID
	Water Quality Station
BW-10	Water Quality Station ID

CANAL IMPACTS ASSESSMENT TOOL

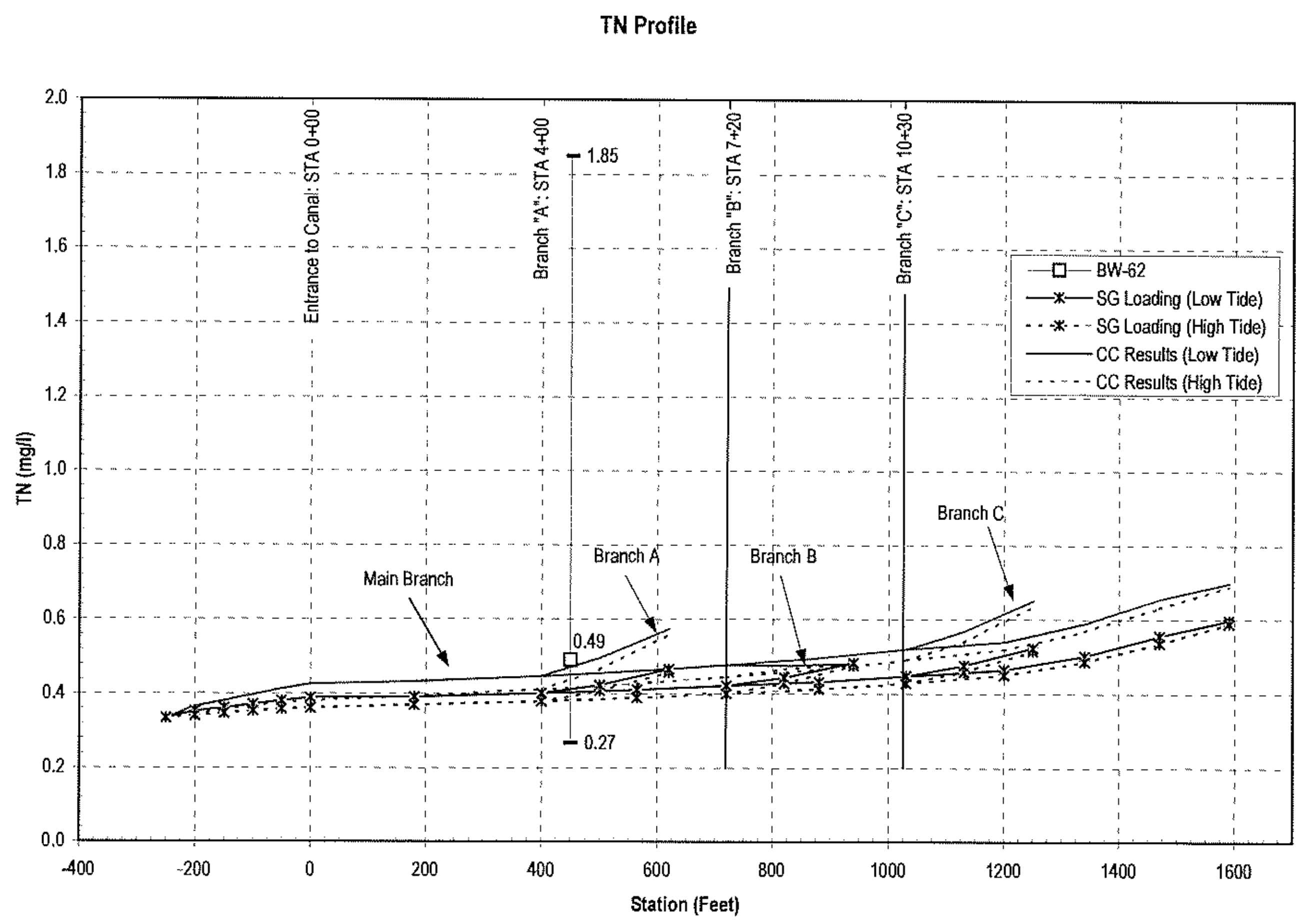
APPENDIX C-B
MODEL OUTPUT



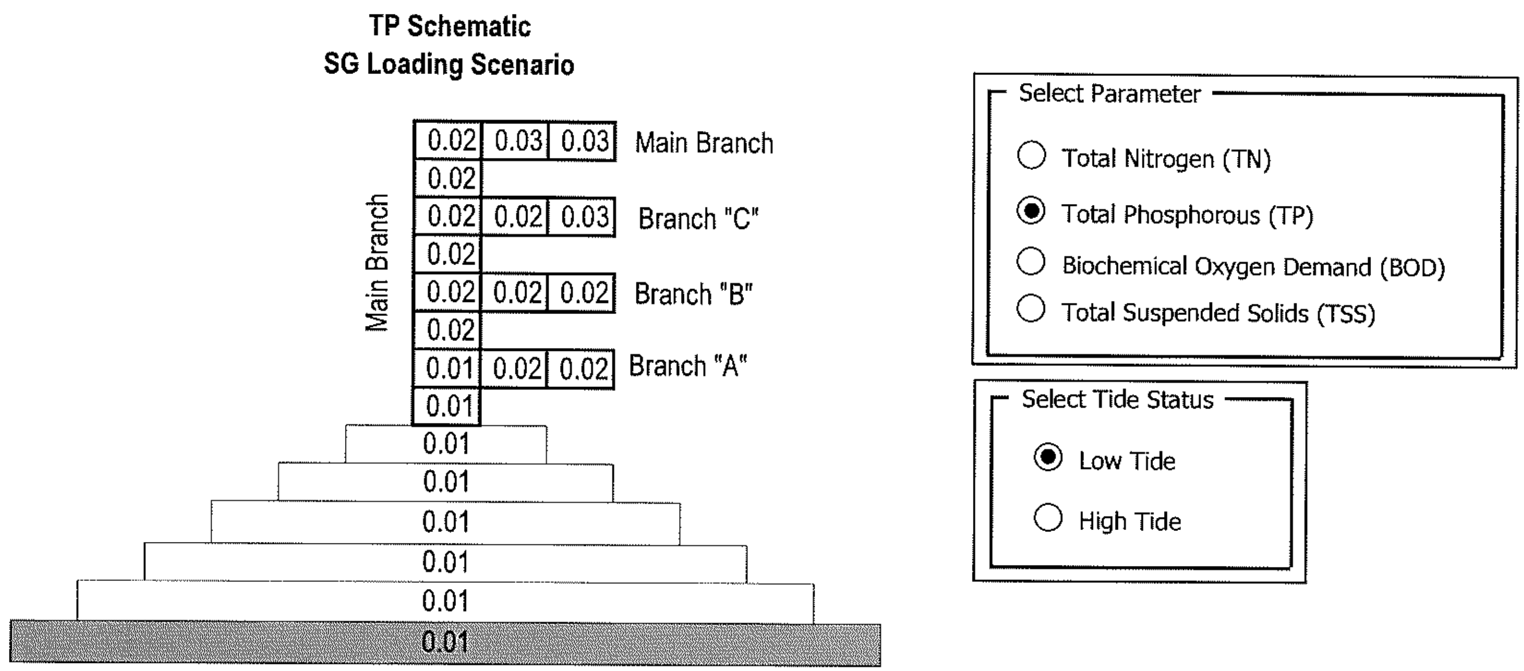
Canal #50, Key Largo Model Output: TN, low tide



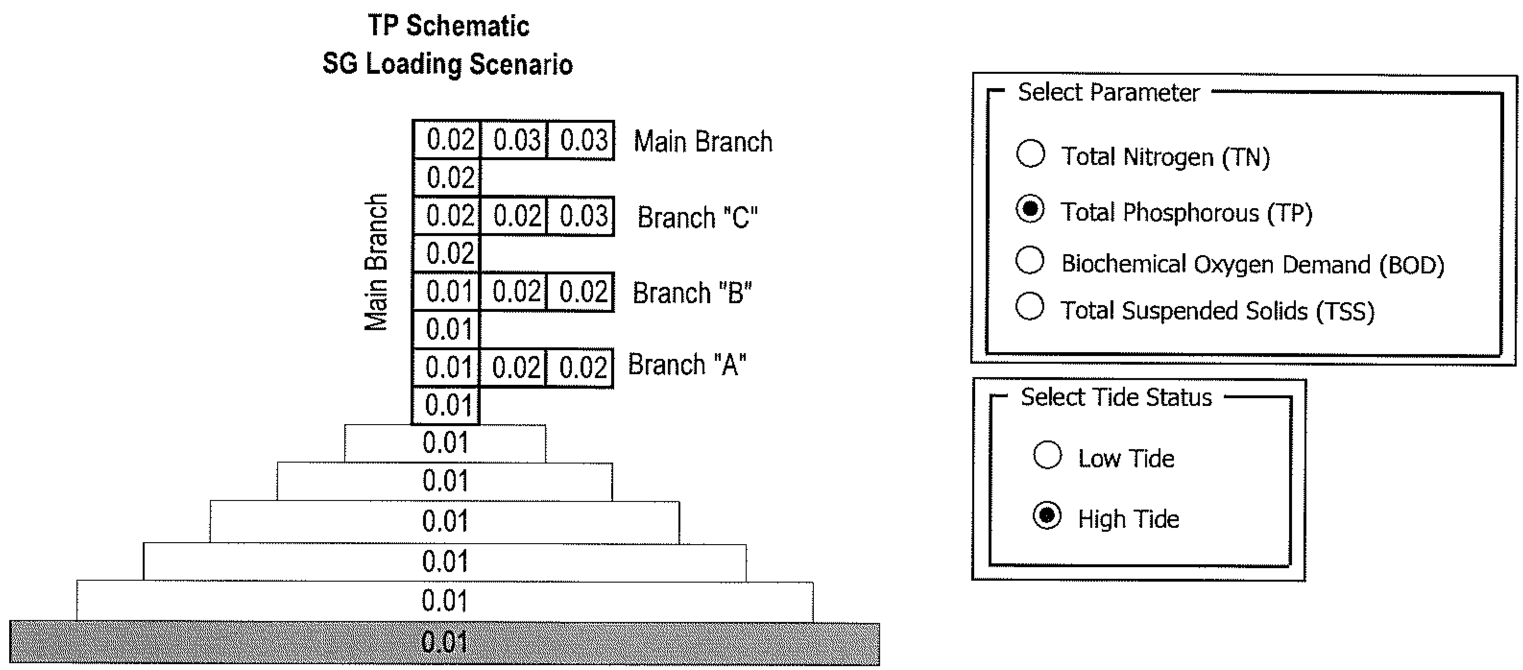
Canal #50, Key Largo Model Output: TN, high tide



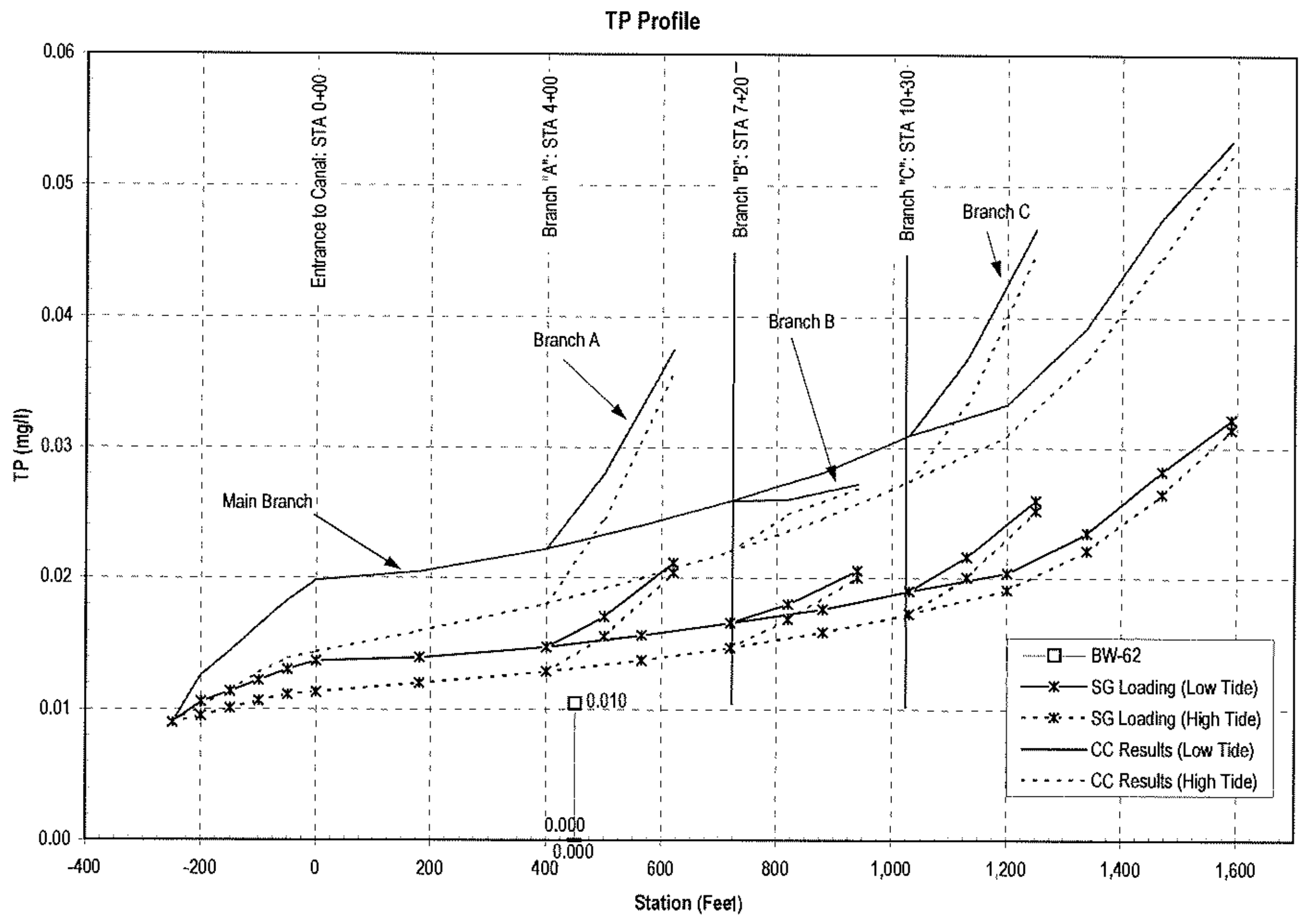
Canal #50, Key Largo Model Output: TN Profile



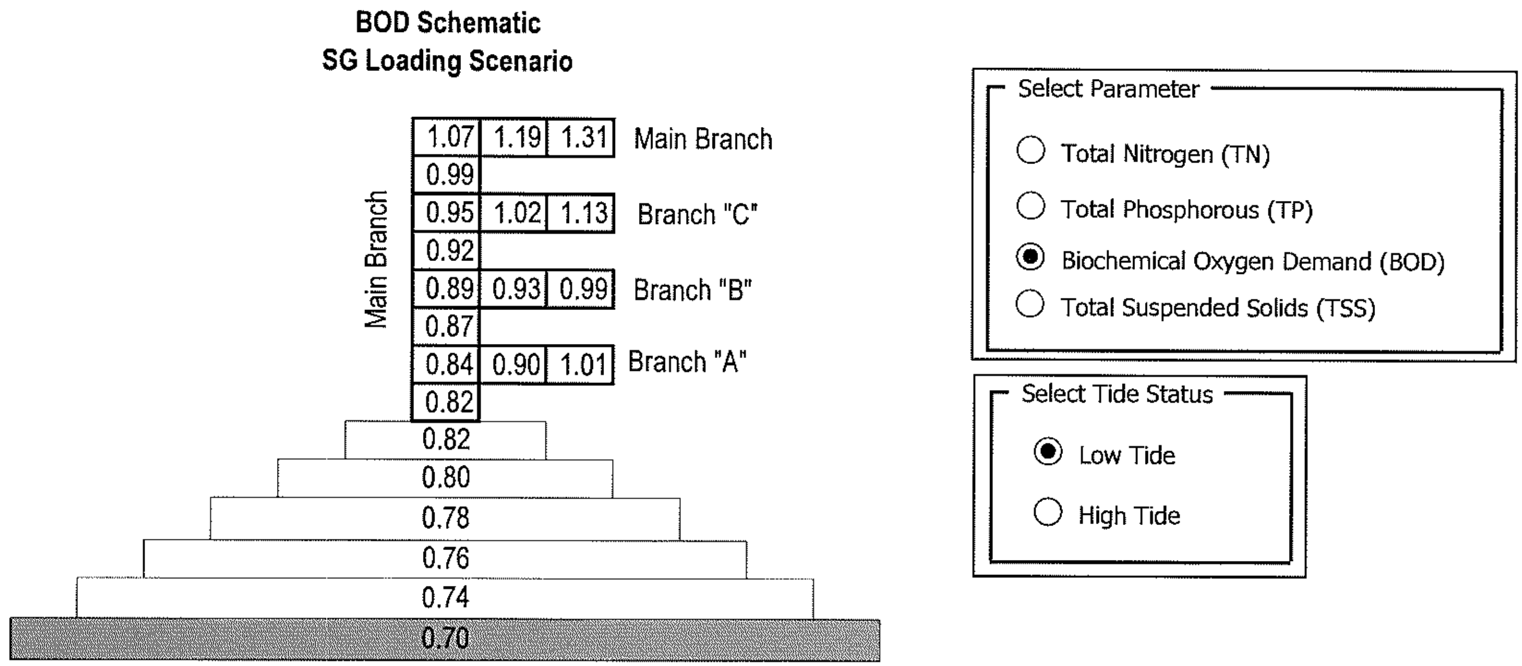
Canal #50, Key Largo Model Output: TP, low tide



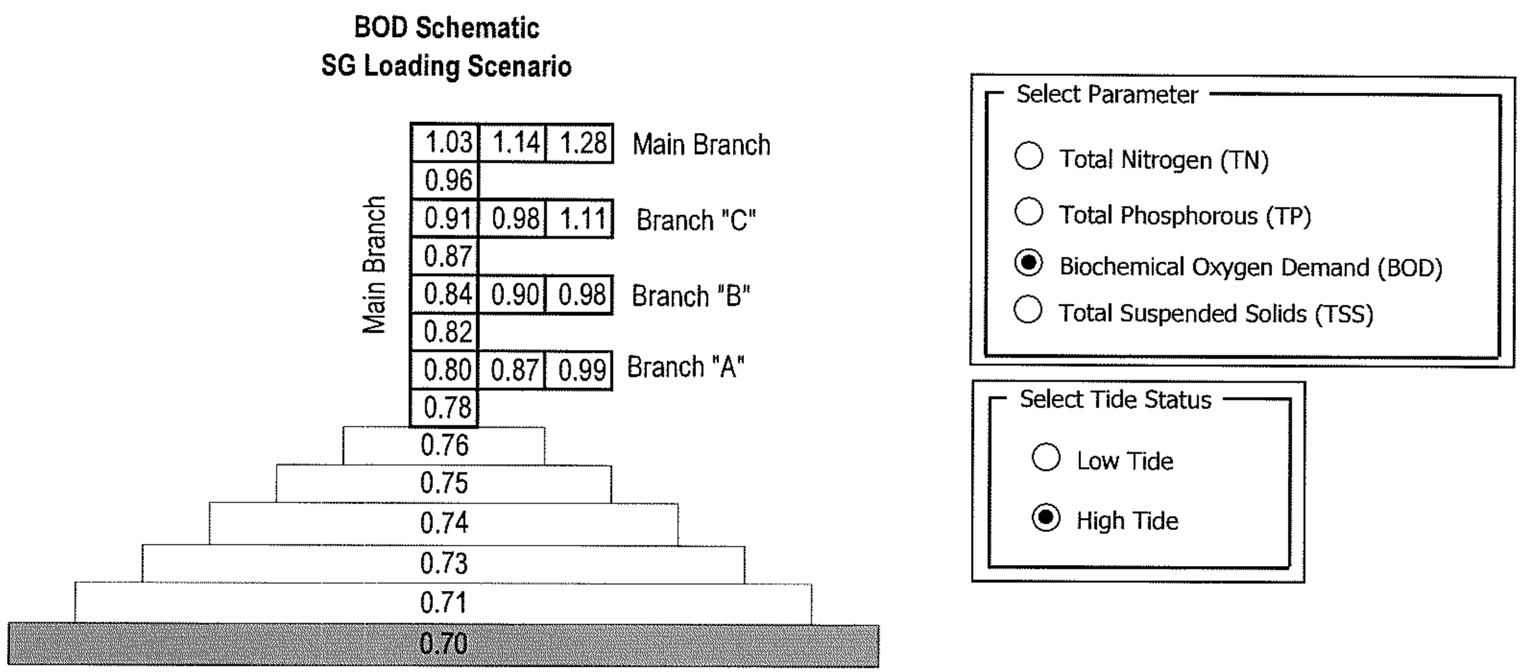
Canal #50, Key Largo Model Output, TP, high tide



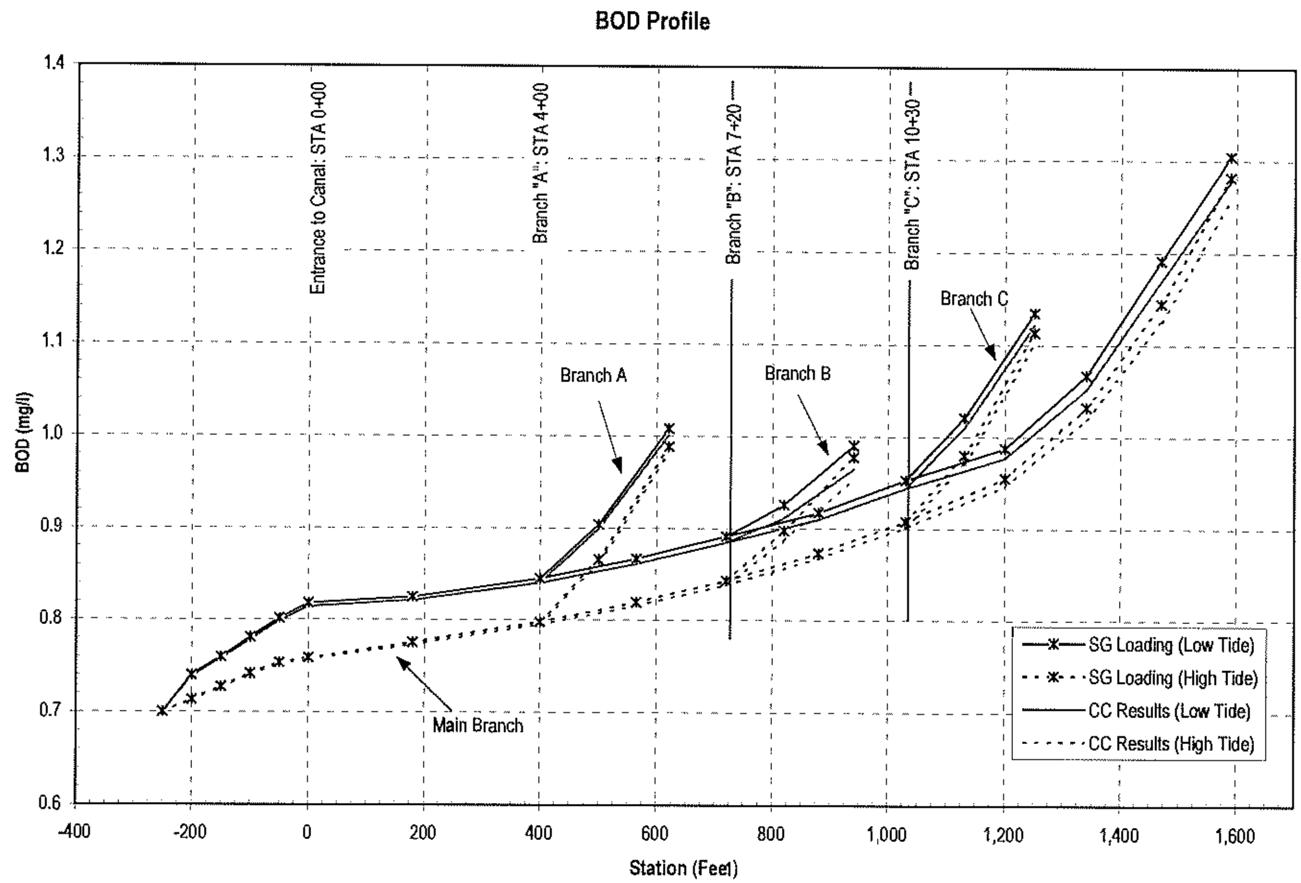
Canal #50, Key Largo Model Output: TP Profile



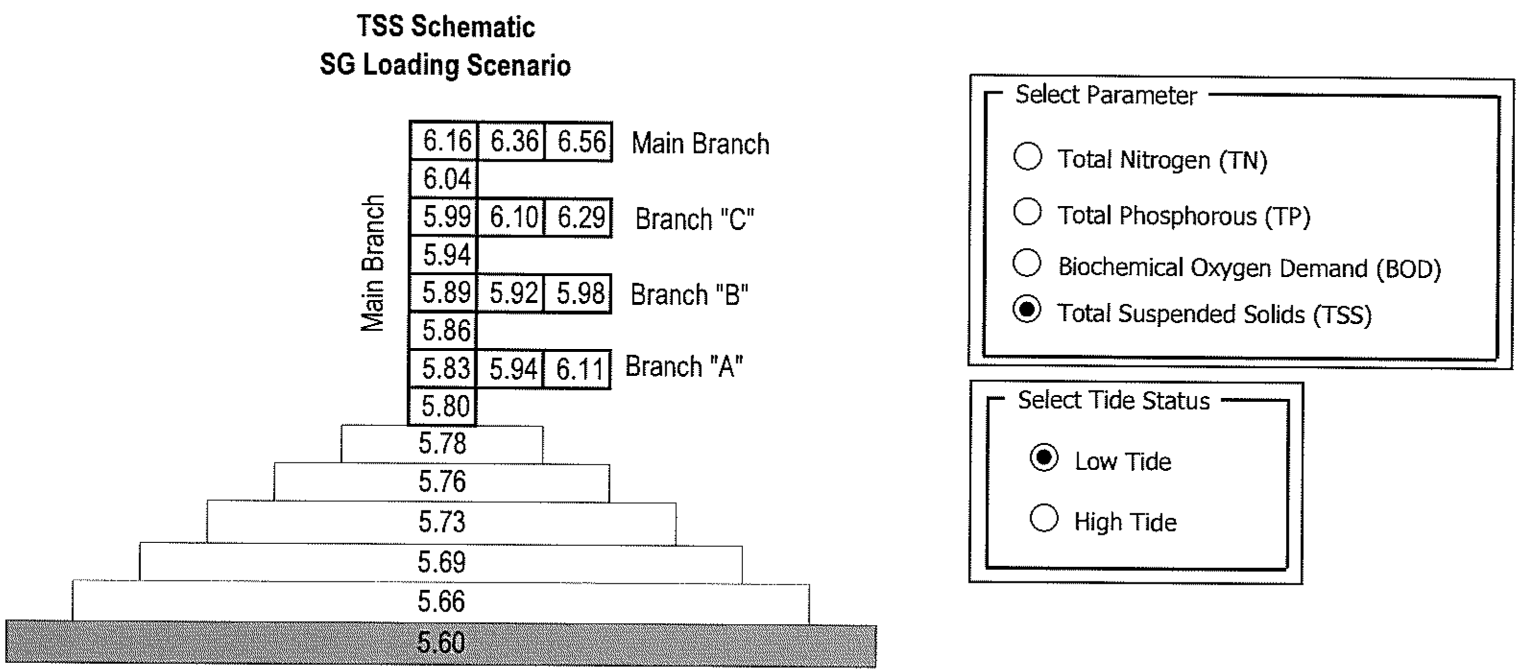
Canal #50, Key Largo Model Output, BOD, low tide



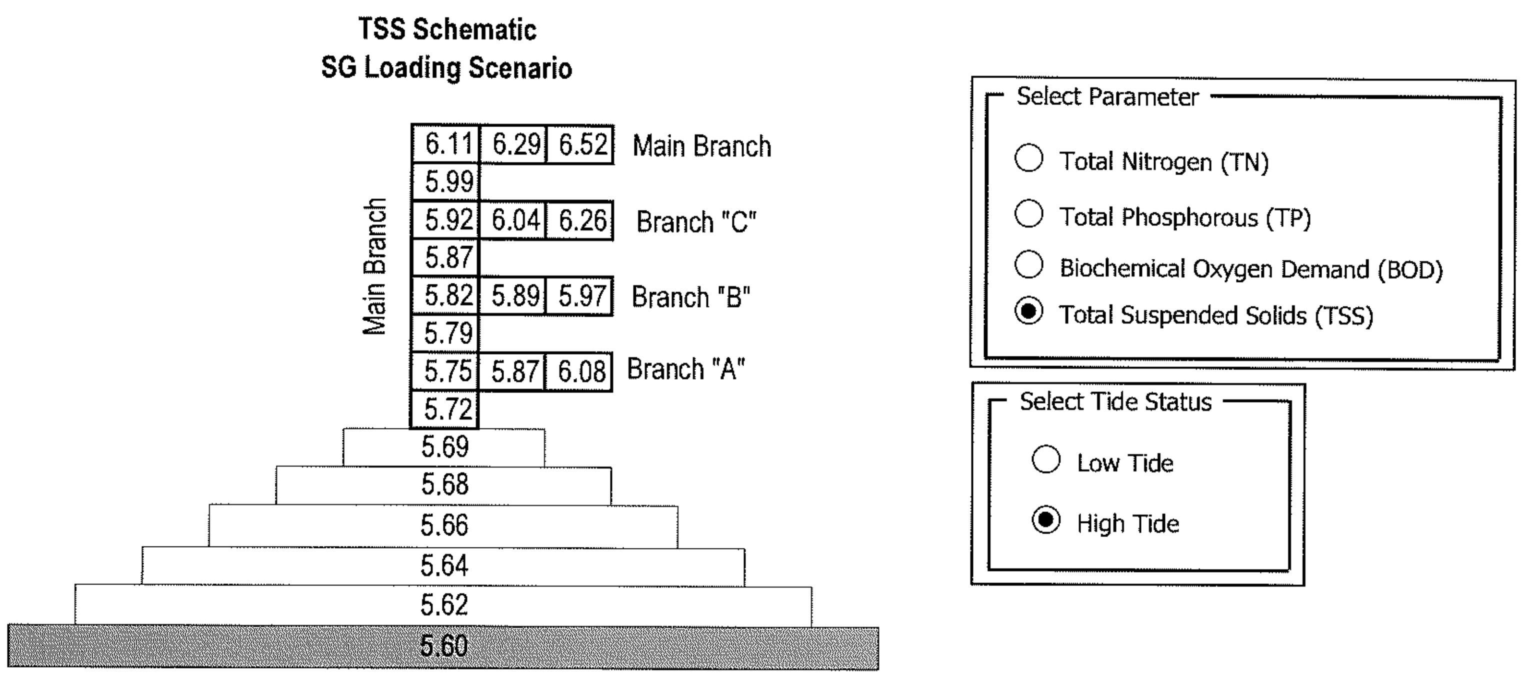
Canal #50, Key Largo Model Output: BOD, high tide



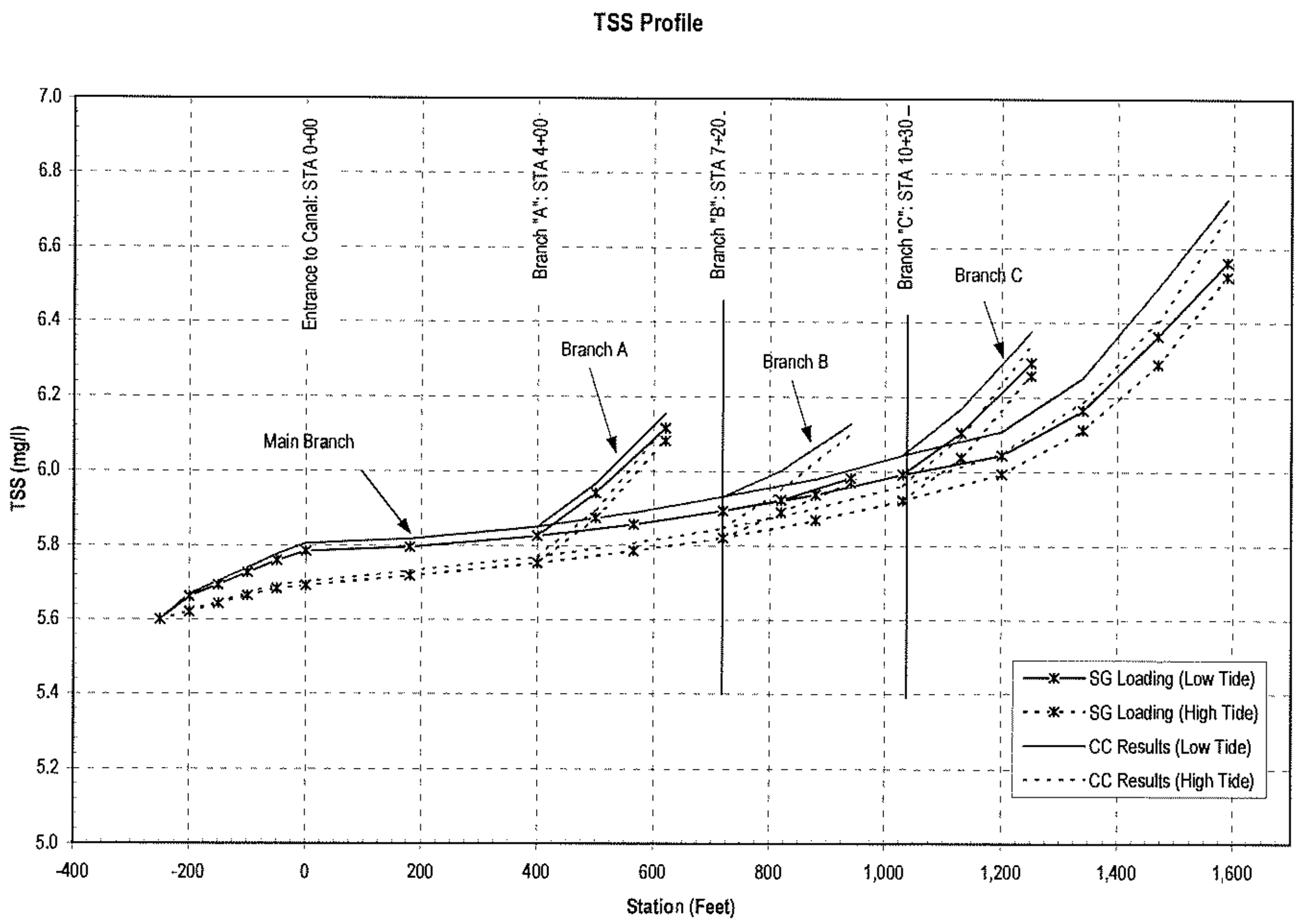
Canal #50, Key Largo Model Output: BOD Profile



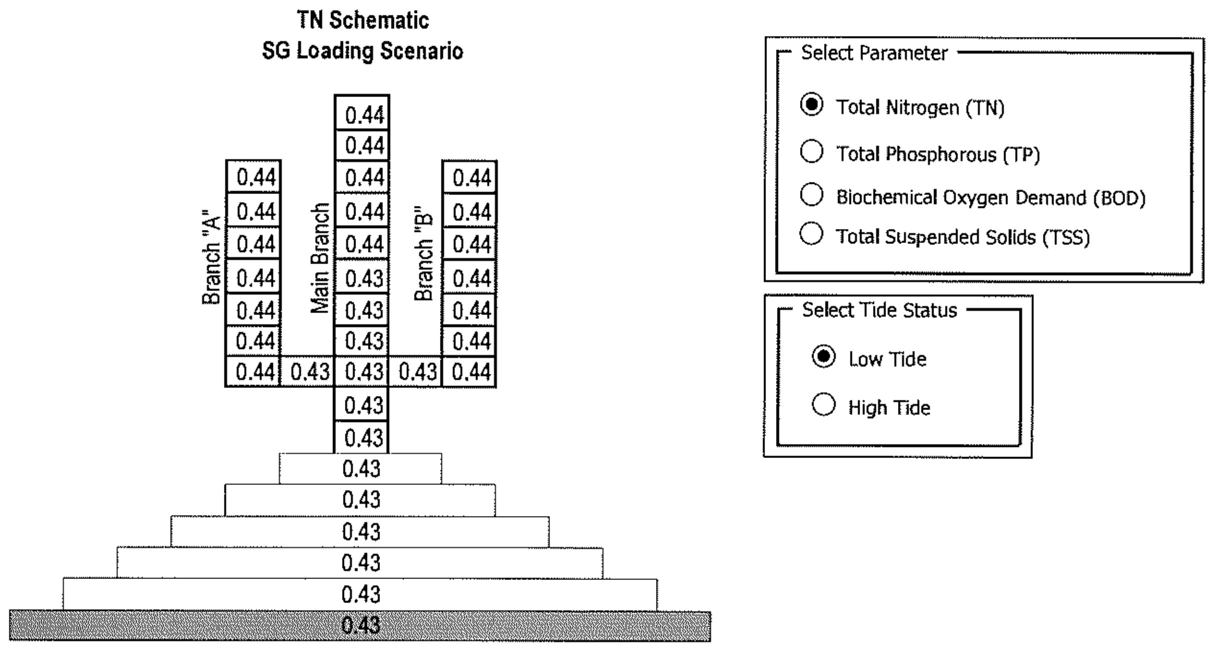
Canal #50, Key Largo Model Output: TSS, low tide



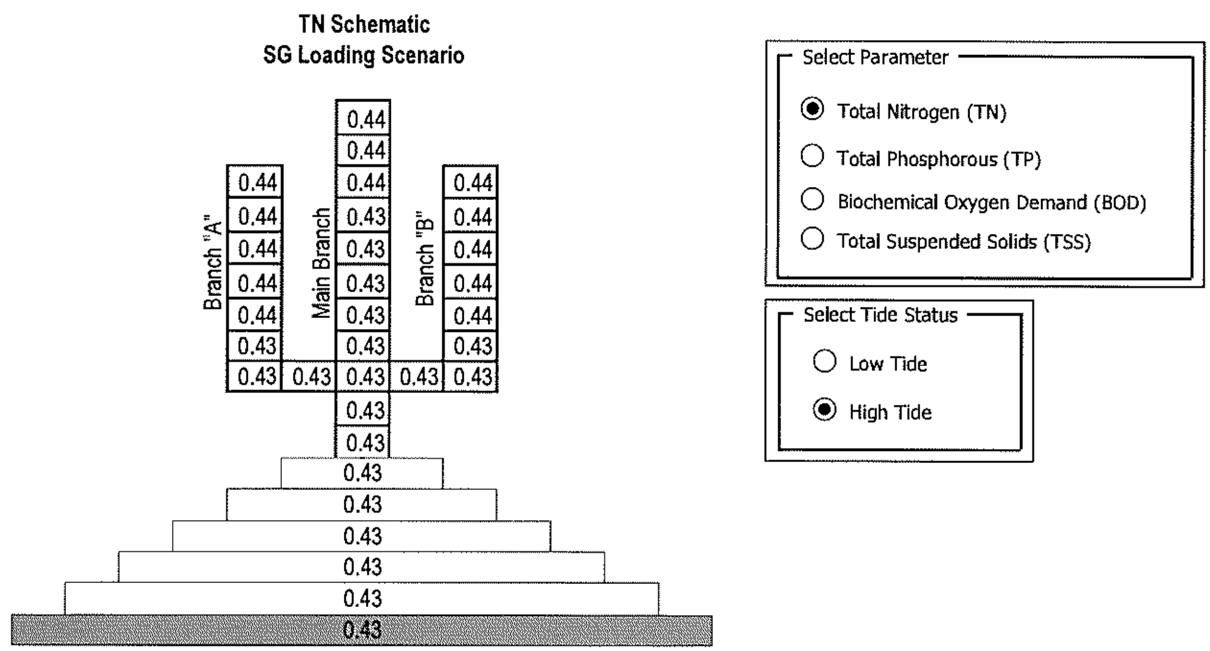
Canal #50, Key Largo Model Output, TSS, high tide



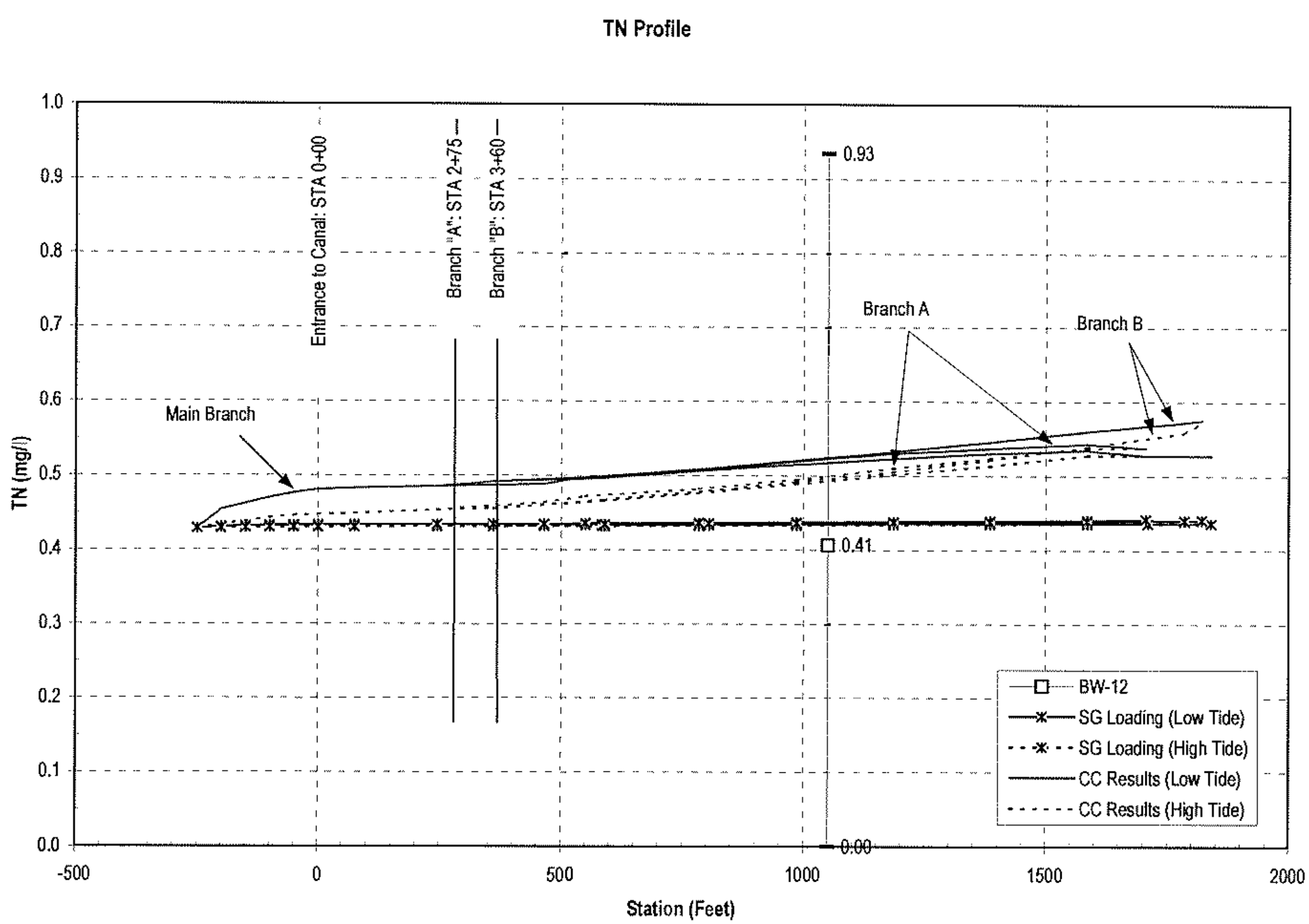
Canal #50, Key Largo Model Output: TSS Profile



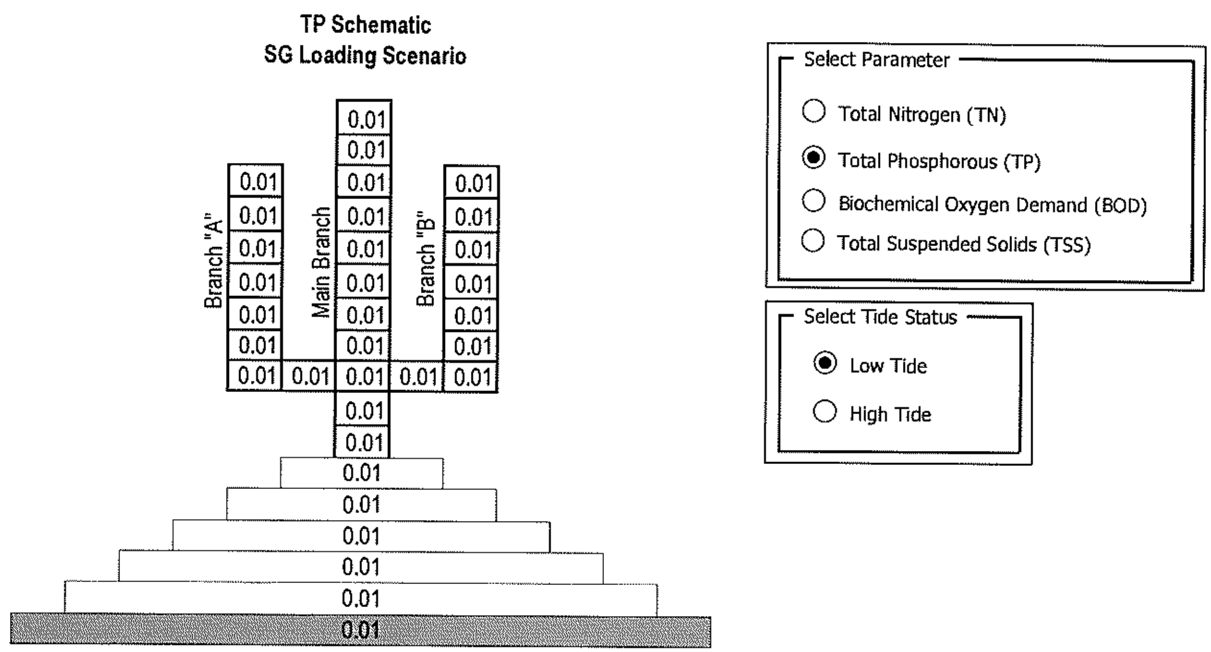
Canal #69, Rock Harbor Model Output: TN, low tide



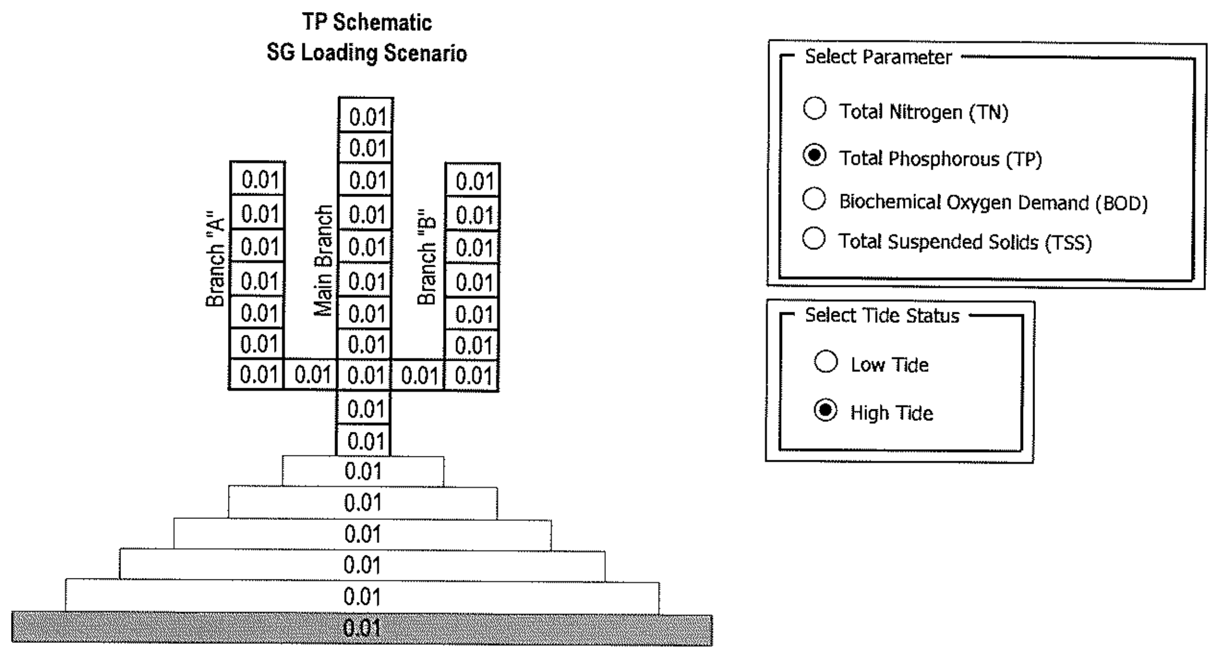
Canal #69, Rock Harbor Model Output: TN, high tide



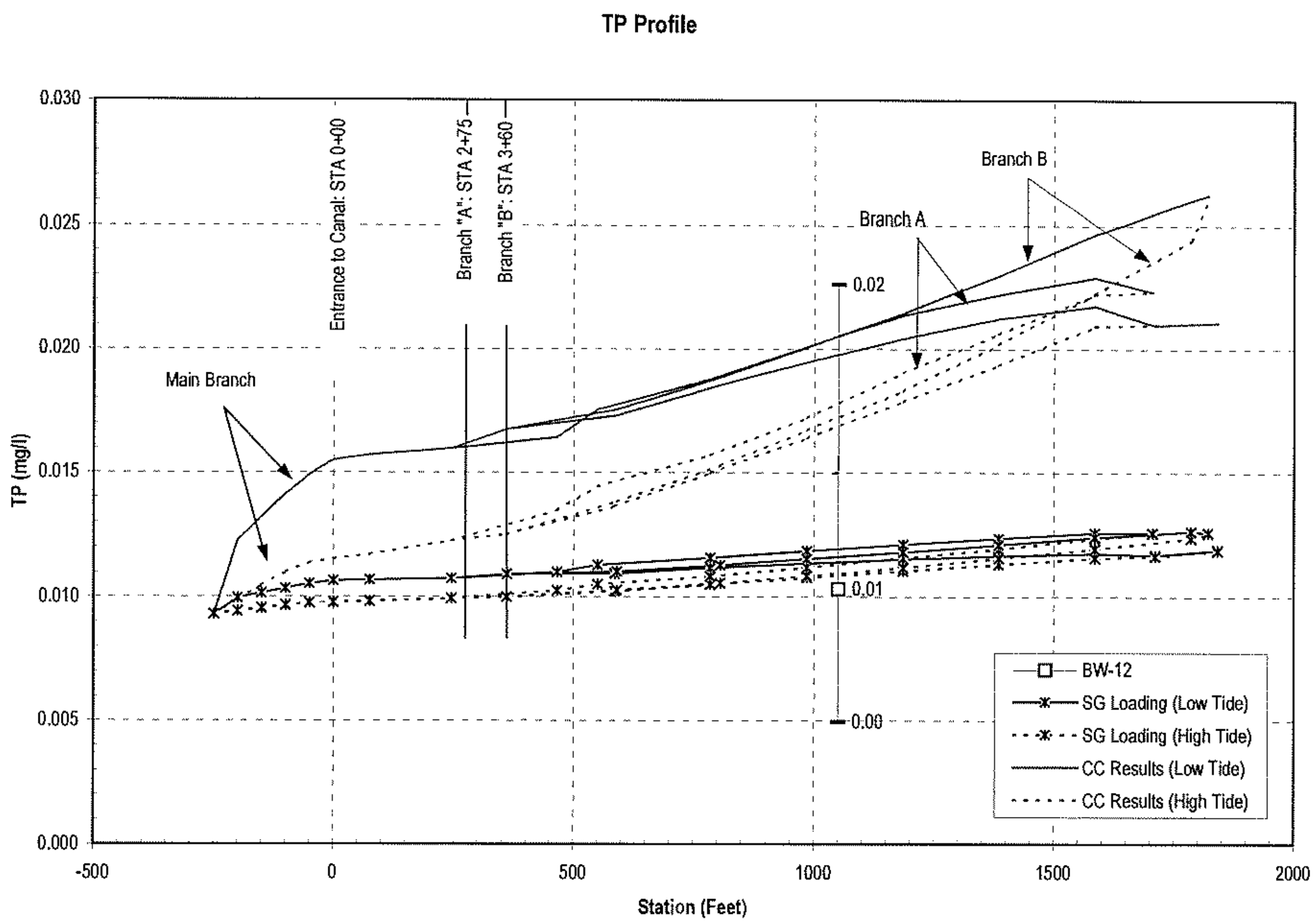
Canal #69, Rock Harbor Model Output: TN Profile



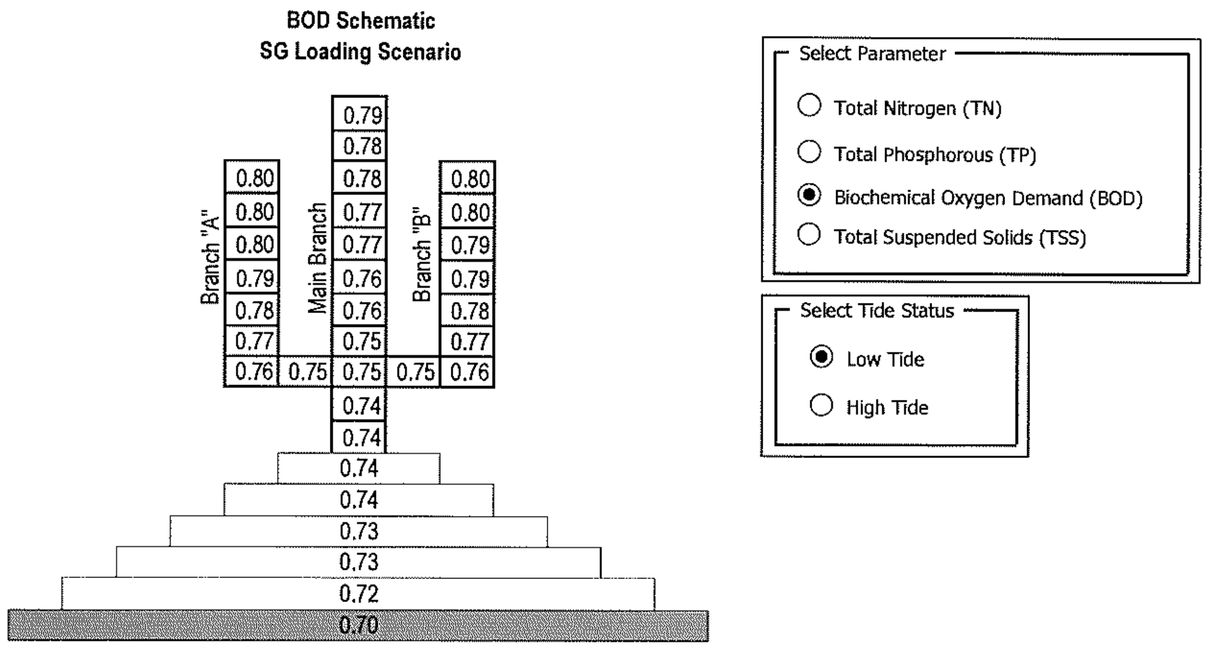
Canal #69, Rock Harbor Model Output: TP, low tide



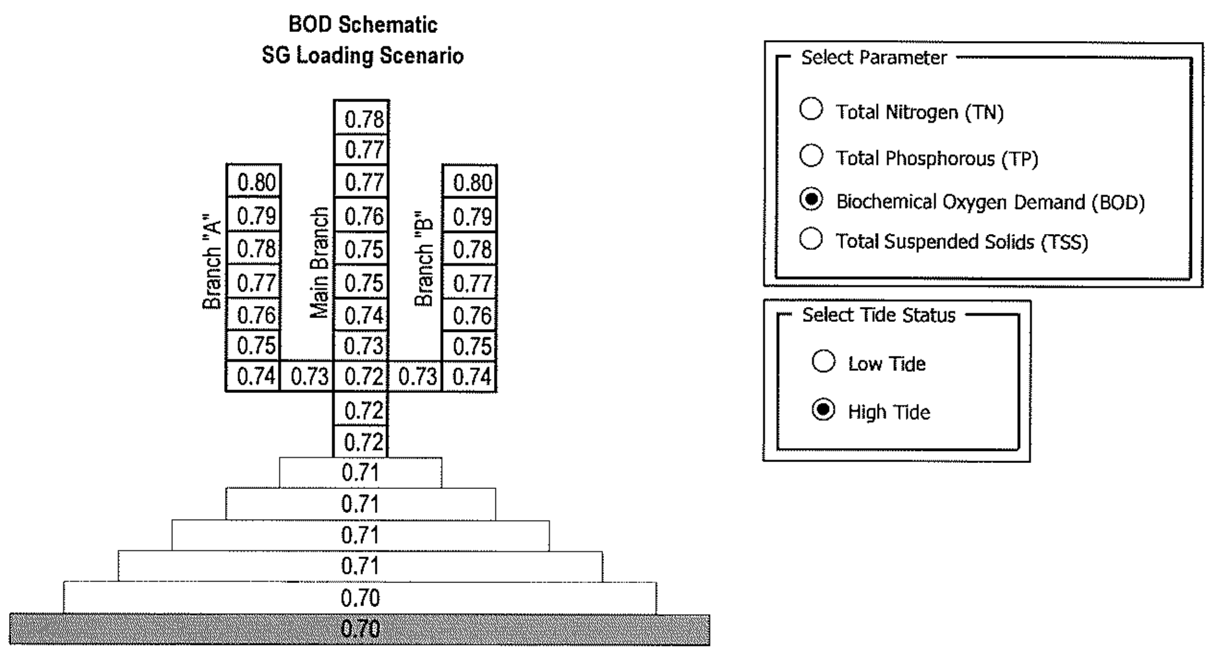
Canal #69, Rock Harbor Model Output: TP, high tide



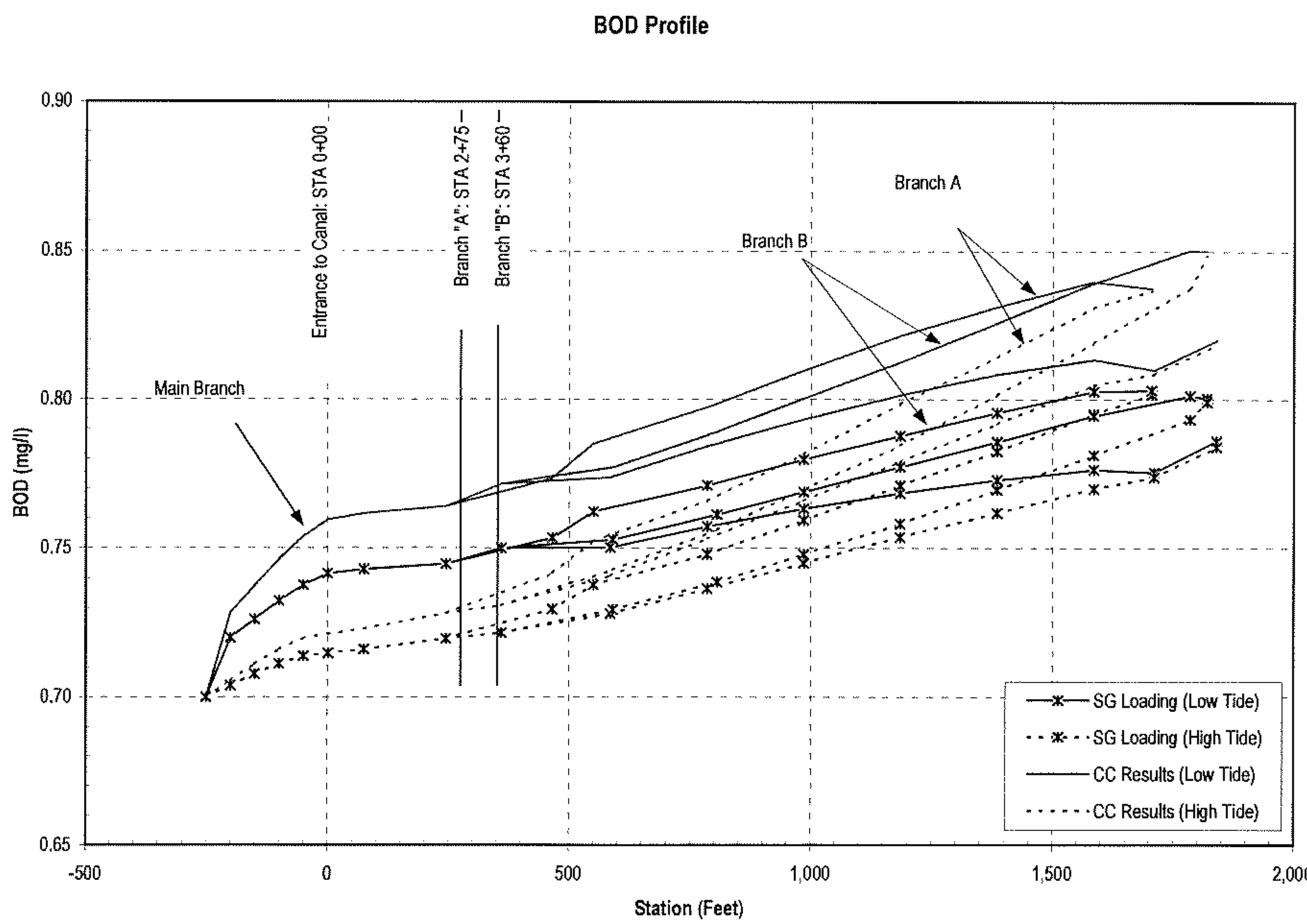
Canal #69, Rock Harbor Model Output, TP Profile



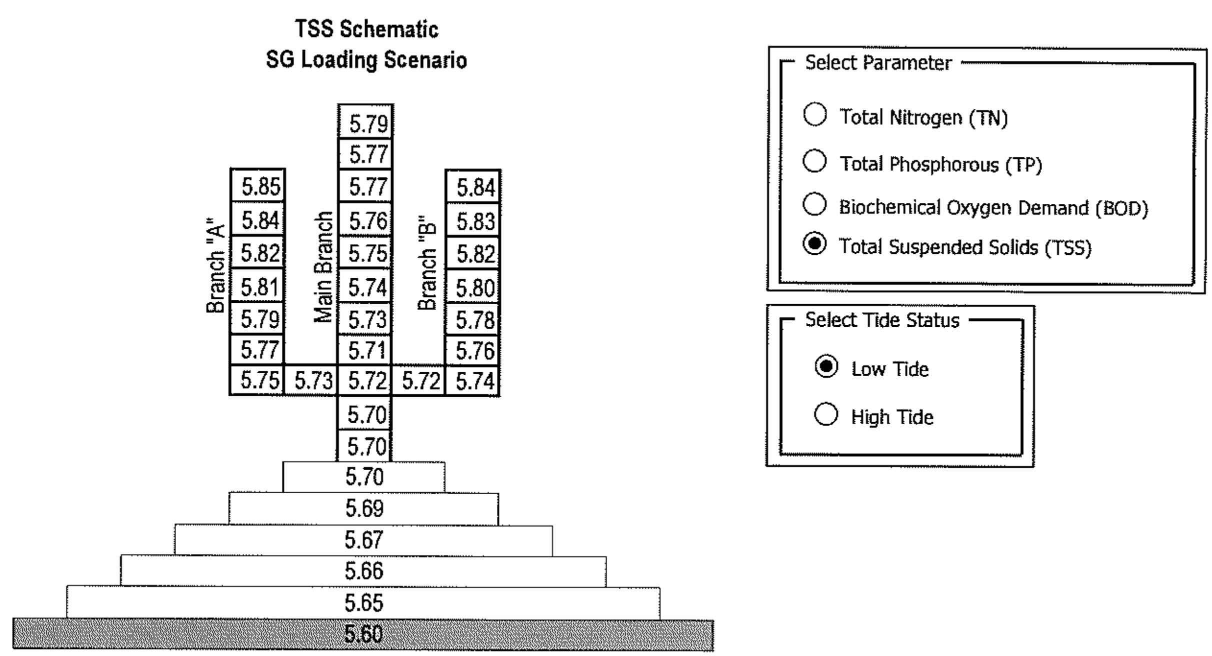
Canal #69, Rock Harbor Model Output, BOD, low tide



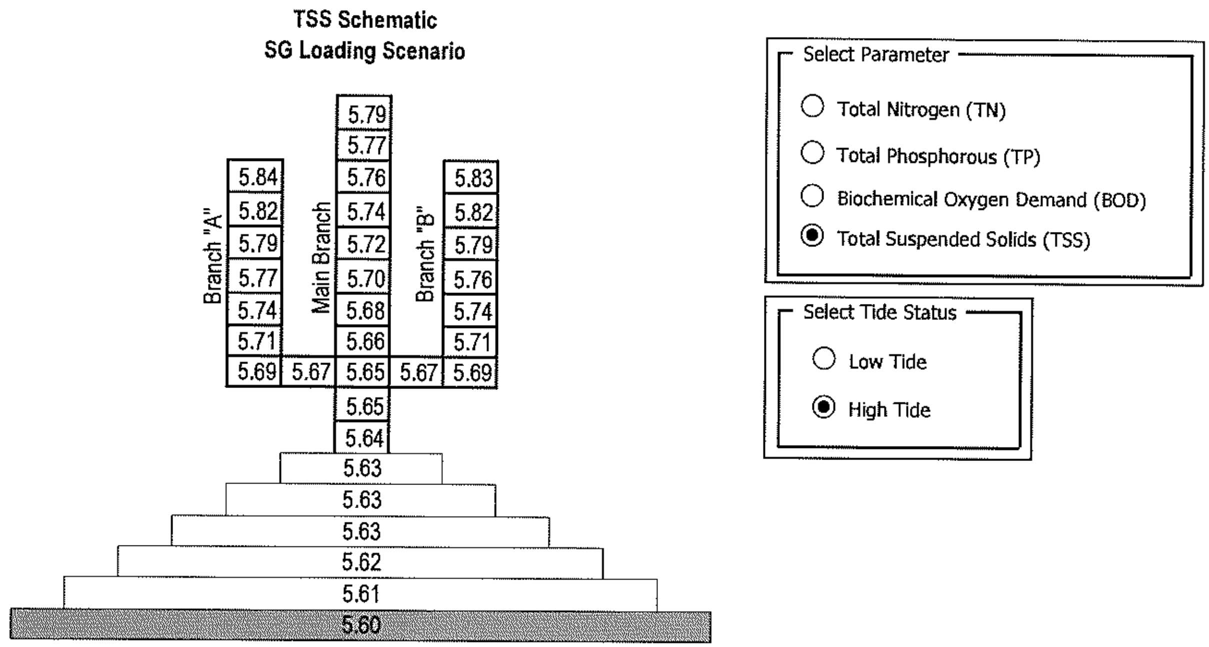
Canal #69, Rock Harbor Model Output, BOD, high tide



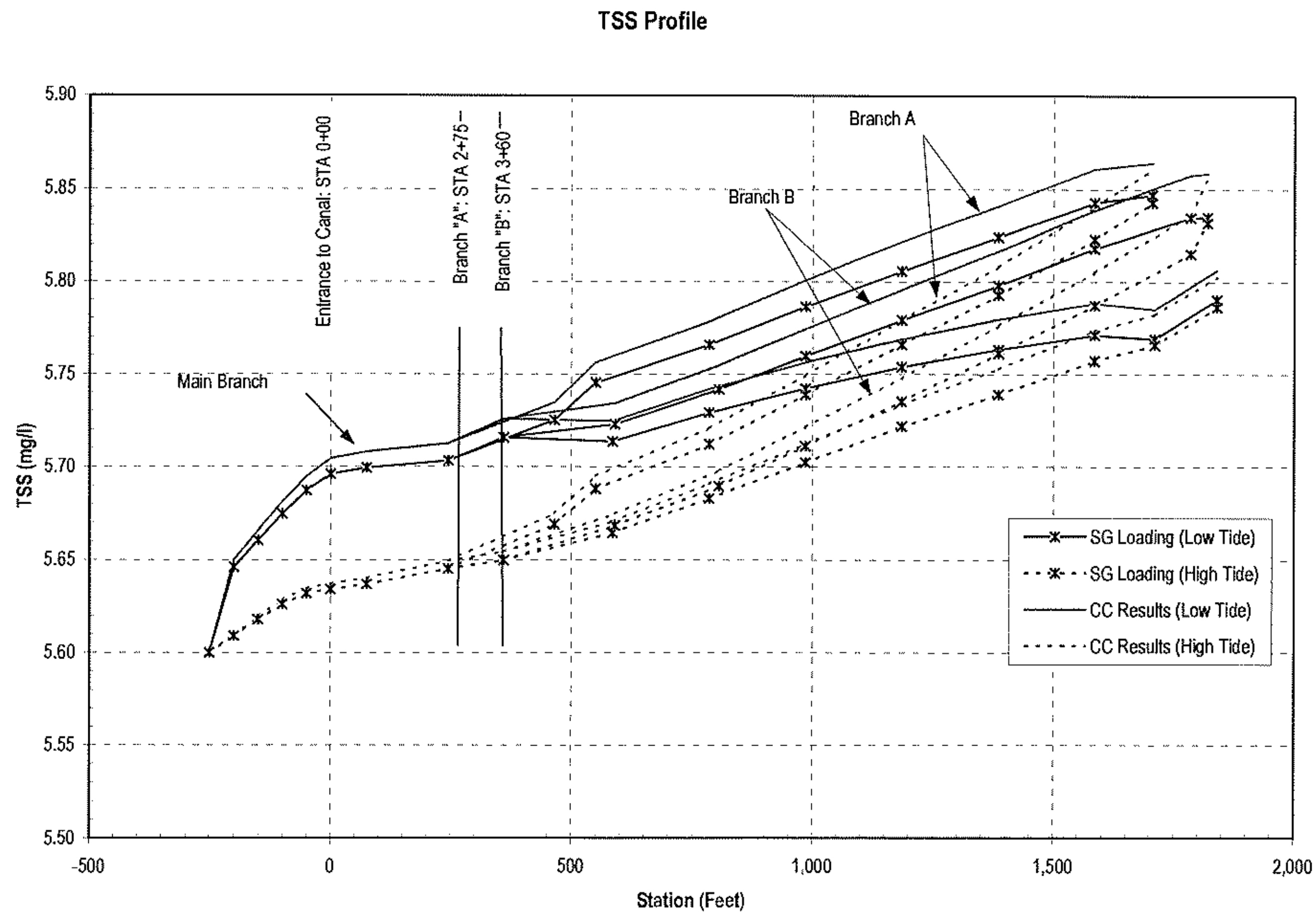
Canal #69, Rock Harbor Model Output: BOD Profile



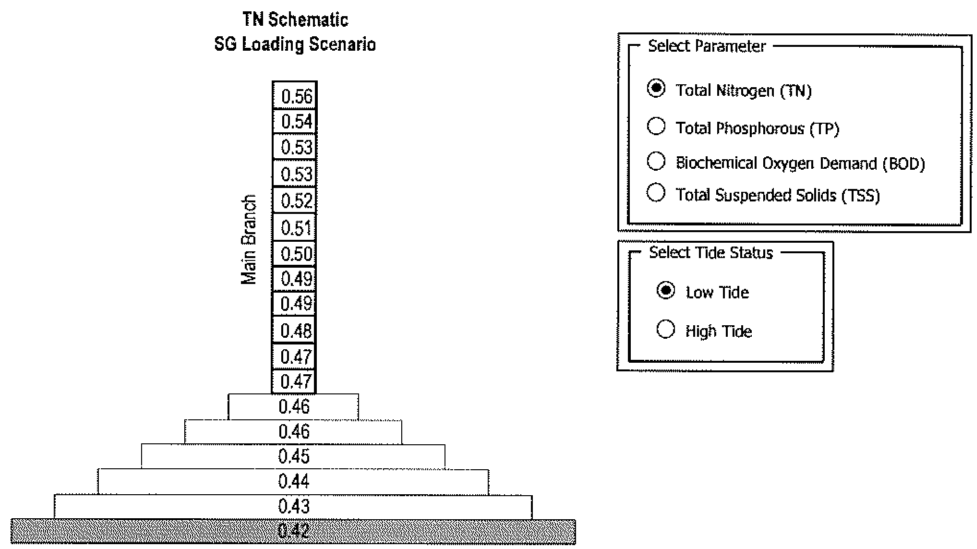
Canal #69, Rock Harbor Model Output, TSS, low tide



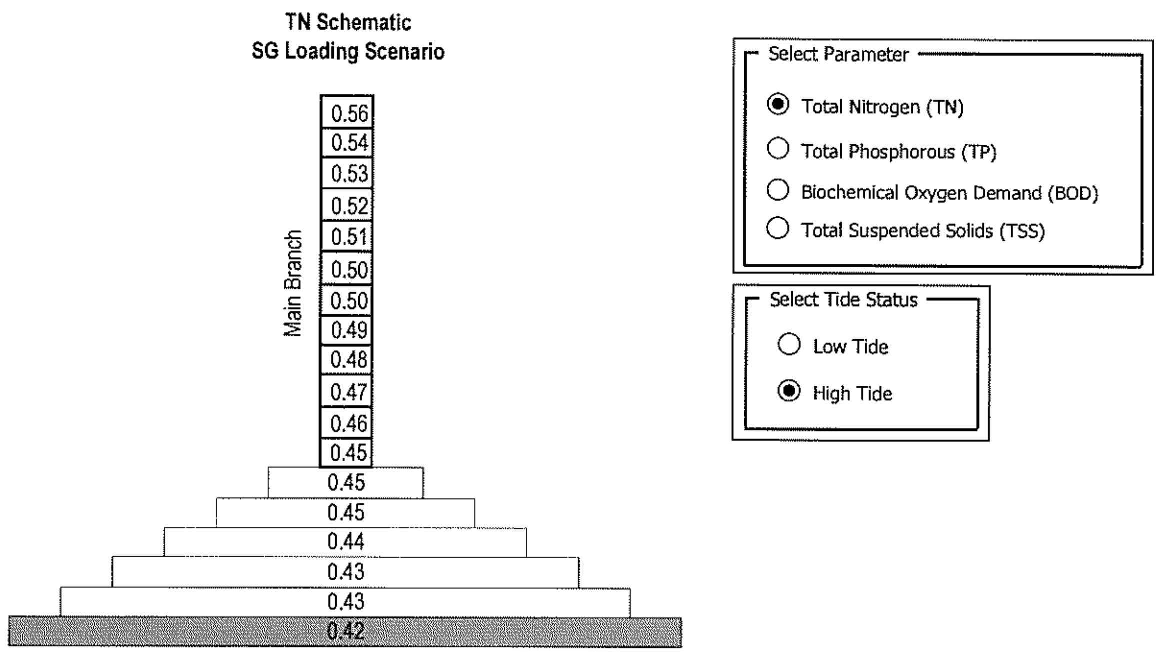
Canal #69, Rock Harbor Model Output, TSS, high tide



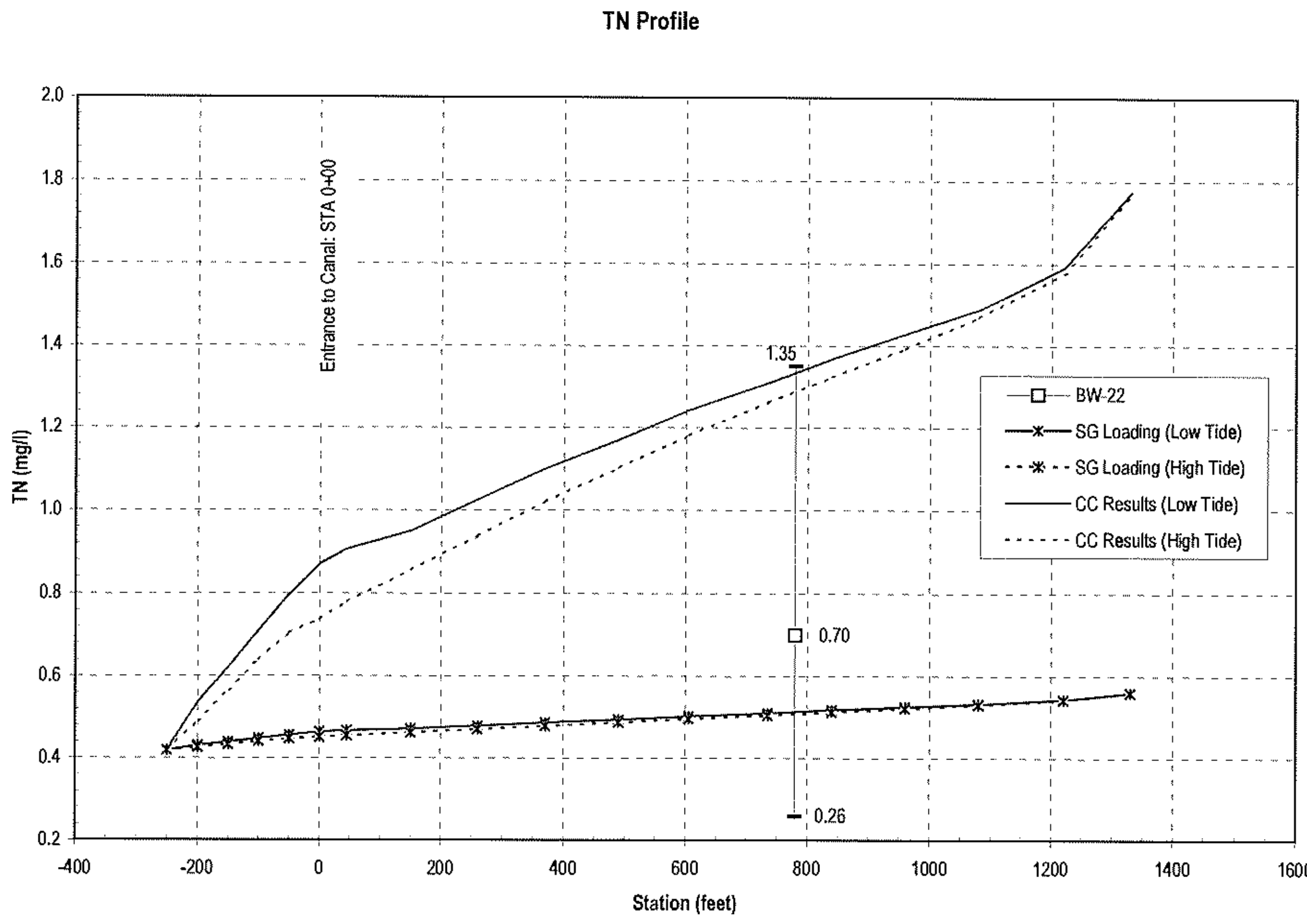
Canal #69, Rock Harbor Model Output, TSS Profile



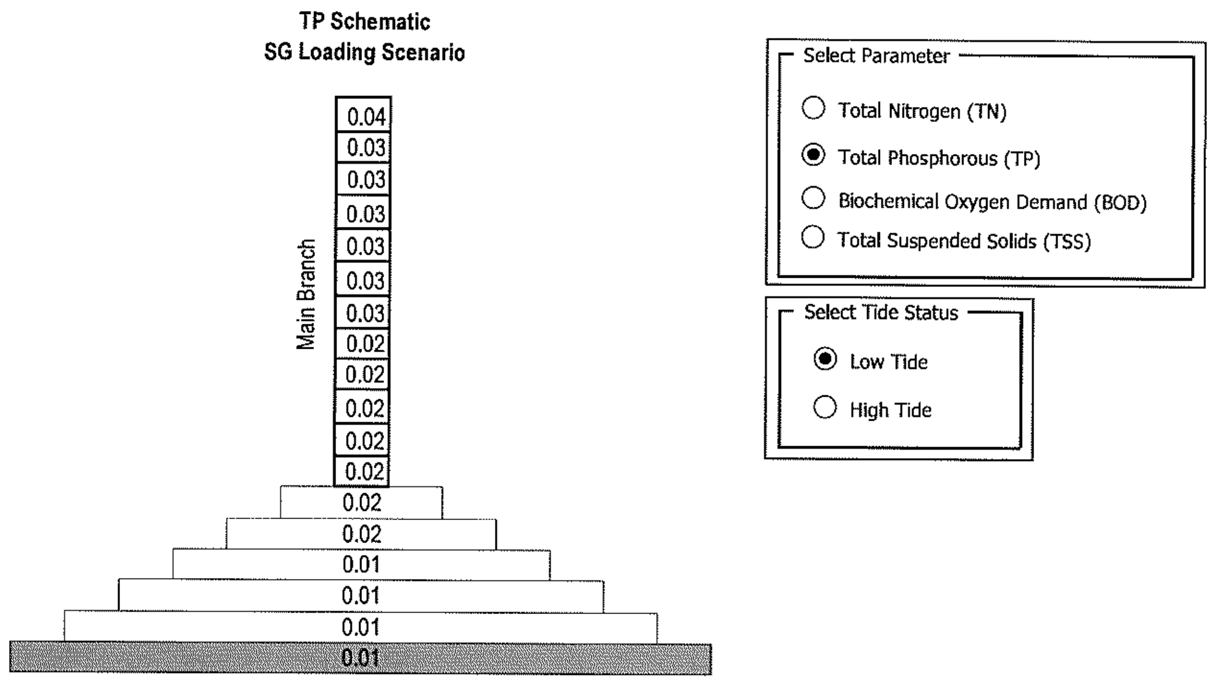
Canal #70, Rock Harbor Model Output: TN, low tide



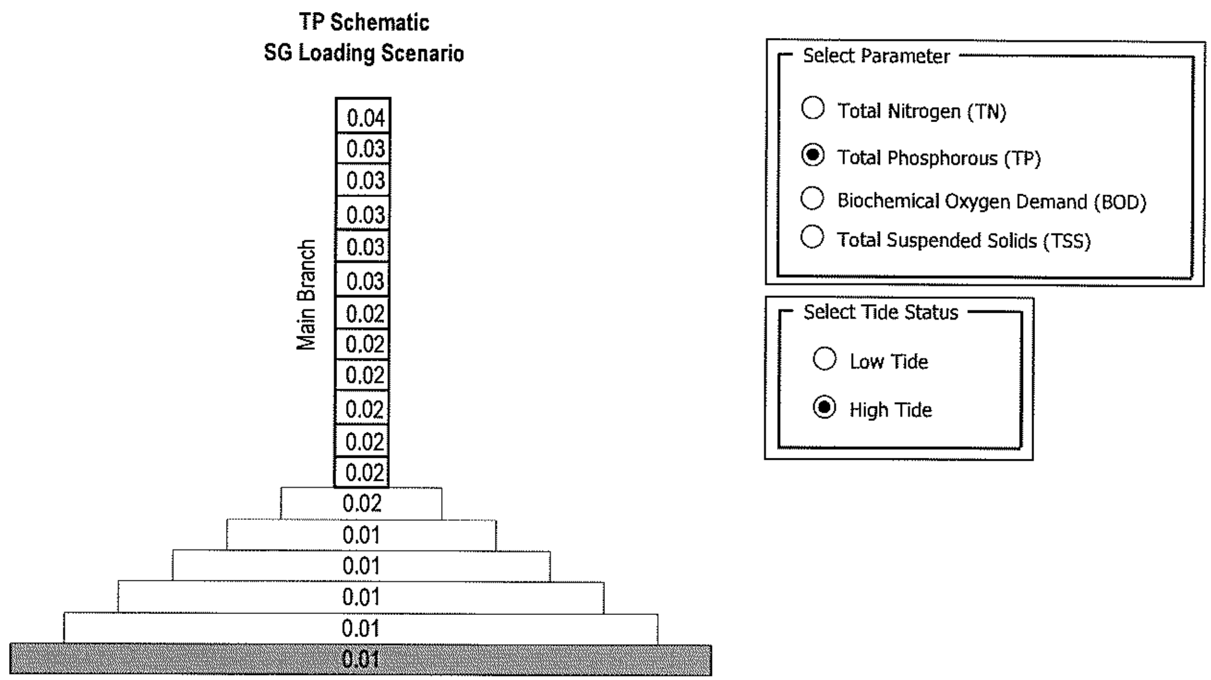
Canal #70, Rock Harbor Model Output: TN, high tide



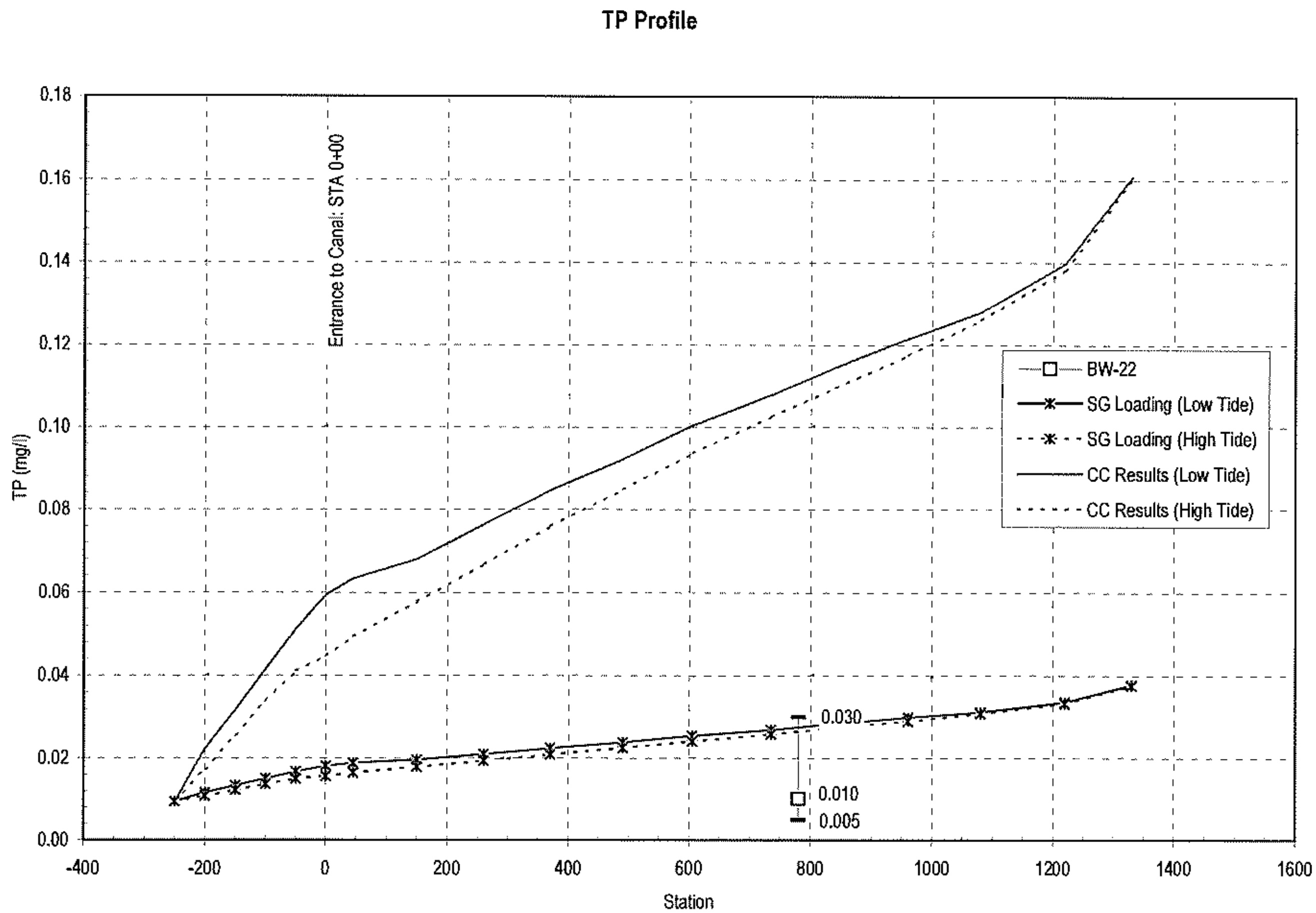
Canal #70, Rock Harbor Model Output: TN Profile



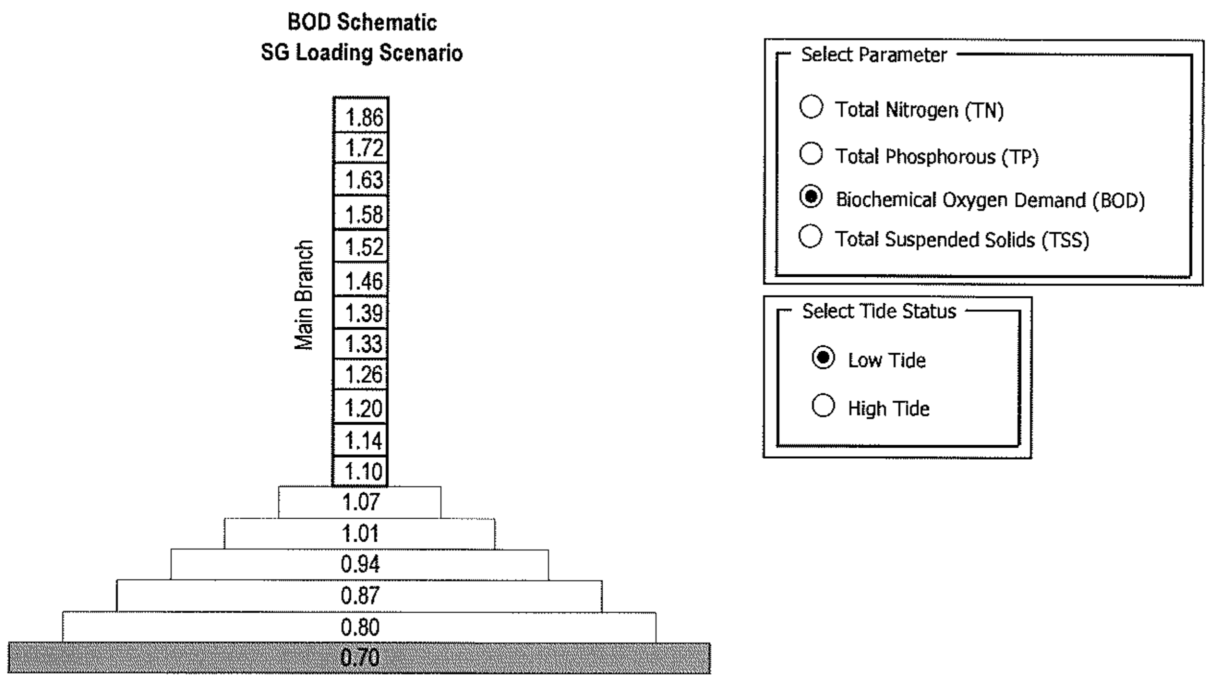
Canal #70, Harbor Rock Model Output: TN, low tide



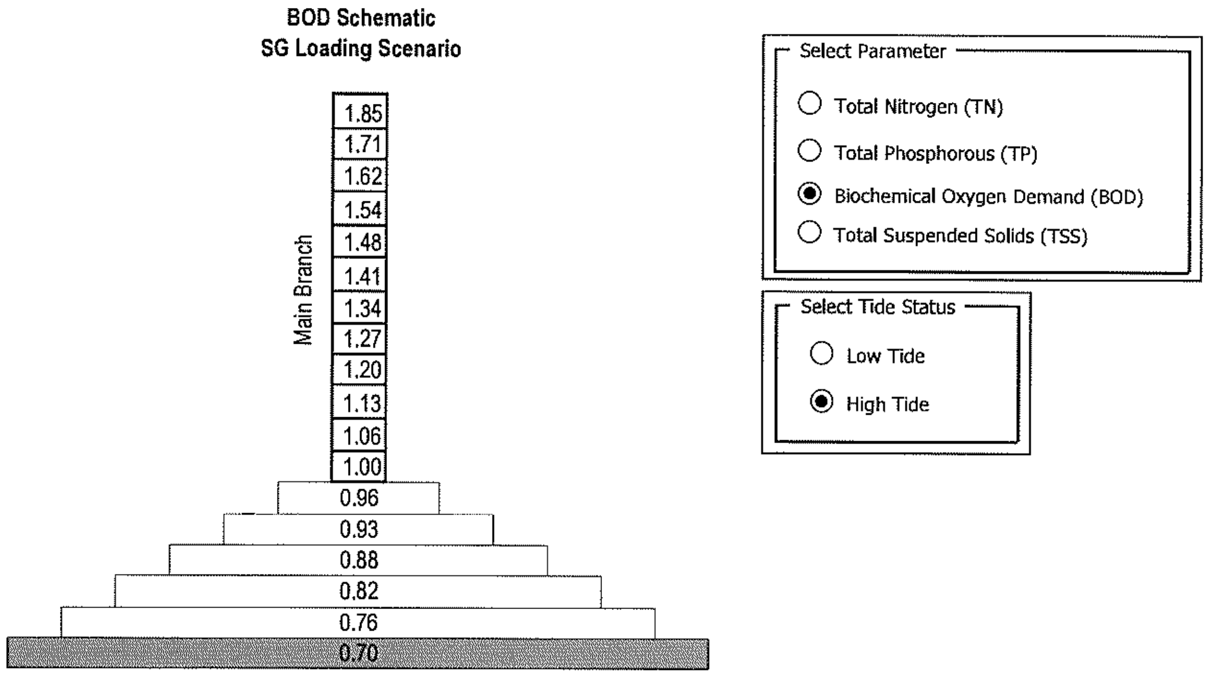
Canal #70, Rock Harbor Model Output: TP, high tide



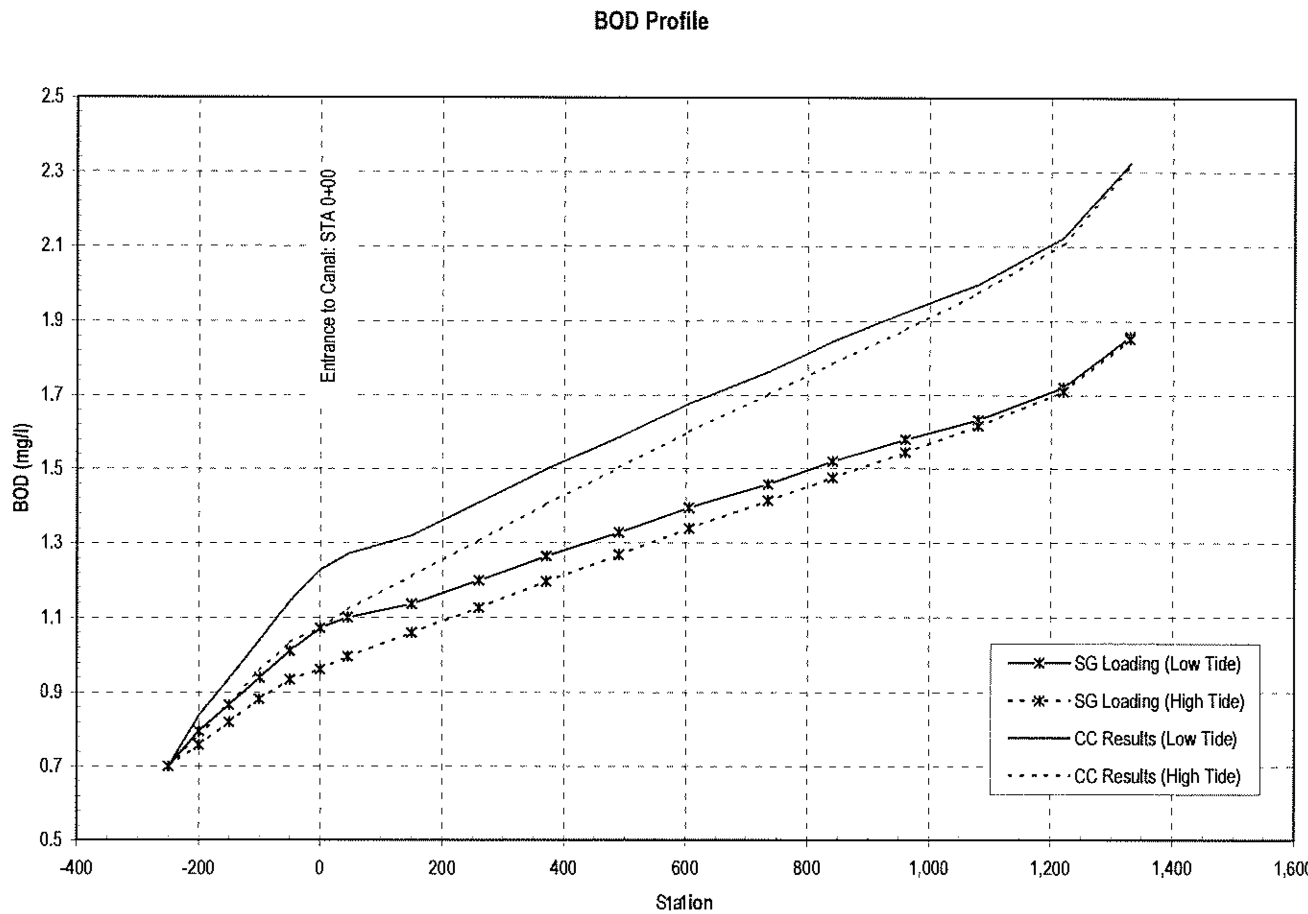
Canal #70, Rock Harbor Model Output: TP Profile



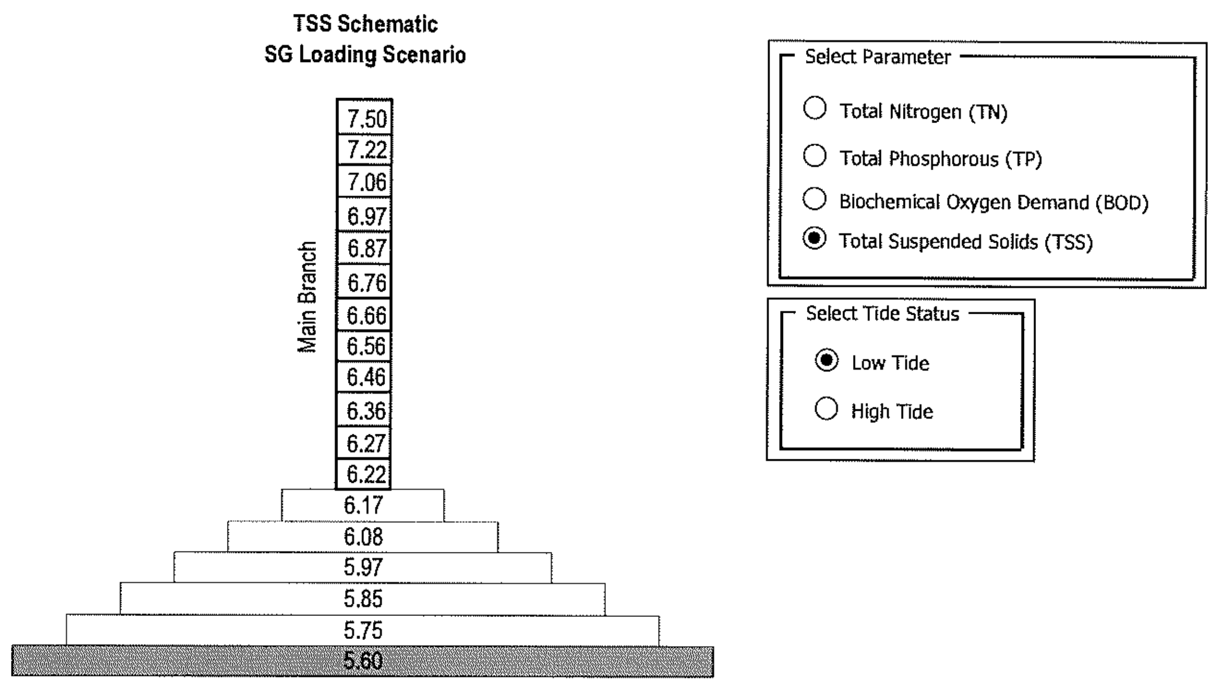
Canal #70, Rock Harbor Model Output: BOD, low tide



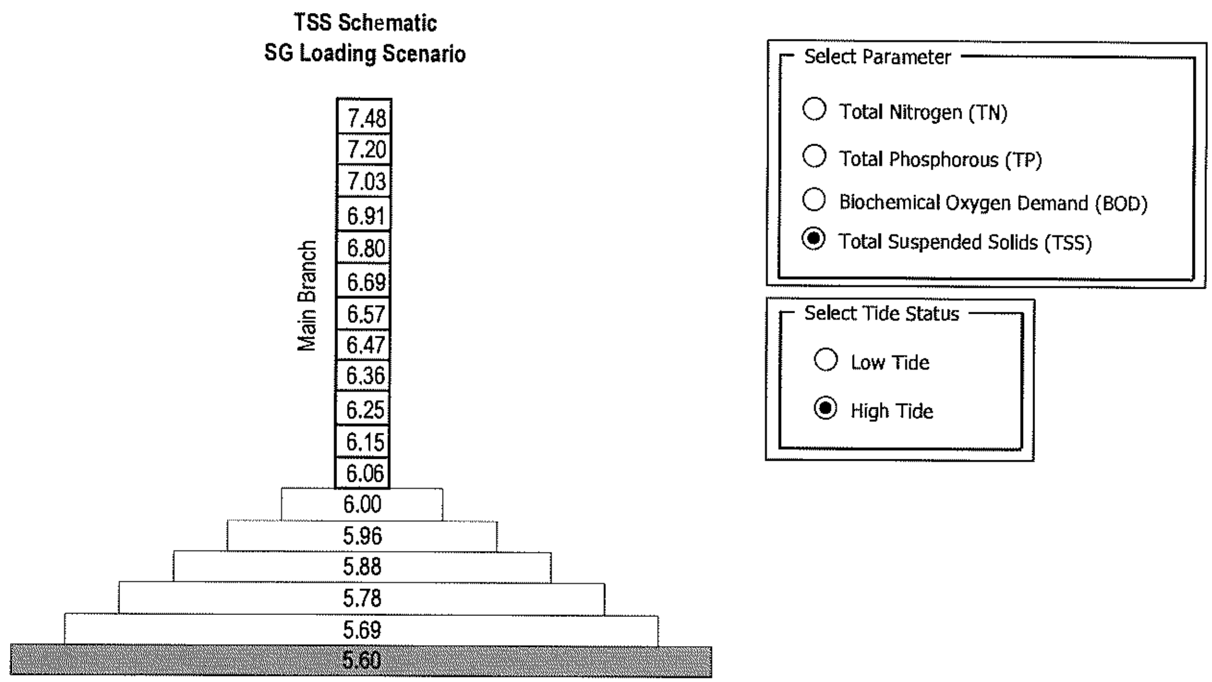
Canal #70, Rock Harbor Model Output: BOD, high tide



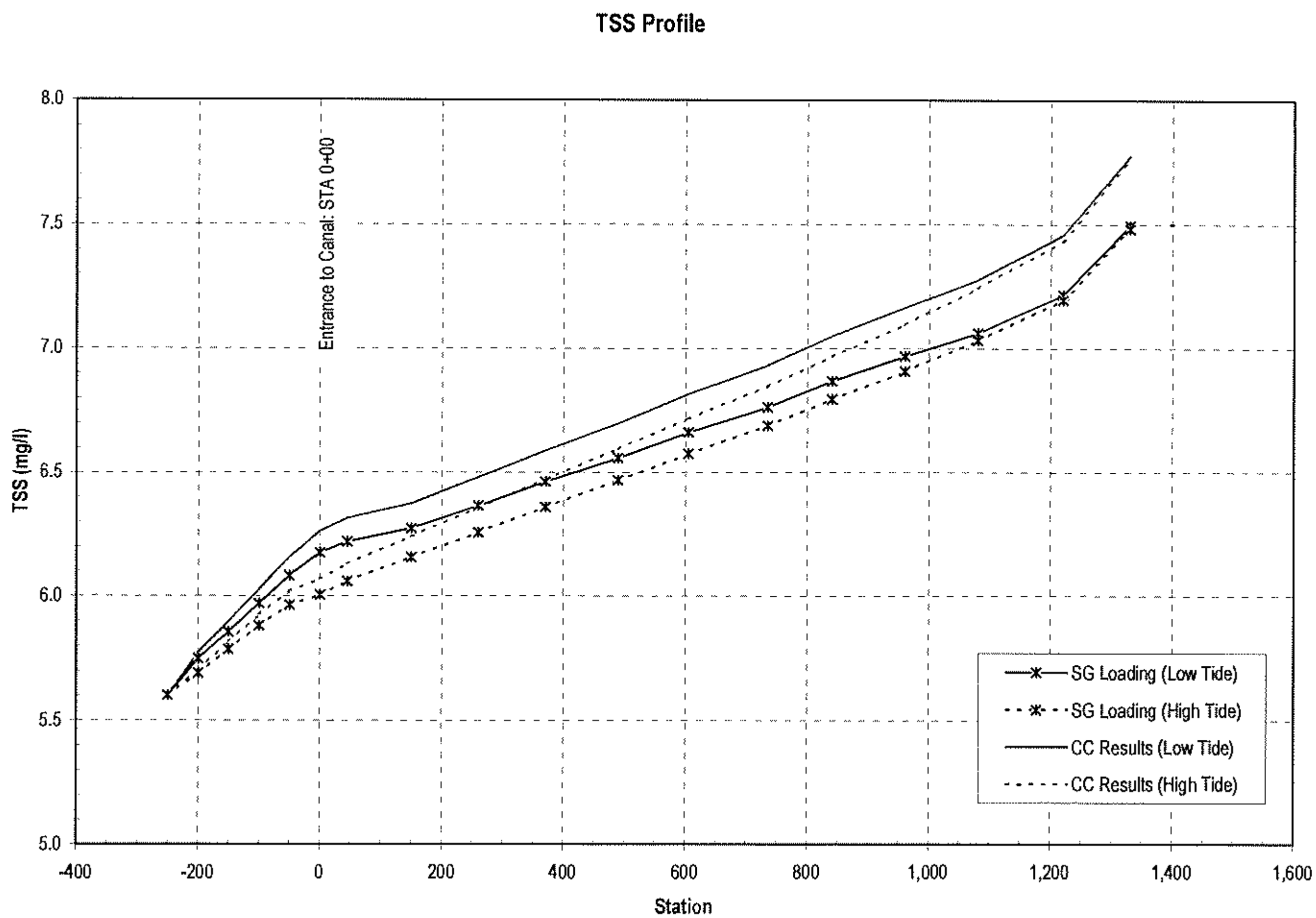
Canal #70, Rock Harbor Model Output: BOD Profile



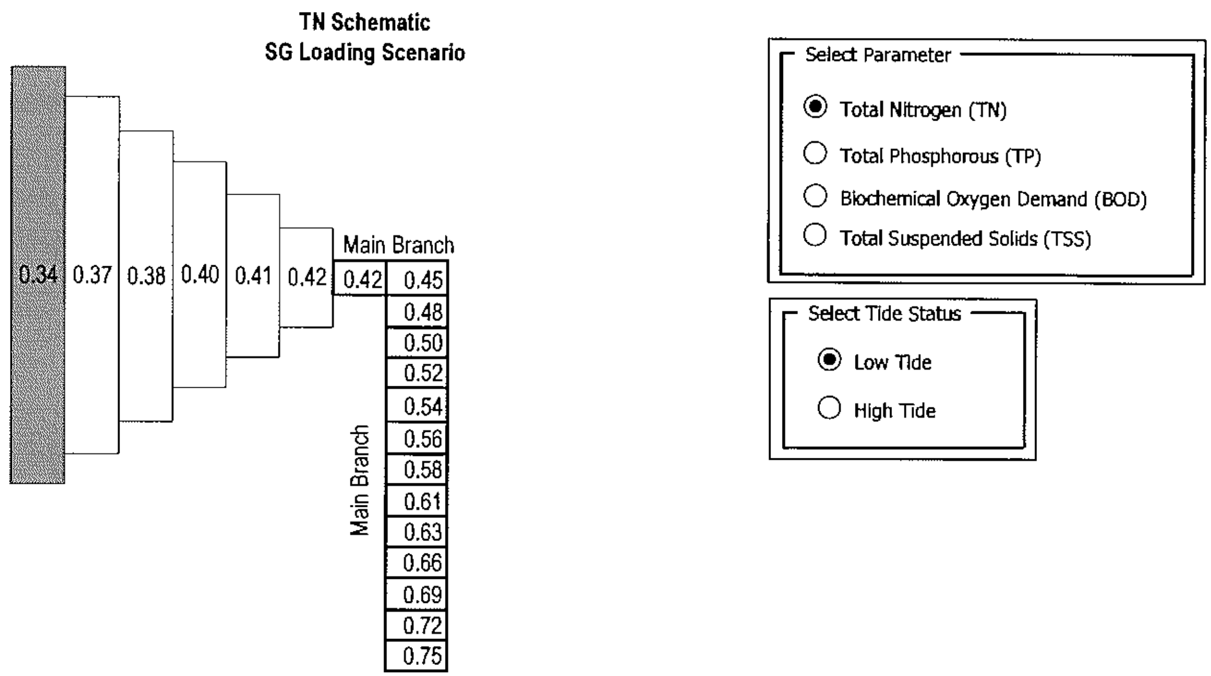
Canal #70, Rock Harbor Model Output: TSS, low tide



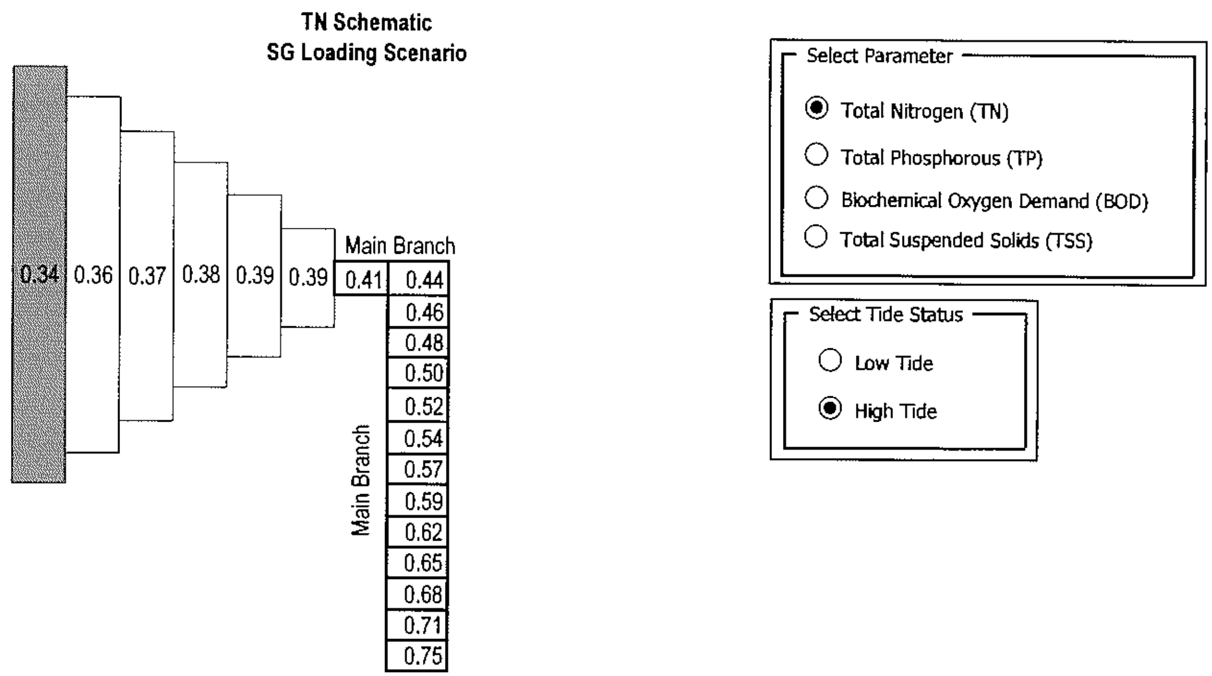
Canal #70, Rock Harbor Model Output: TSS, high tide



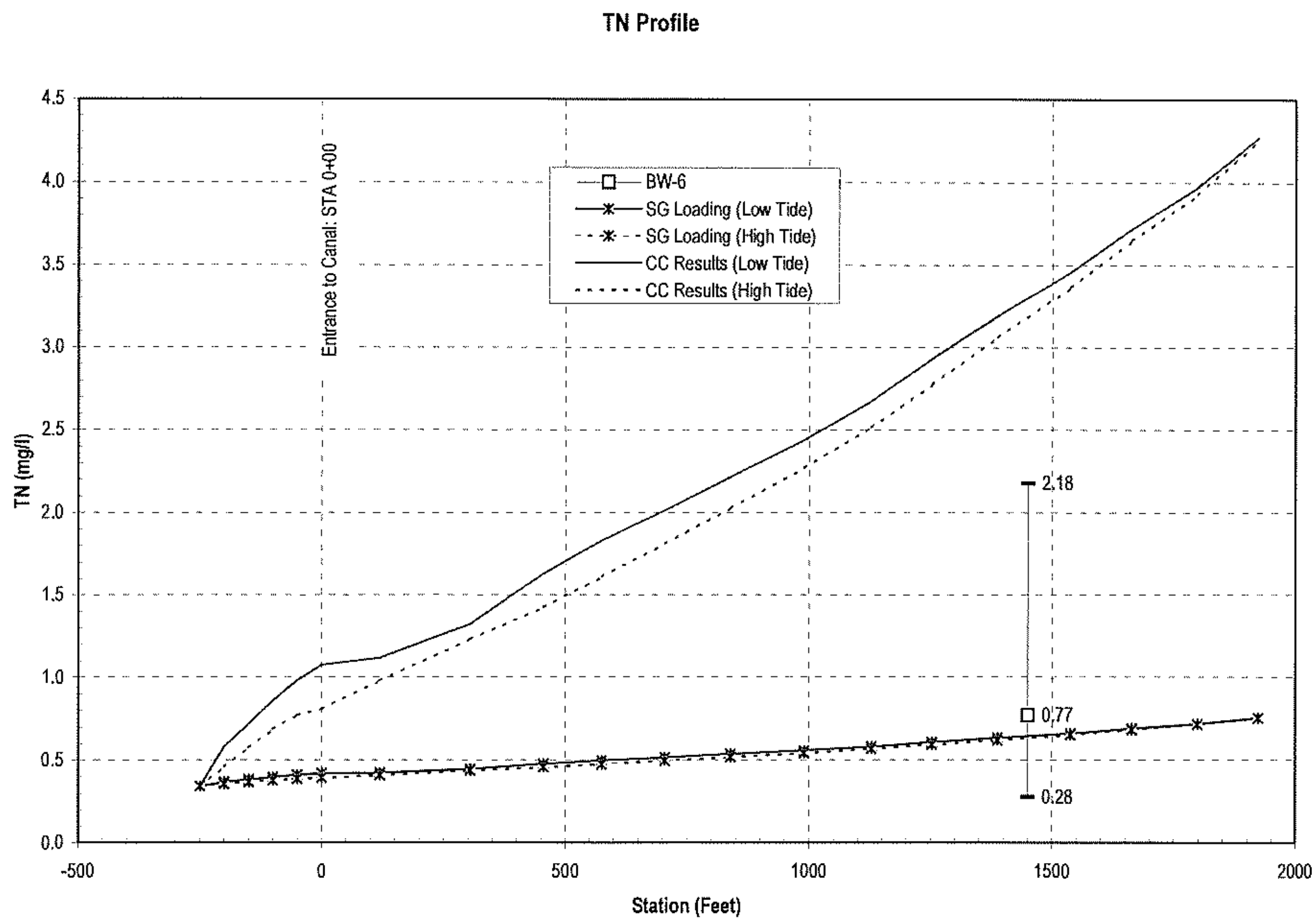
Canal #70, Rock Harbor Model Output, TSS Profile



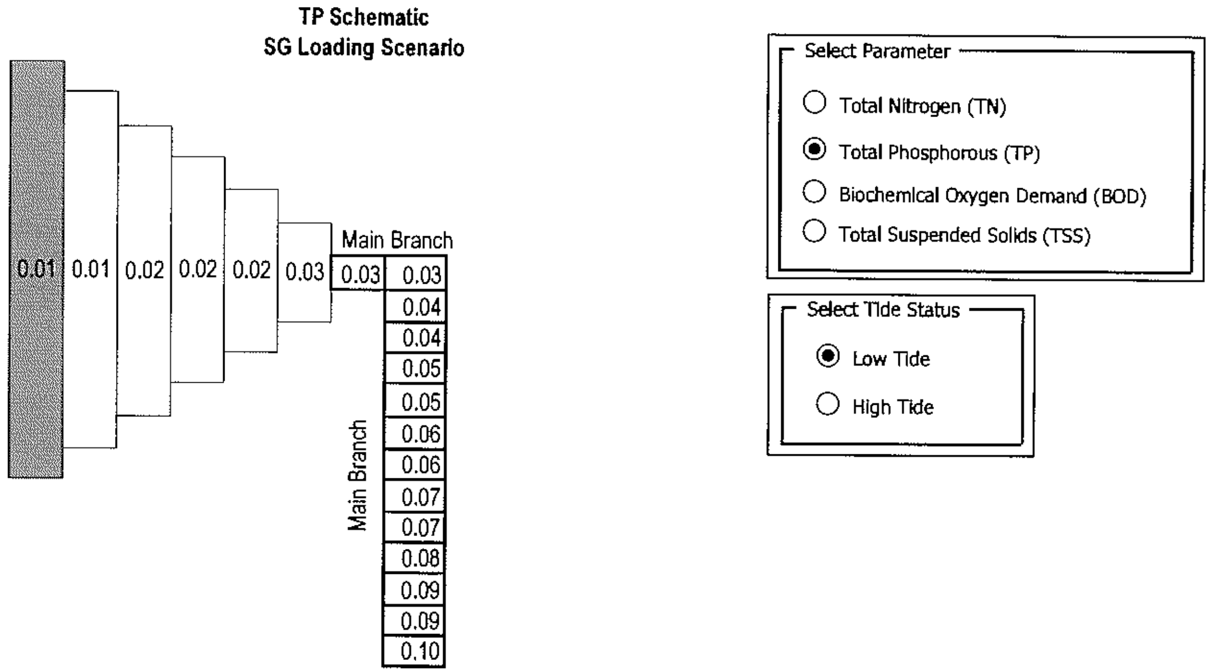
Canal #117 Plantation Model Output: TN, low tide



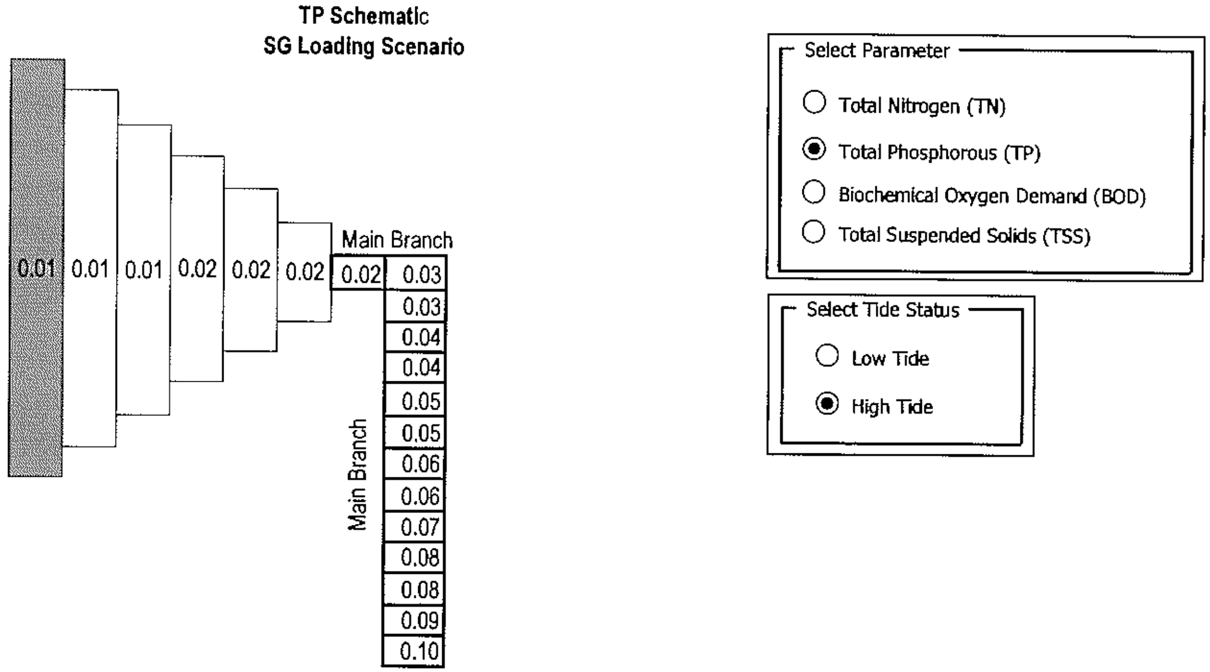
Canal #117, Plantation Model Output: TN, high tide



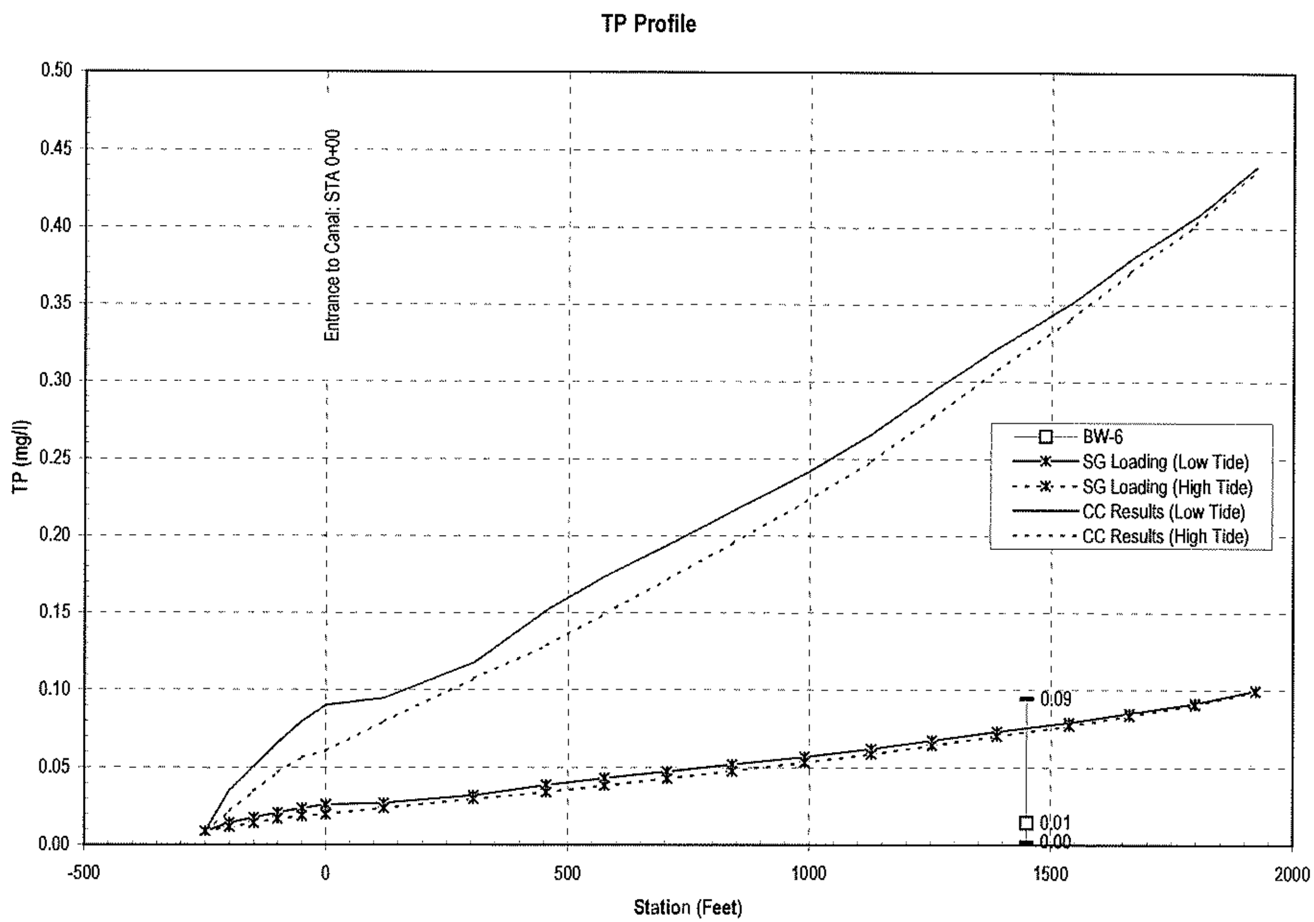
Canal #117, Plantation Model Output: TN Profile



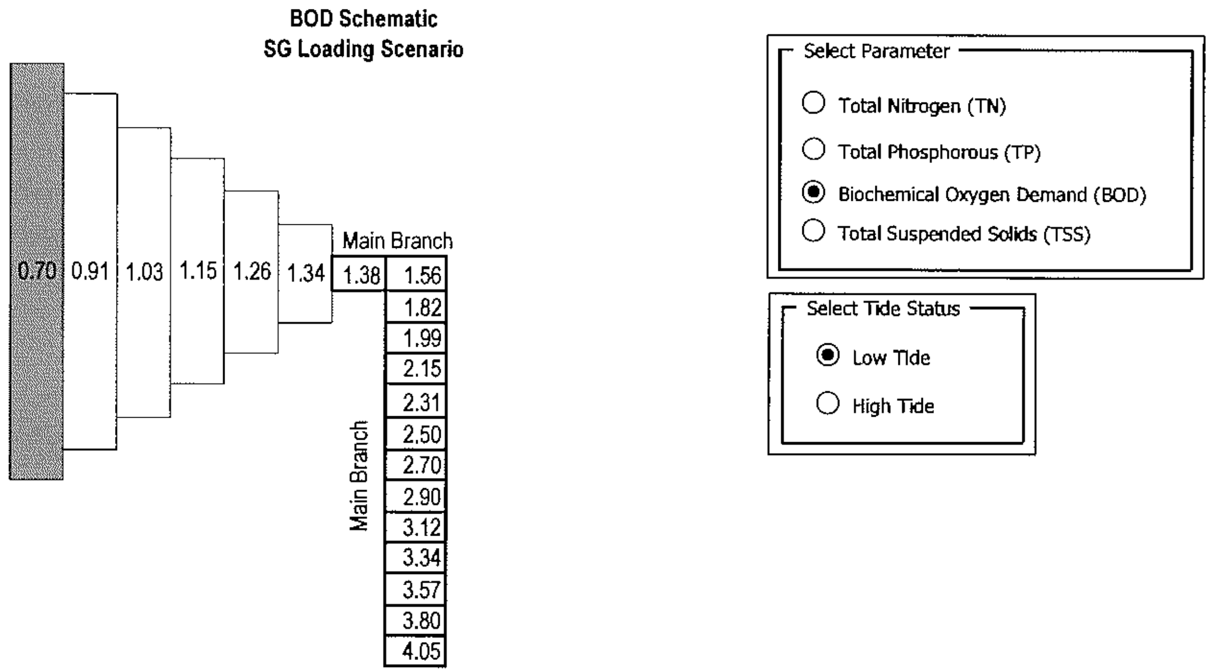
Canal #117, Plantation Model Output: TP, low tide



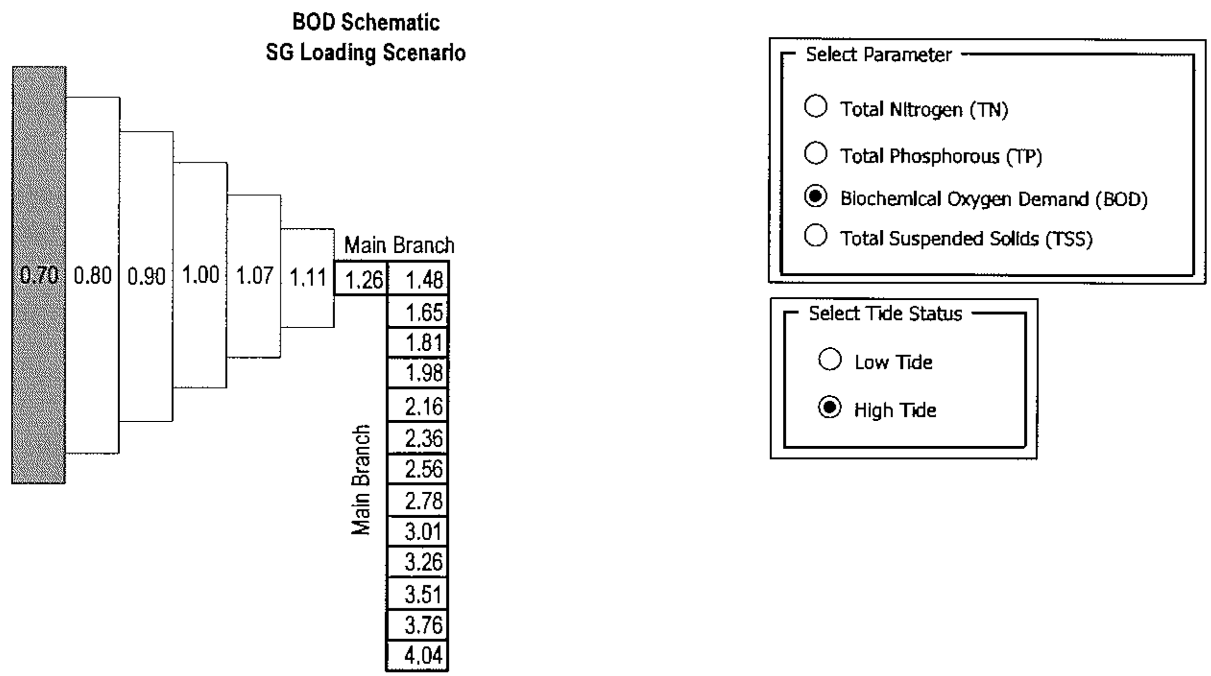
Canal #117 Plantation Model Output: TP, high tide



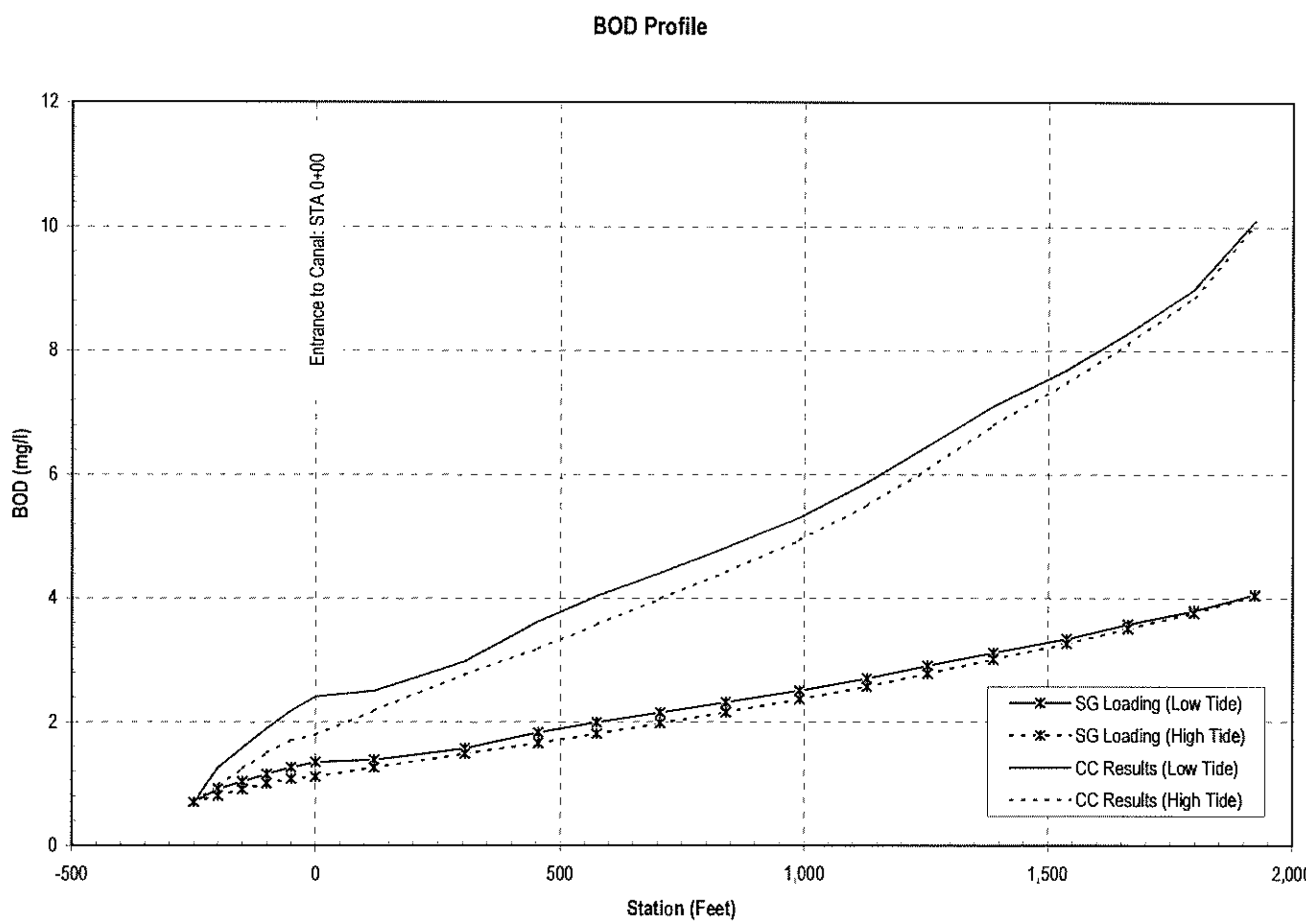
Canal #117, Plantation Model Output: TP Profile



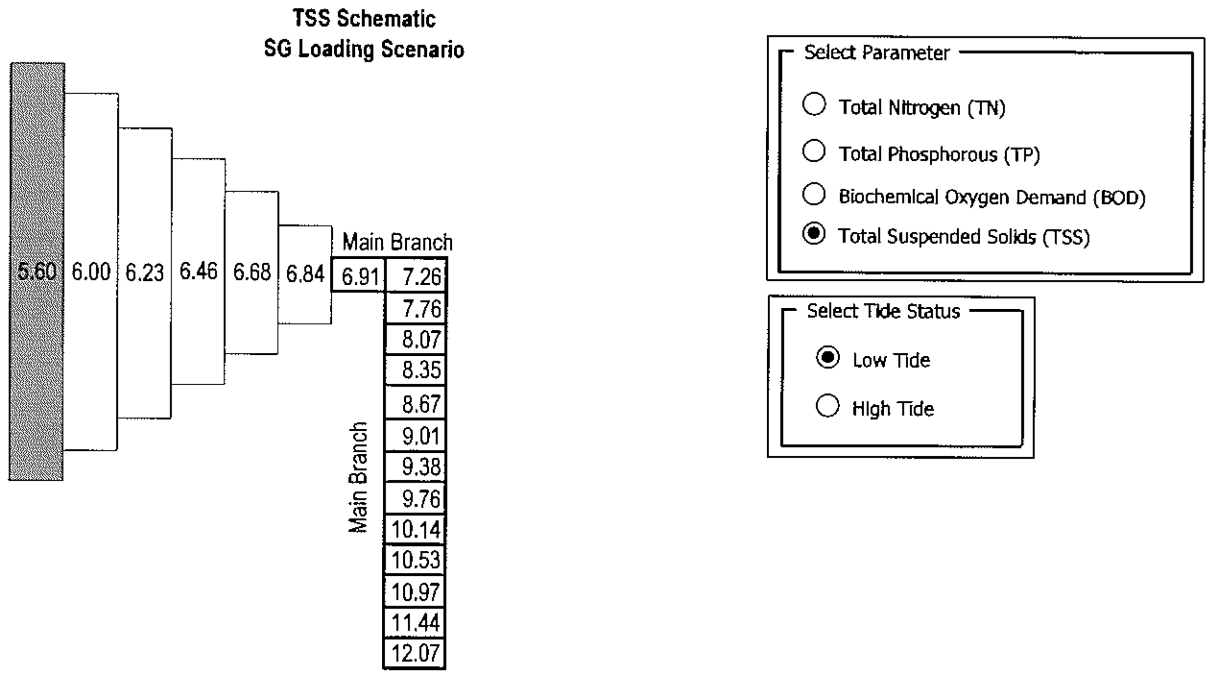
Canal #117, Plantation Model Output: BOD, low tide



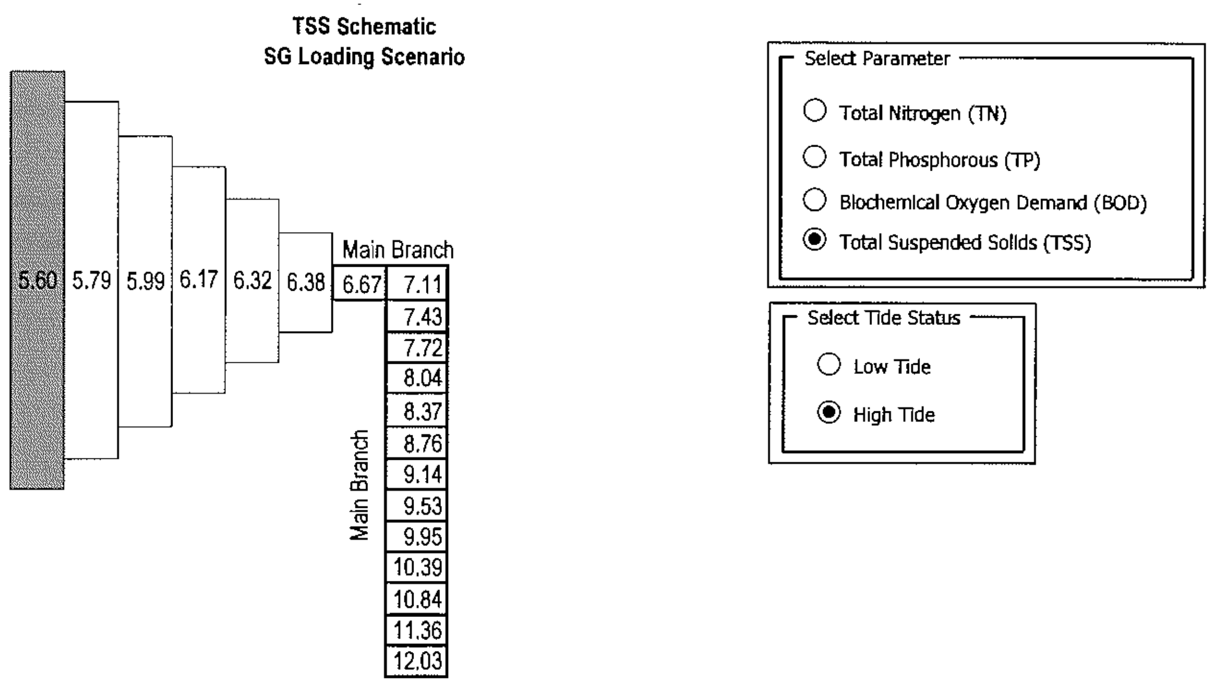
Canal #117, Plantation Model Output: BOD, high tide



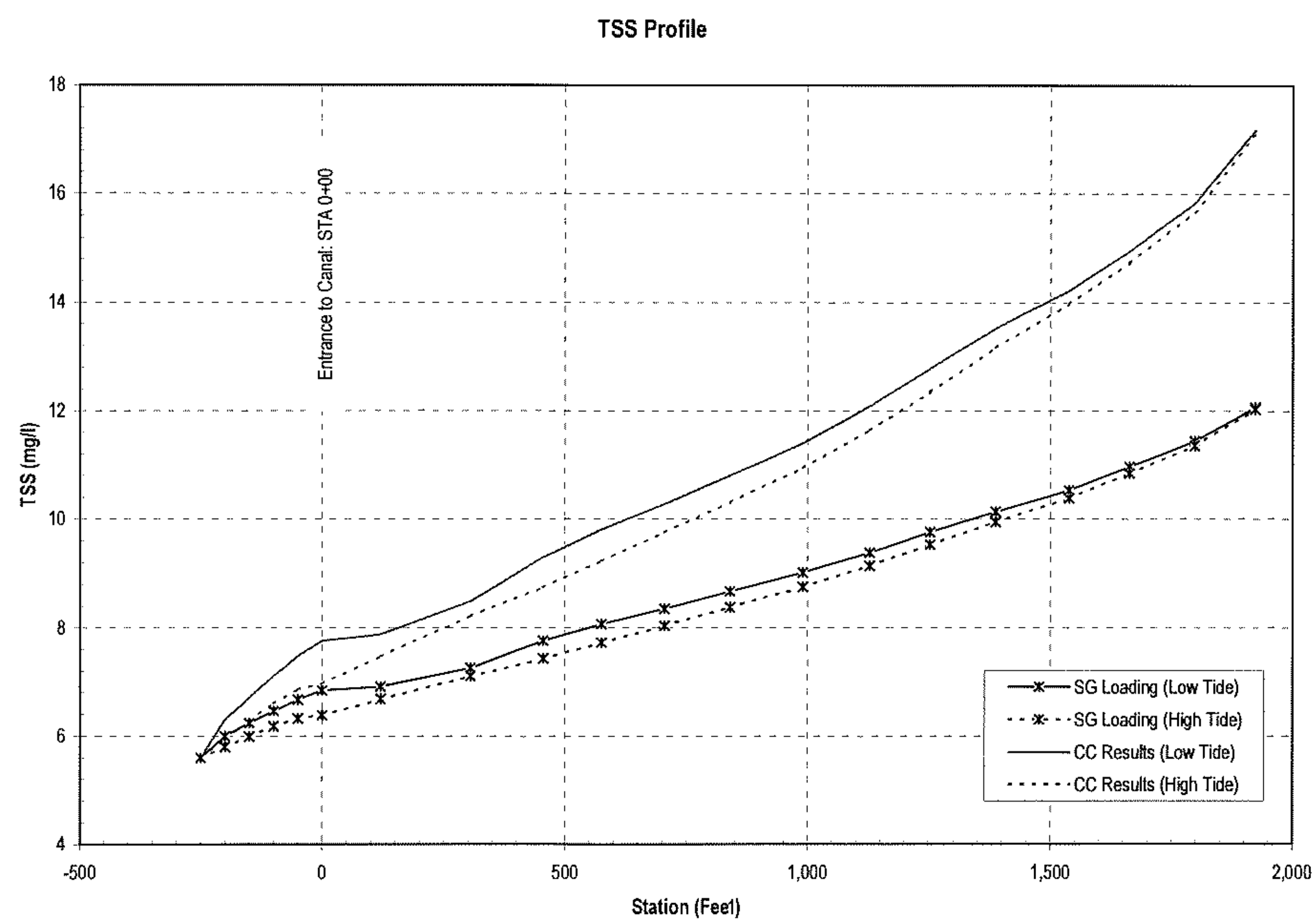
Canal #117, Plantation Model Output: BOD Profile



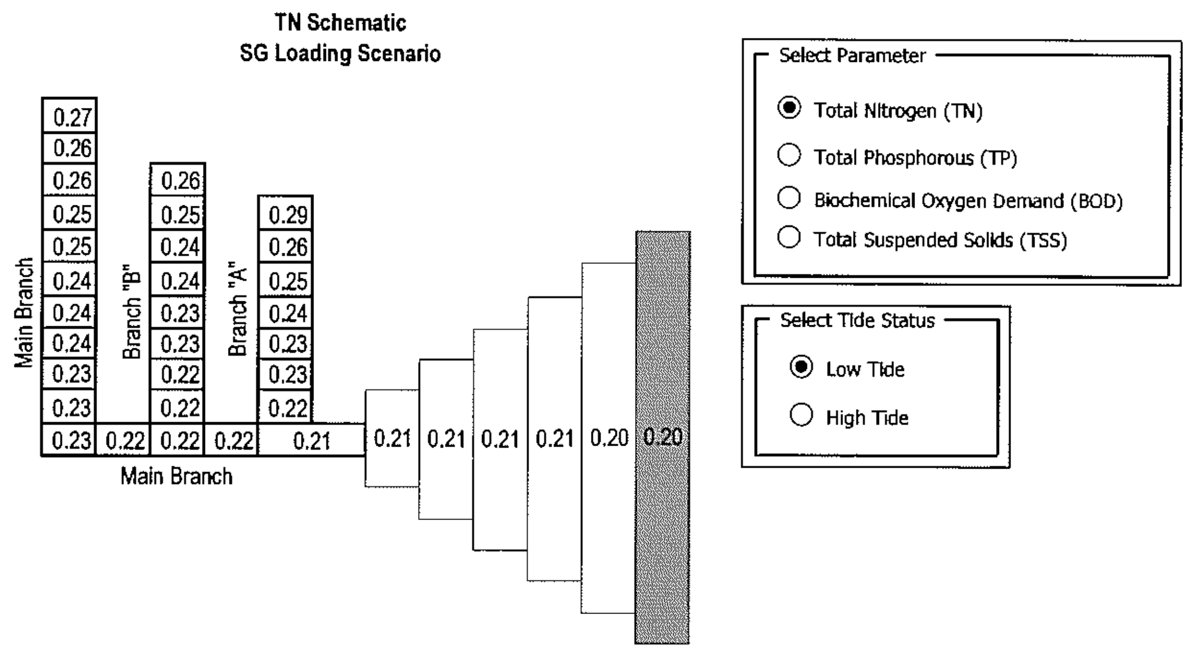
Canal #70, Plantation Model Output: TSS, low tide



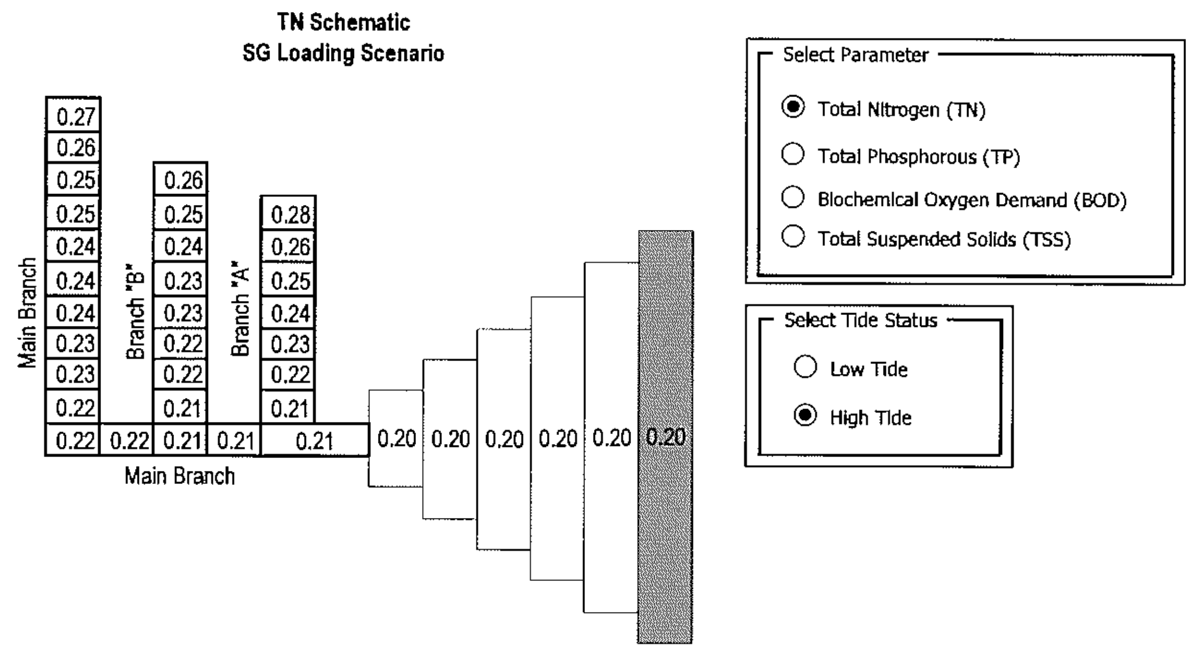
Canal #117, Plantation Model Output: TSS, high tide



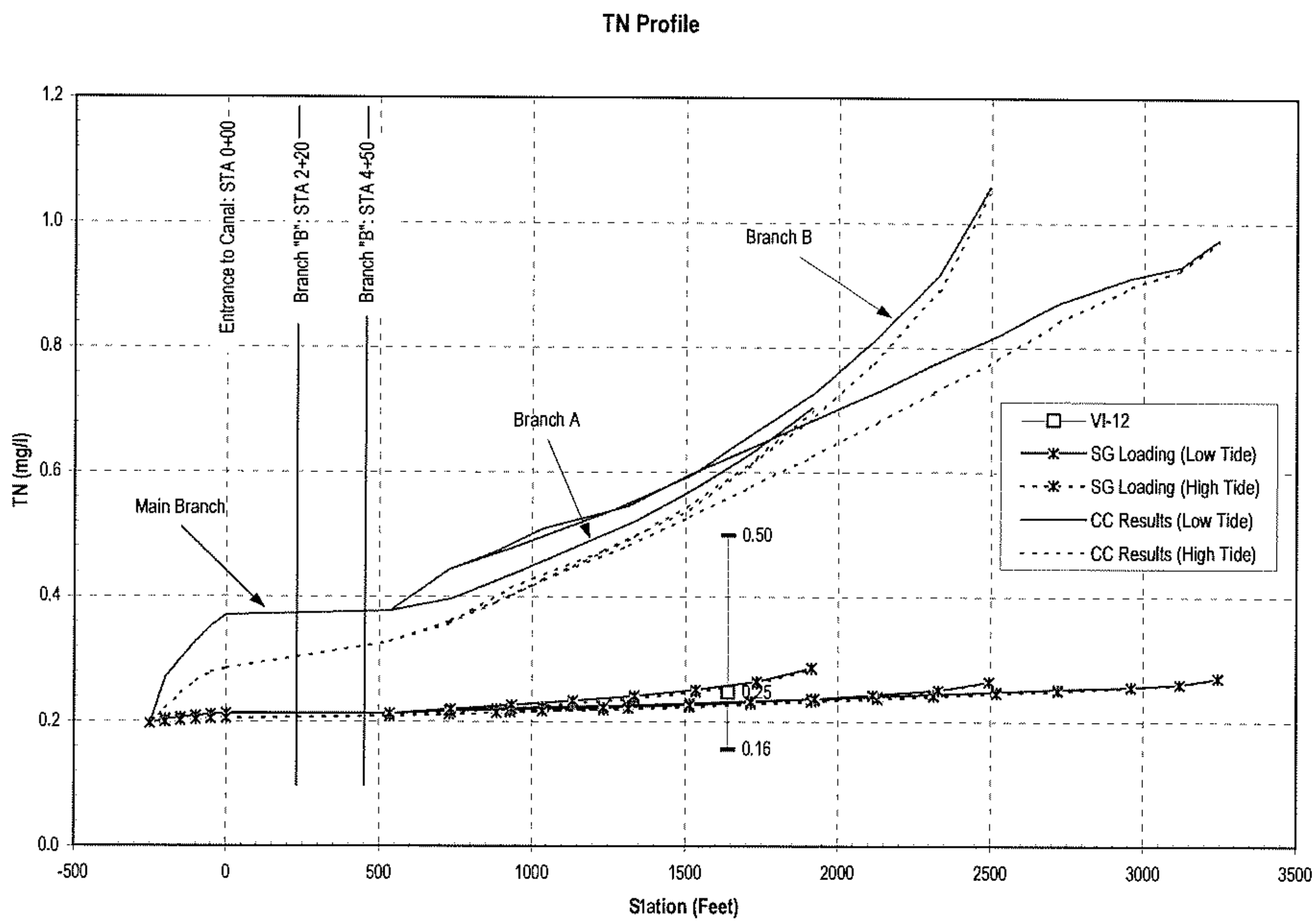
Canal #117, Plantation Model Output: TSS Profile



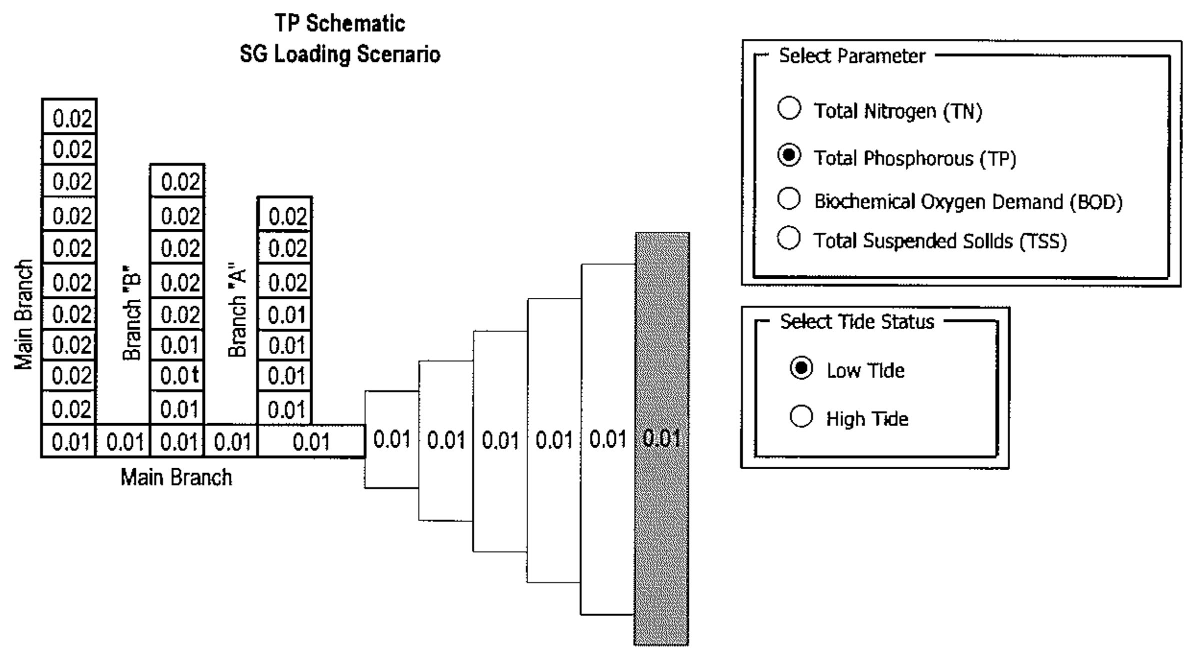
Canal #152, Lower Matecumbe Model Output, TN, low tide



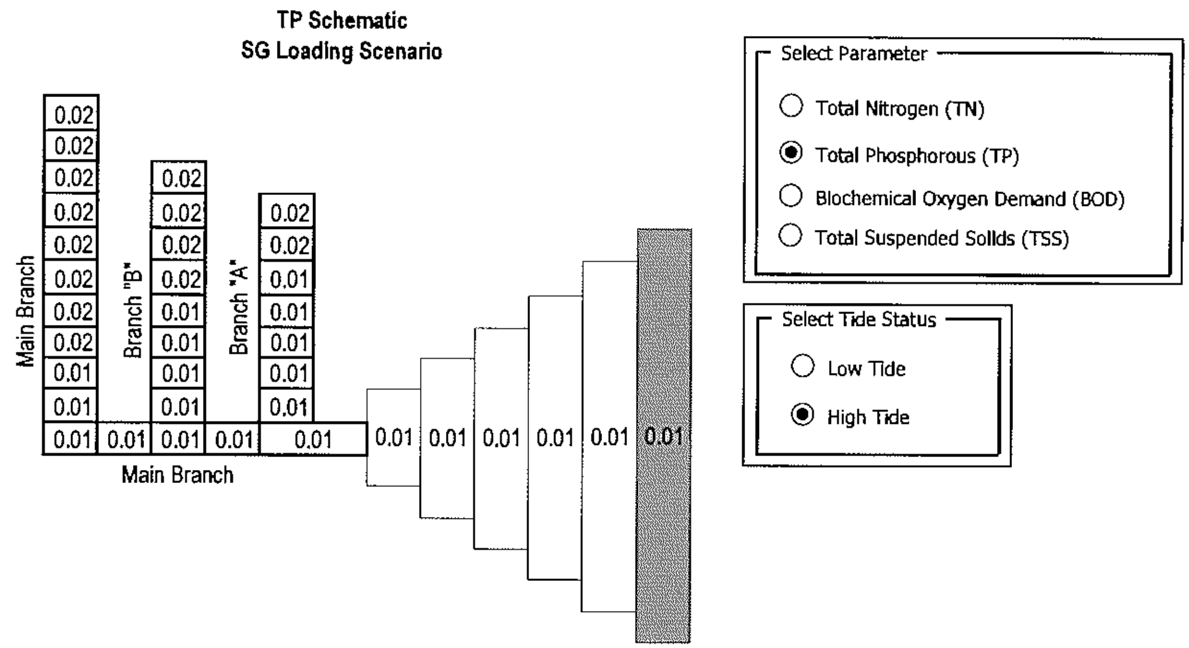
Canal #152, Lower Matecumbe Model Output: TN, high tide



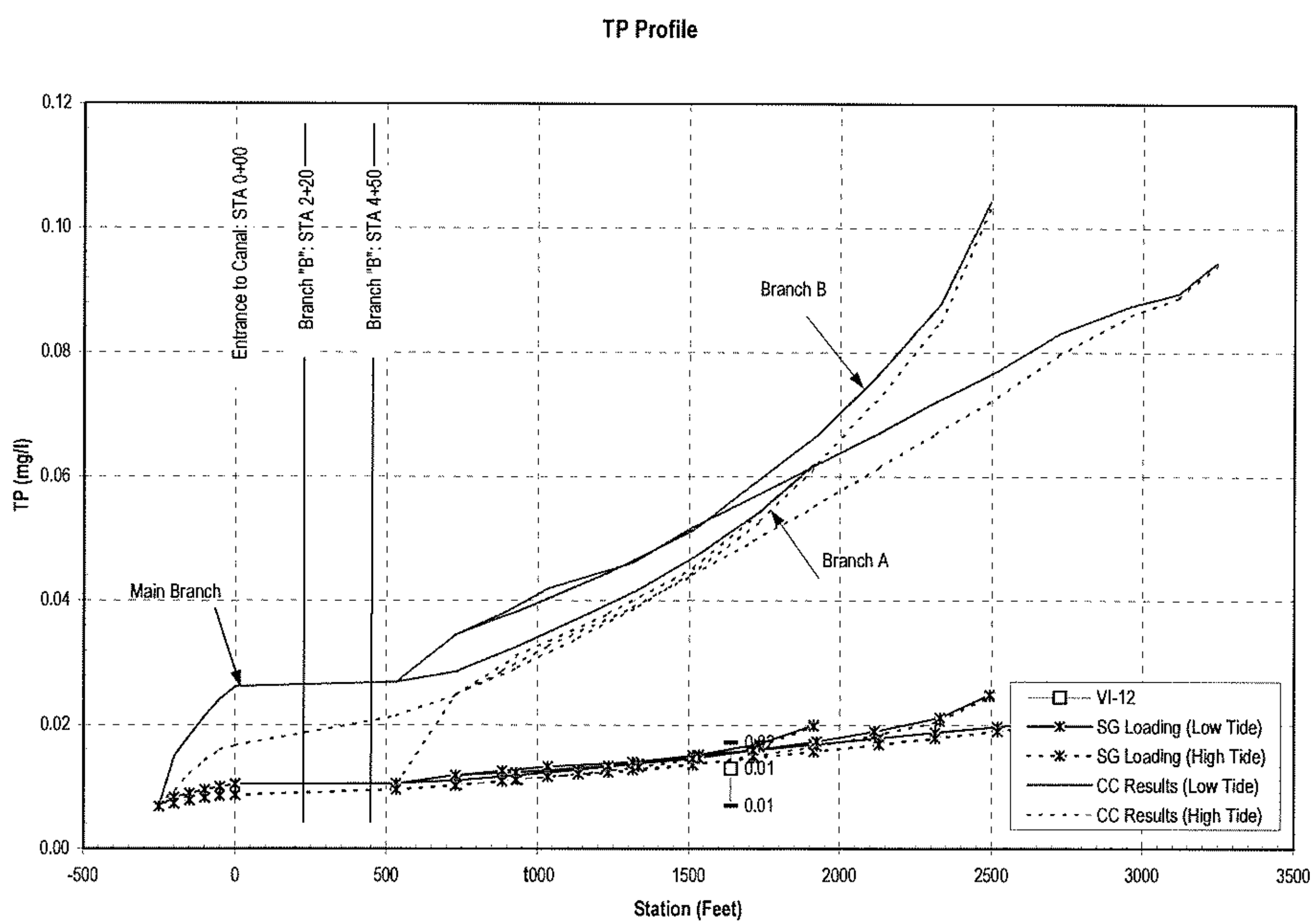
Canal #152, Matecumbe Model Output: TN Profile



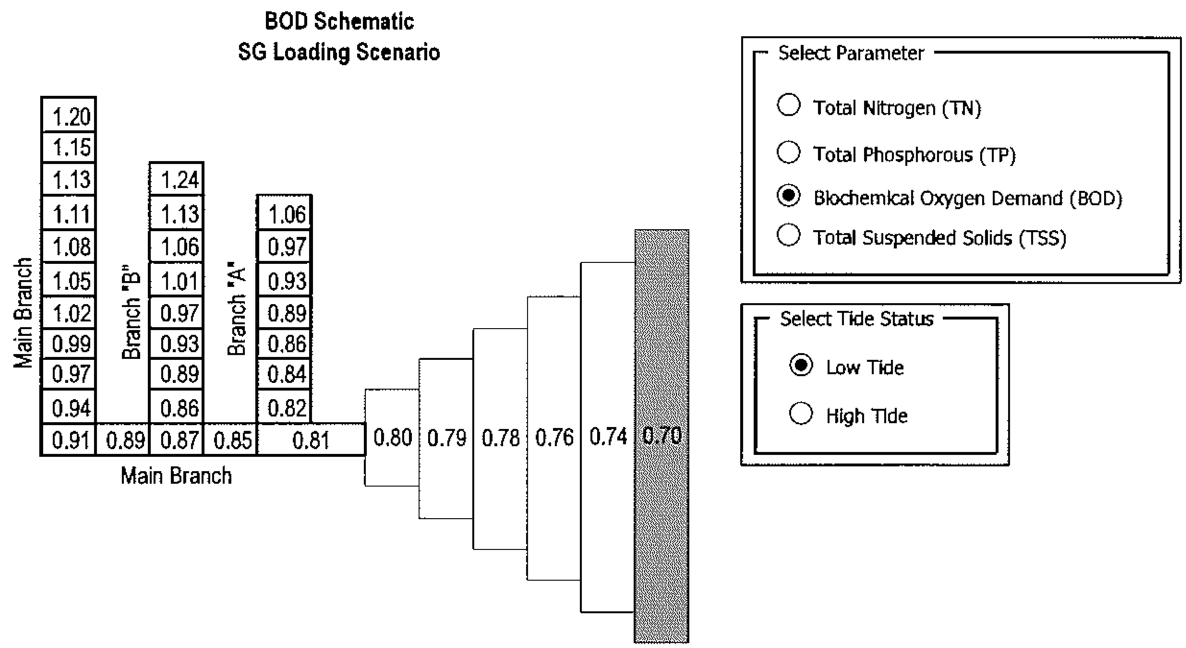
Canal #152, Lower Matecumbe Model Output: TP, low tide



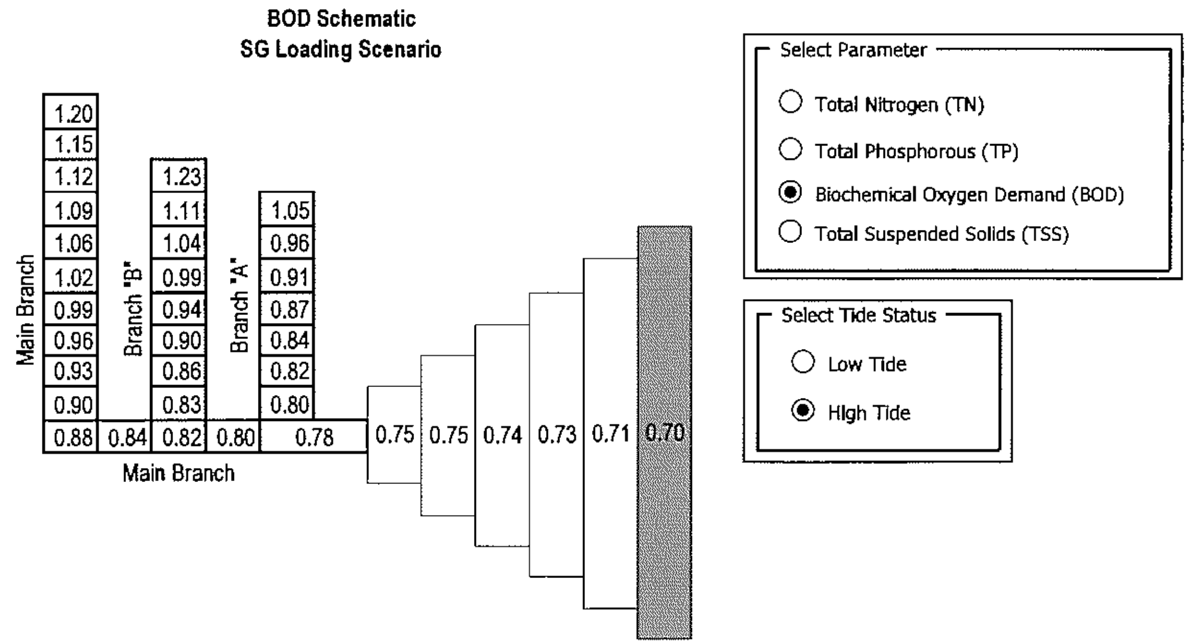
Canal #152, Lower Matecumbe Model Output: TP, high tide



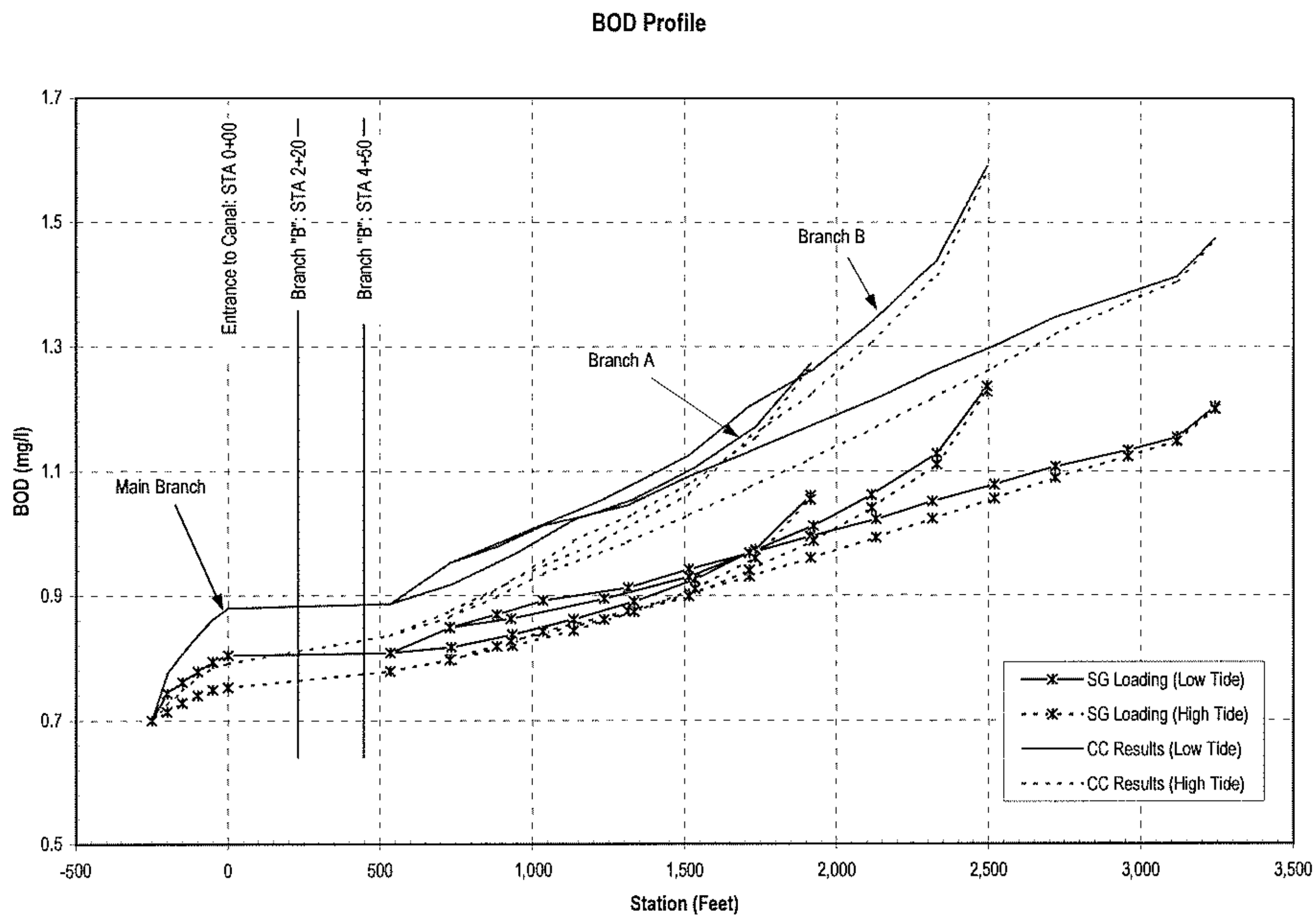
Canal #152, Lower Matecumbe Model Output: TP Profile



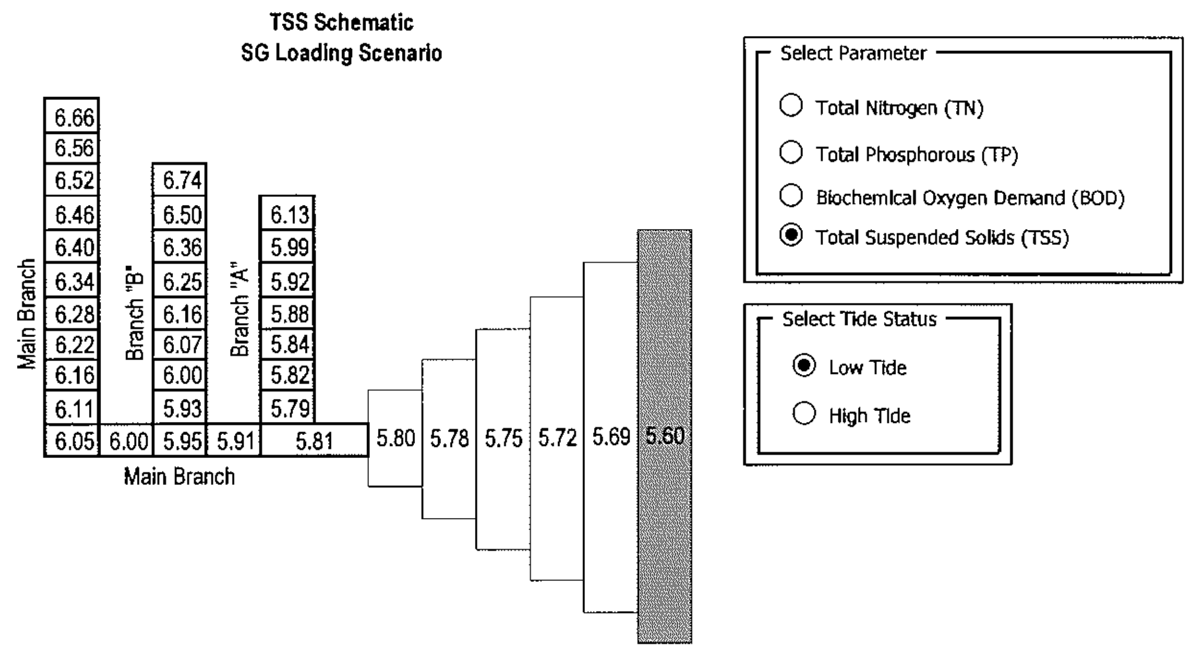
Canal #152, Lower Matecumbe Model Output: BOD, low tide



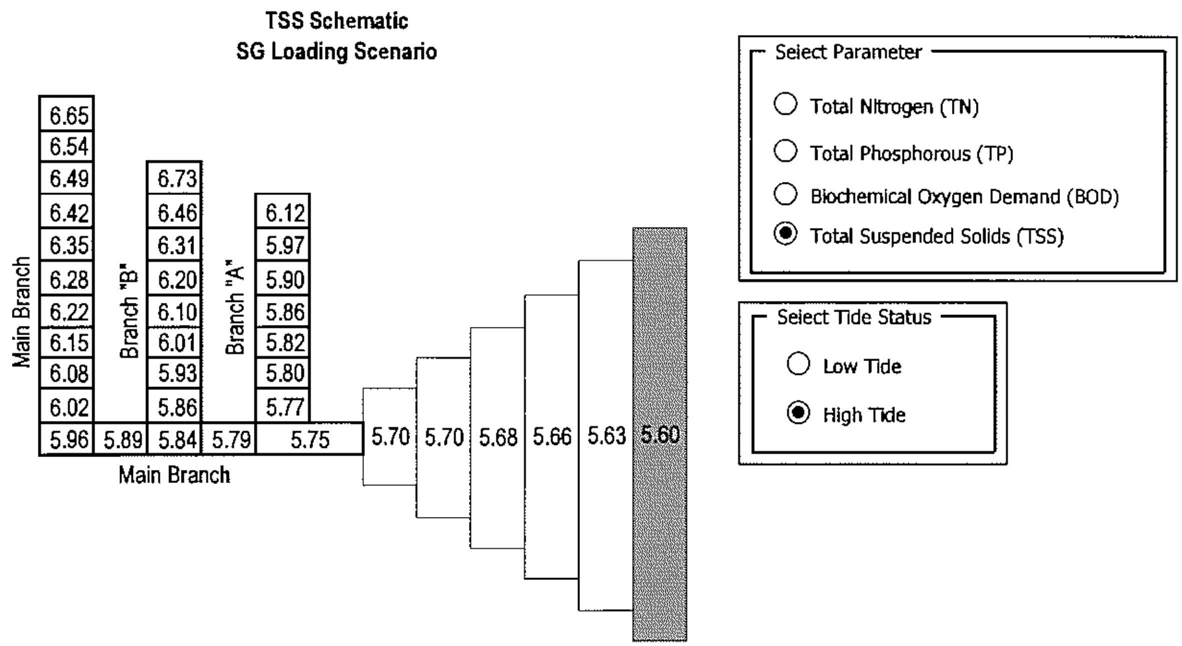
Canal #152, Lower Matecumbe Model Output: BOD, high tide



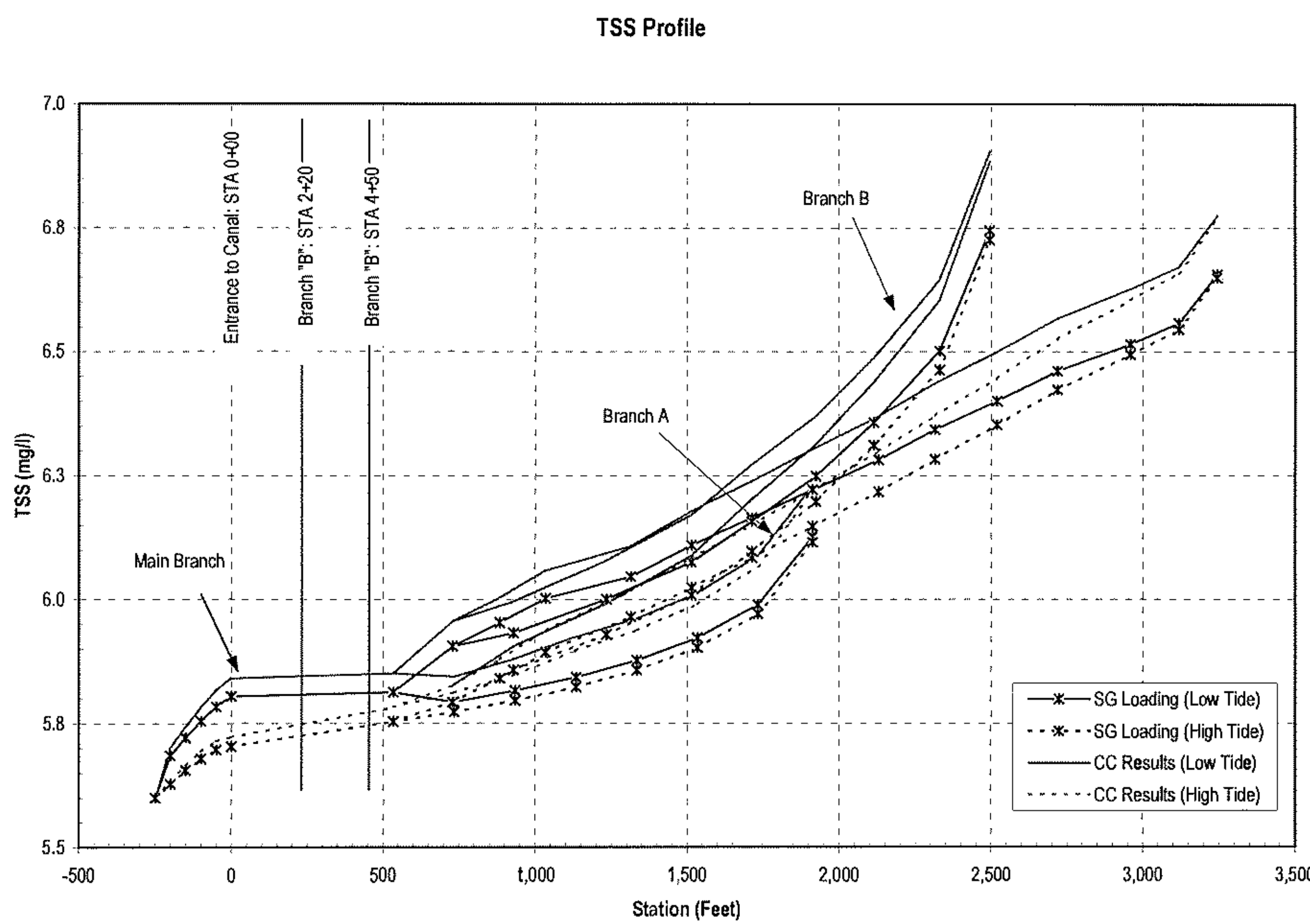
Canal #152, Lower Matecumbe Model Output: BOD Profile



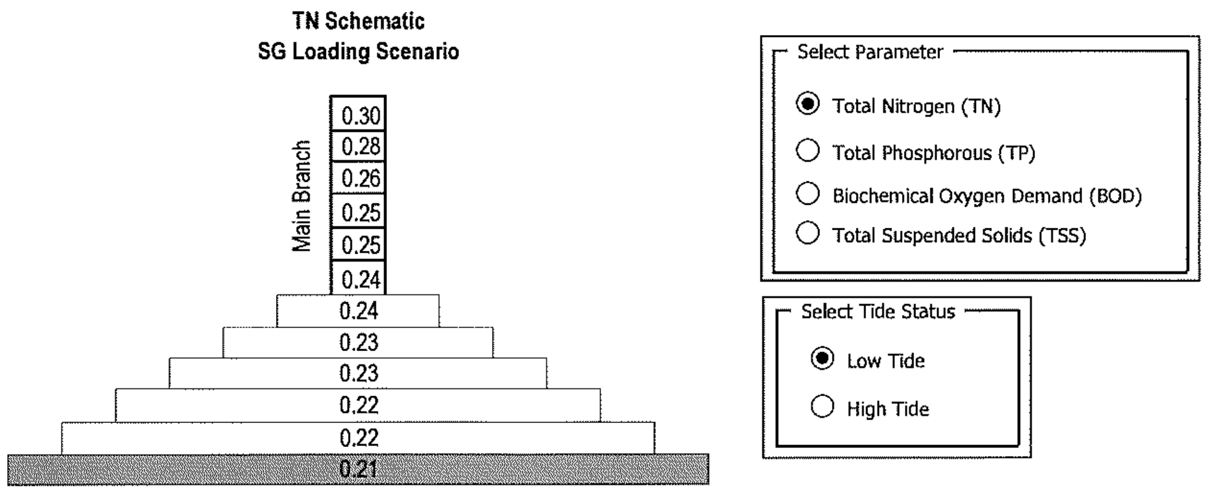
Canal #152, Lower Matecumbe Model Output: TSS, low tide



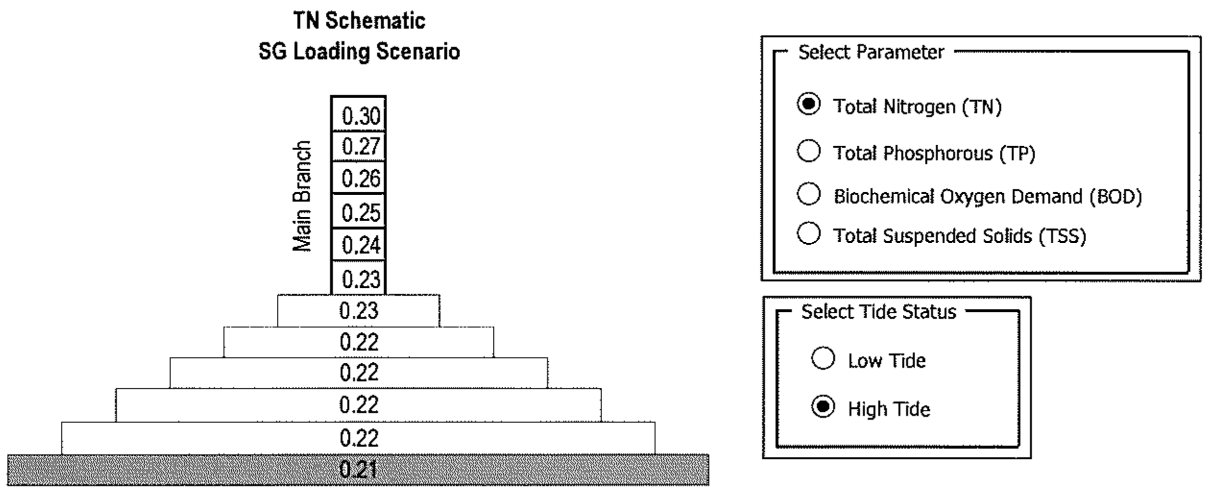
Canal #152, Lower Matecumbe Model Output: TSS, high tide



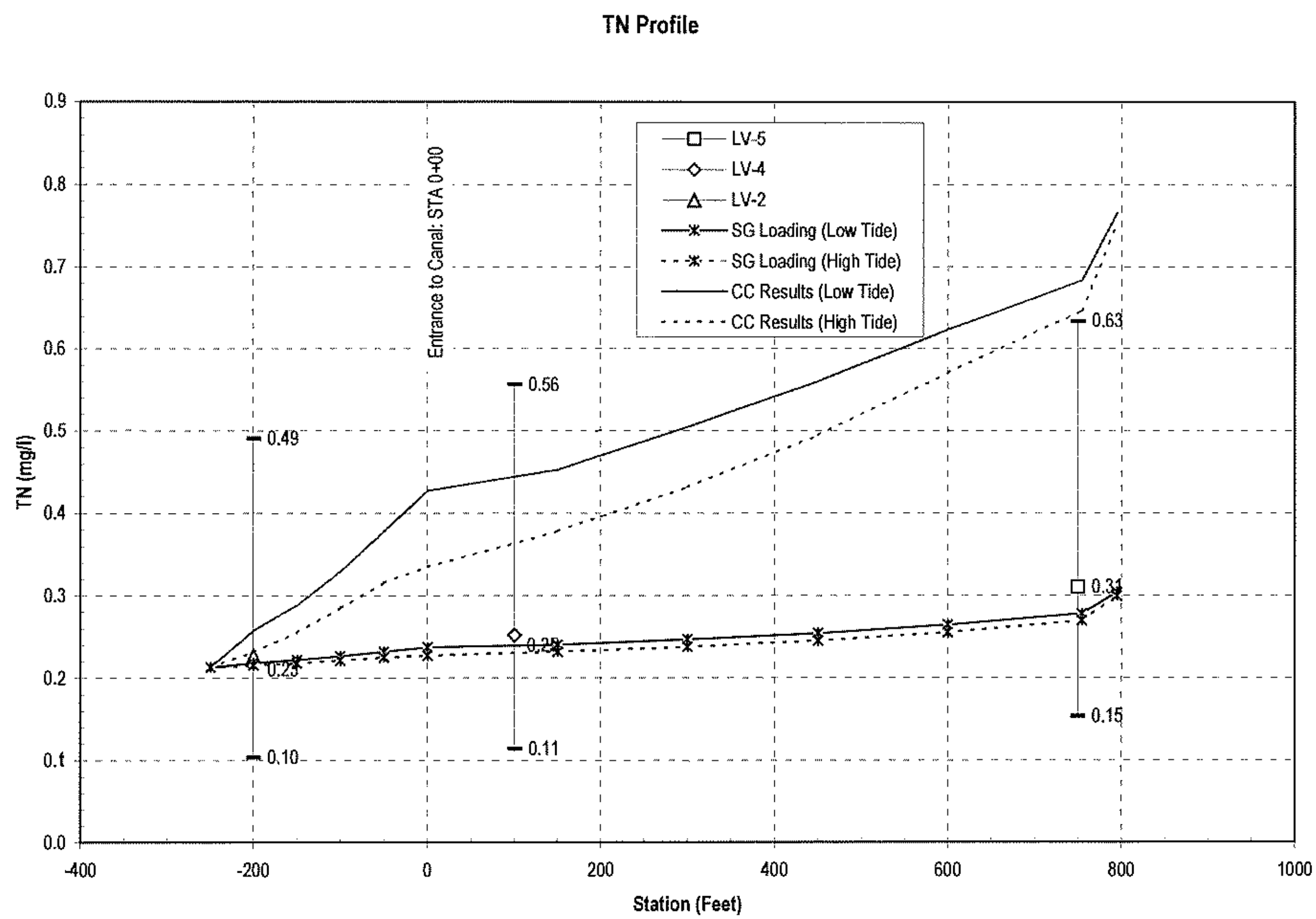
Canal #152, Lower Matecumbe Model Output: TSS Profile



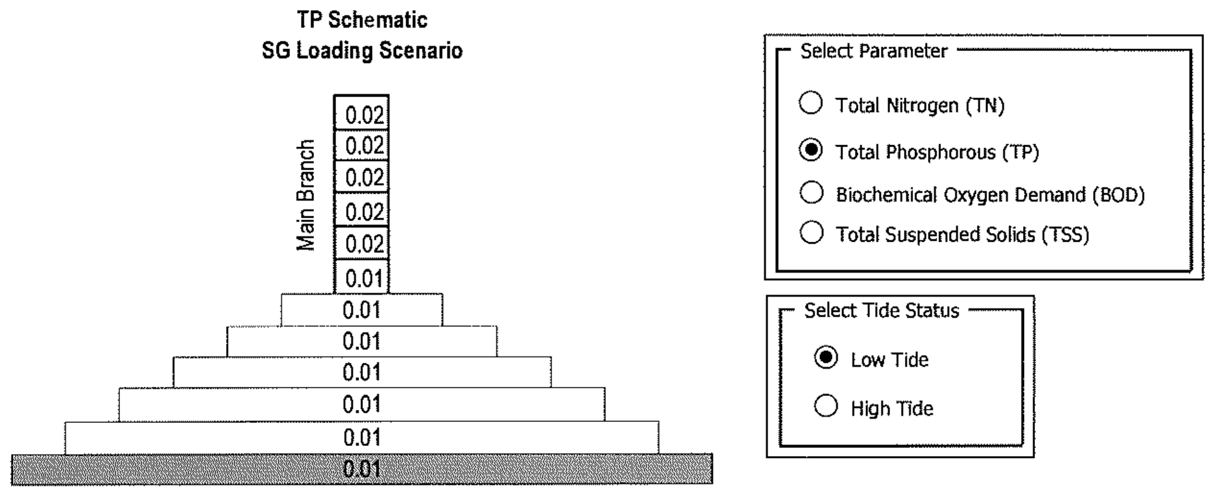
Canal #204, Marathon Model Output: TN, low tide



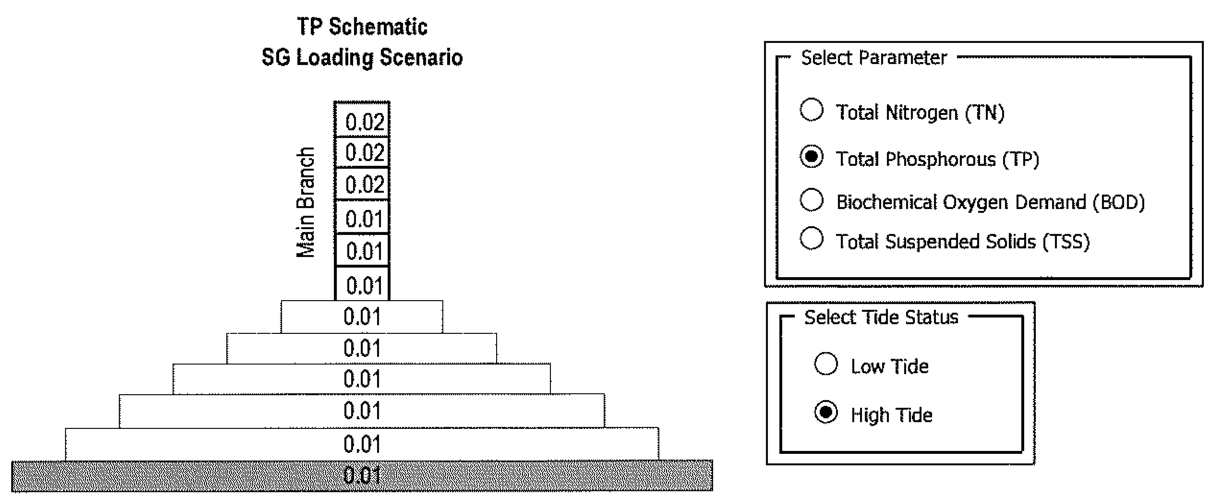
Canal #204, Marathon Model Output: TN, high tide



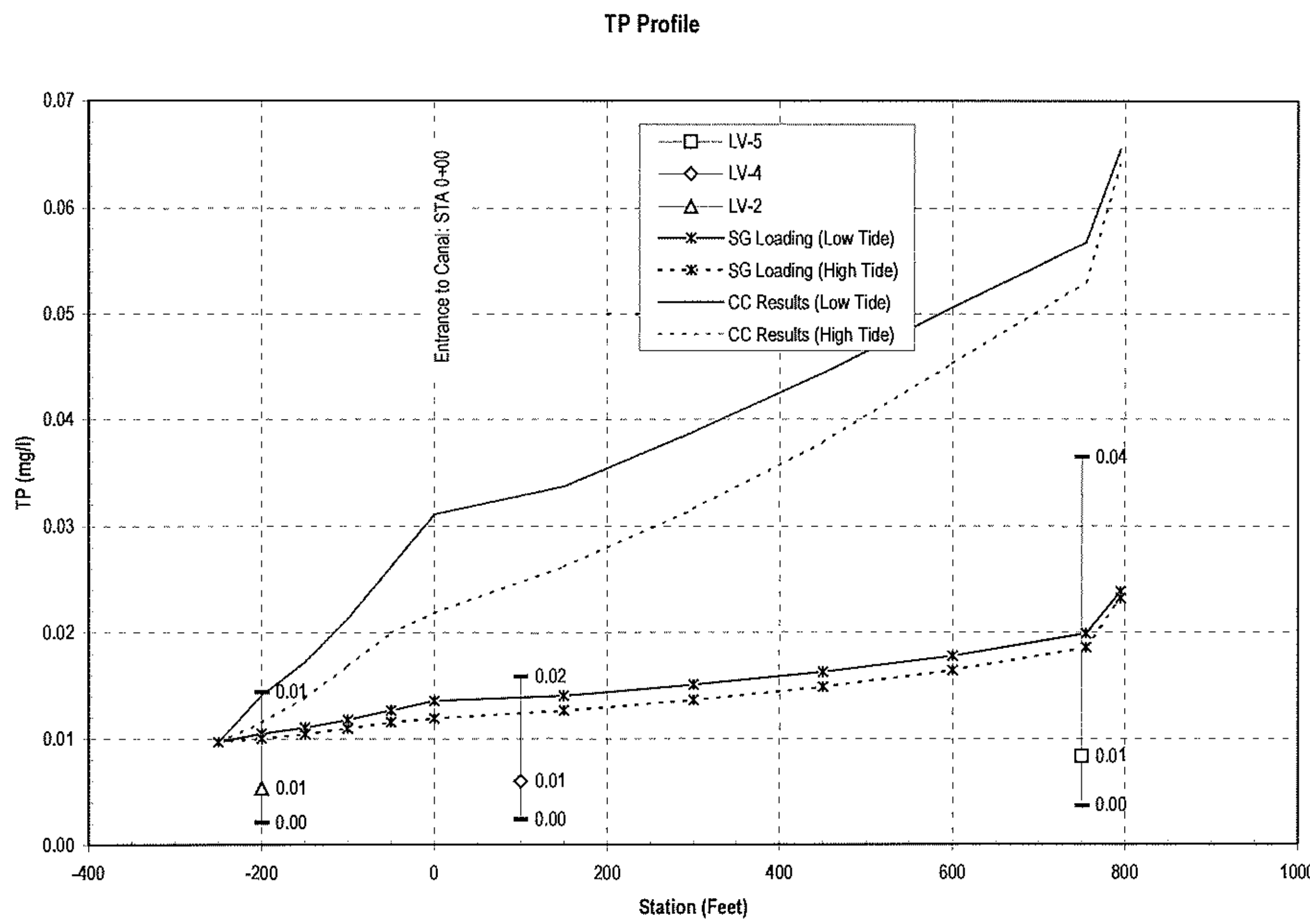
Canal #204, Marathon Model Output: TN Profile



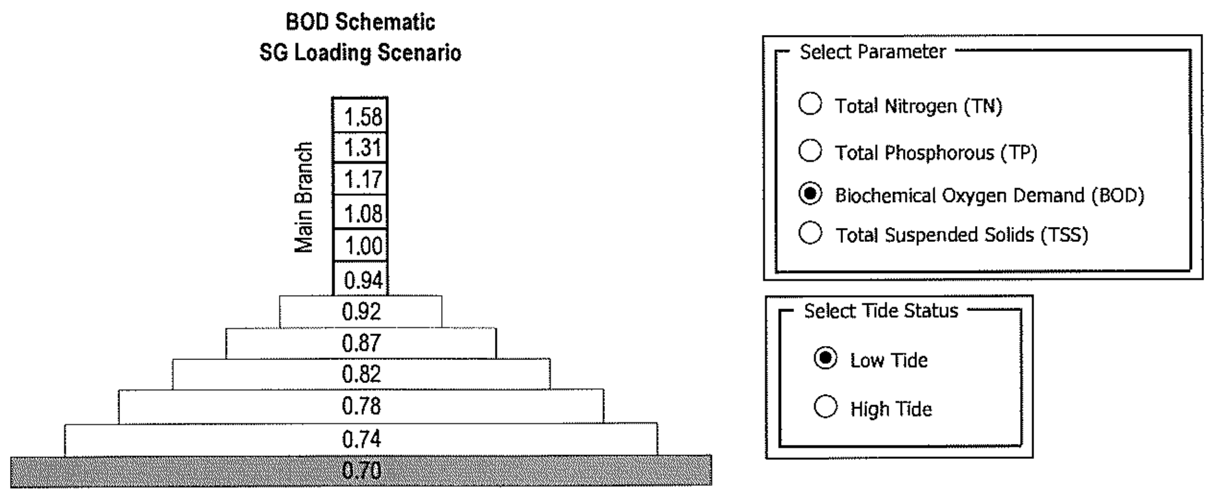
Canal #204, Marathon Model Output: TP, low tide



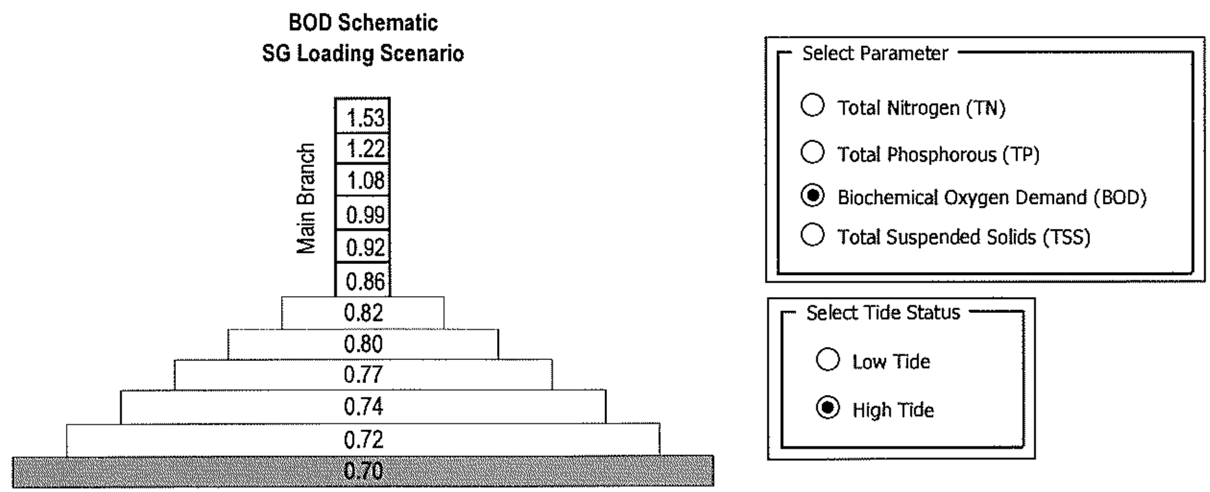
Canal #204, Marathon Model Output: TP, high tide



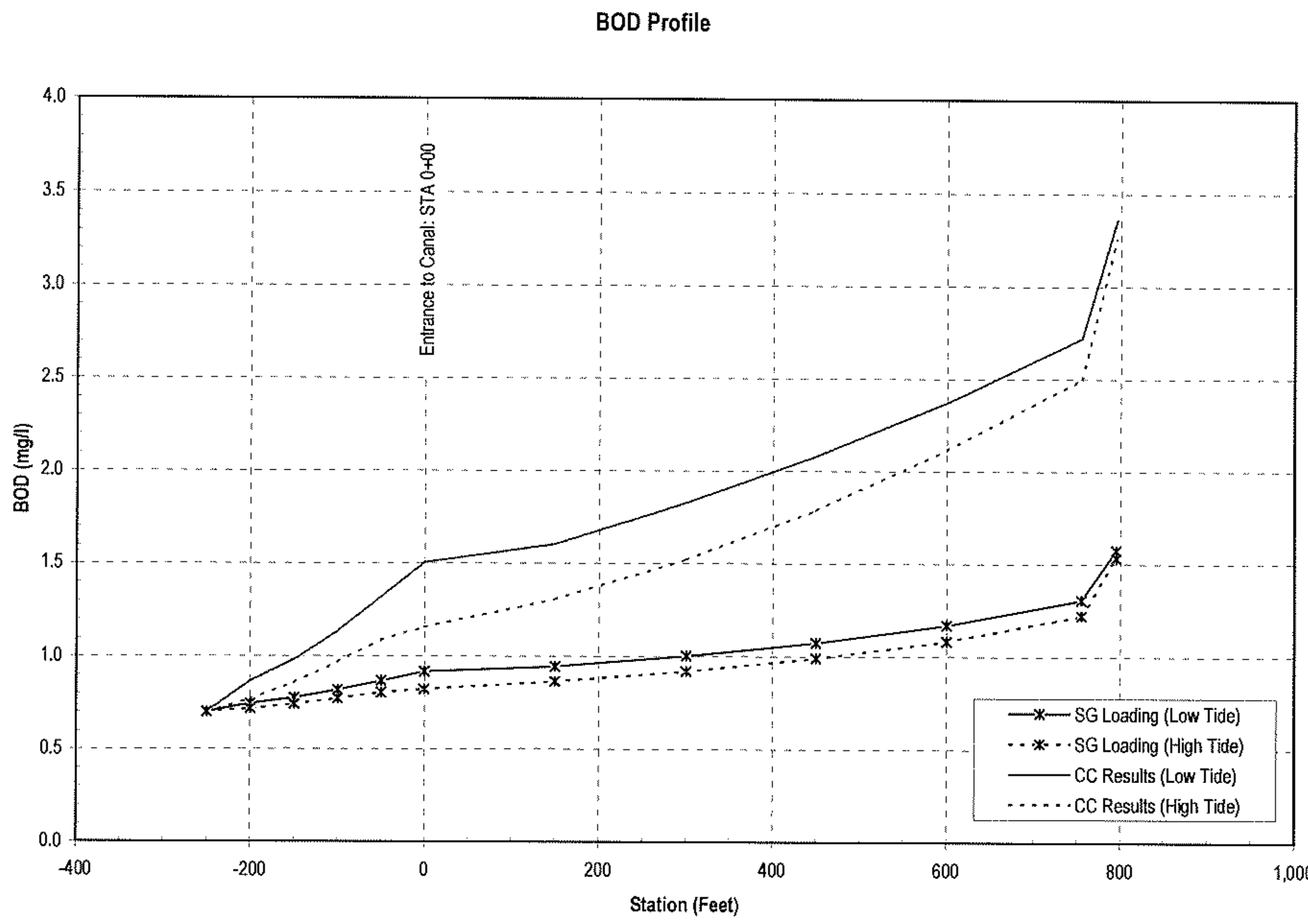
Canal #204, Marathon Model Output: TP Profile



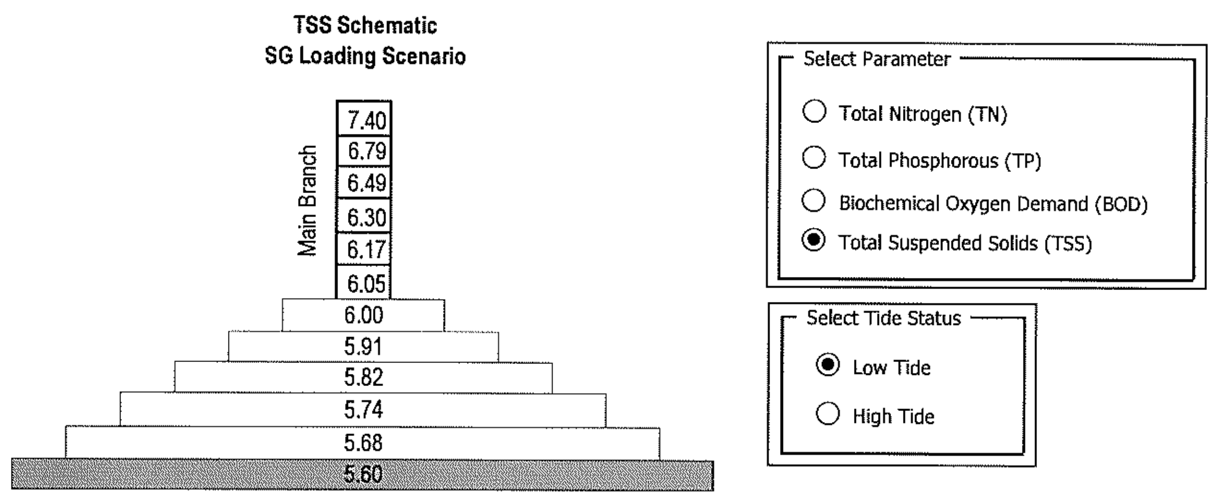
Canal #204, Marathon Model Output: BOD, low tide



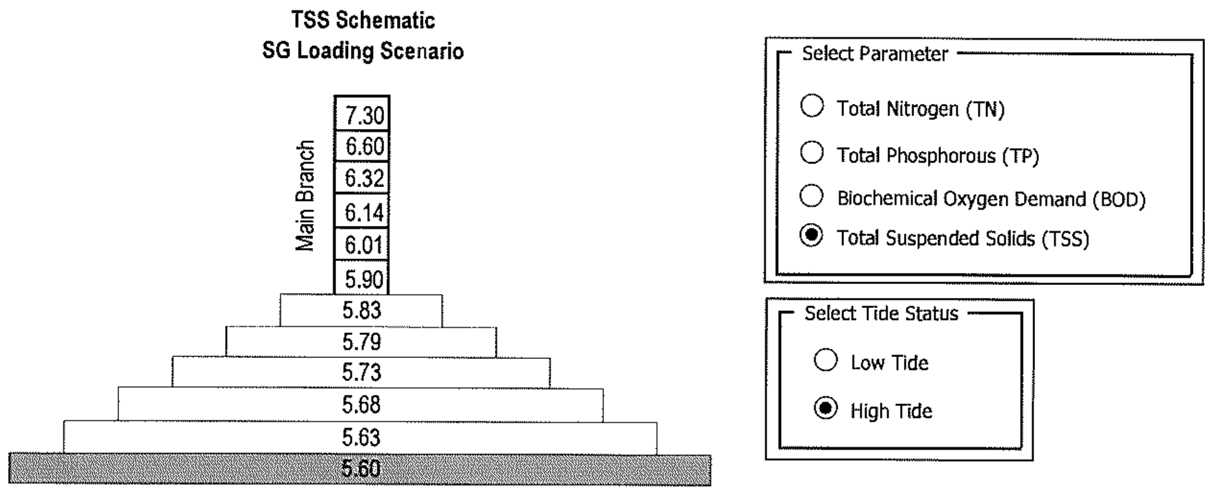
Canal #204, Marathon Model Output: BOD, high tide



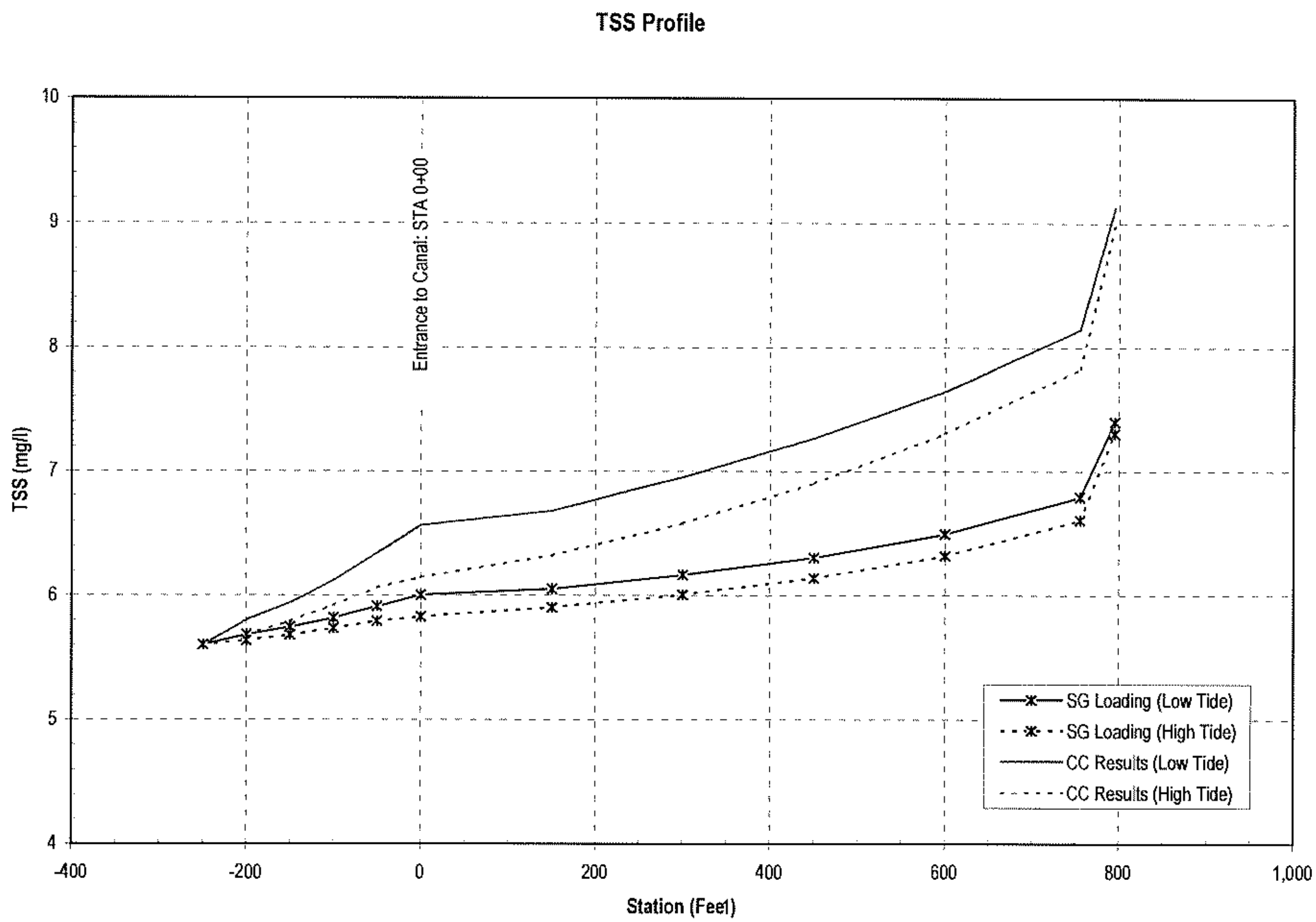
Canal #204, Marathon Model Output: BOD Profile



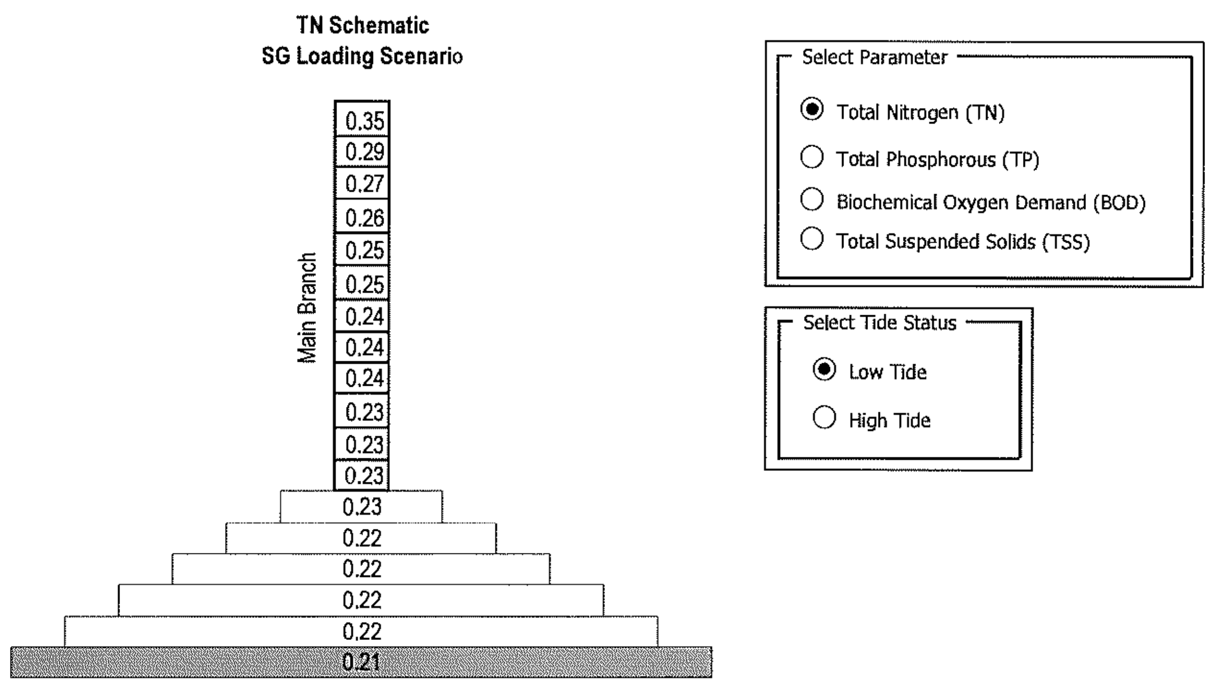
Canal #204, Marathon Model Output: TSS, low tide



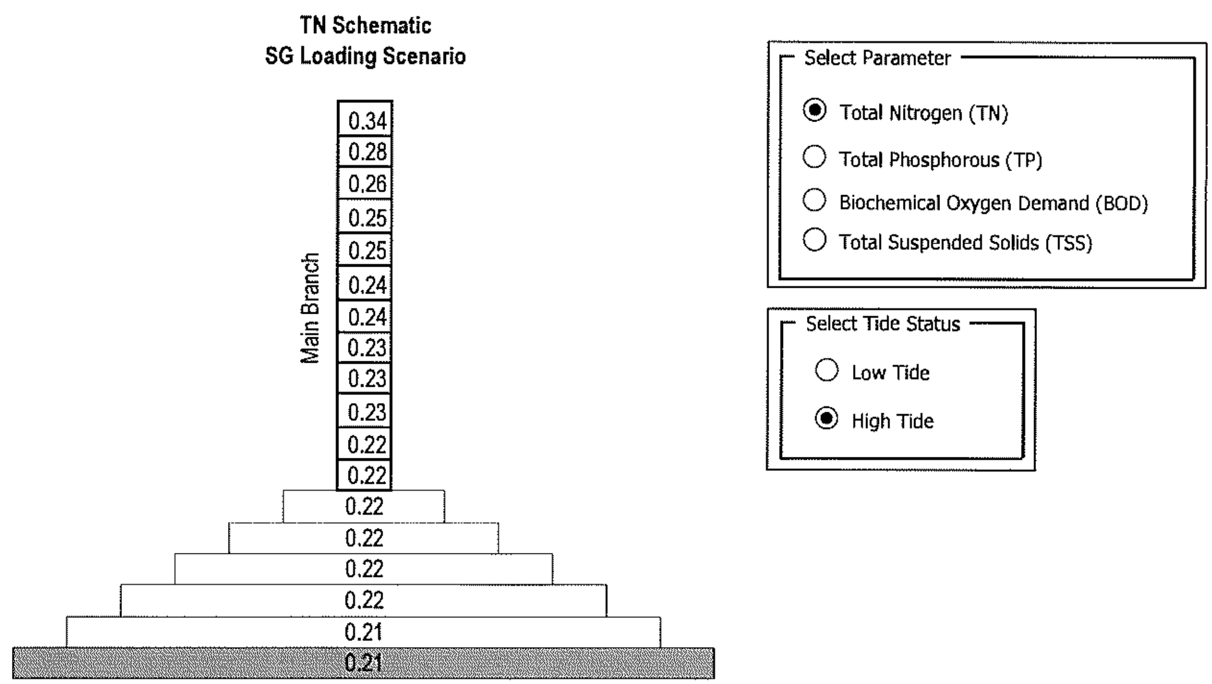
Canal #204, Marathon Model Output: TSS, high tide



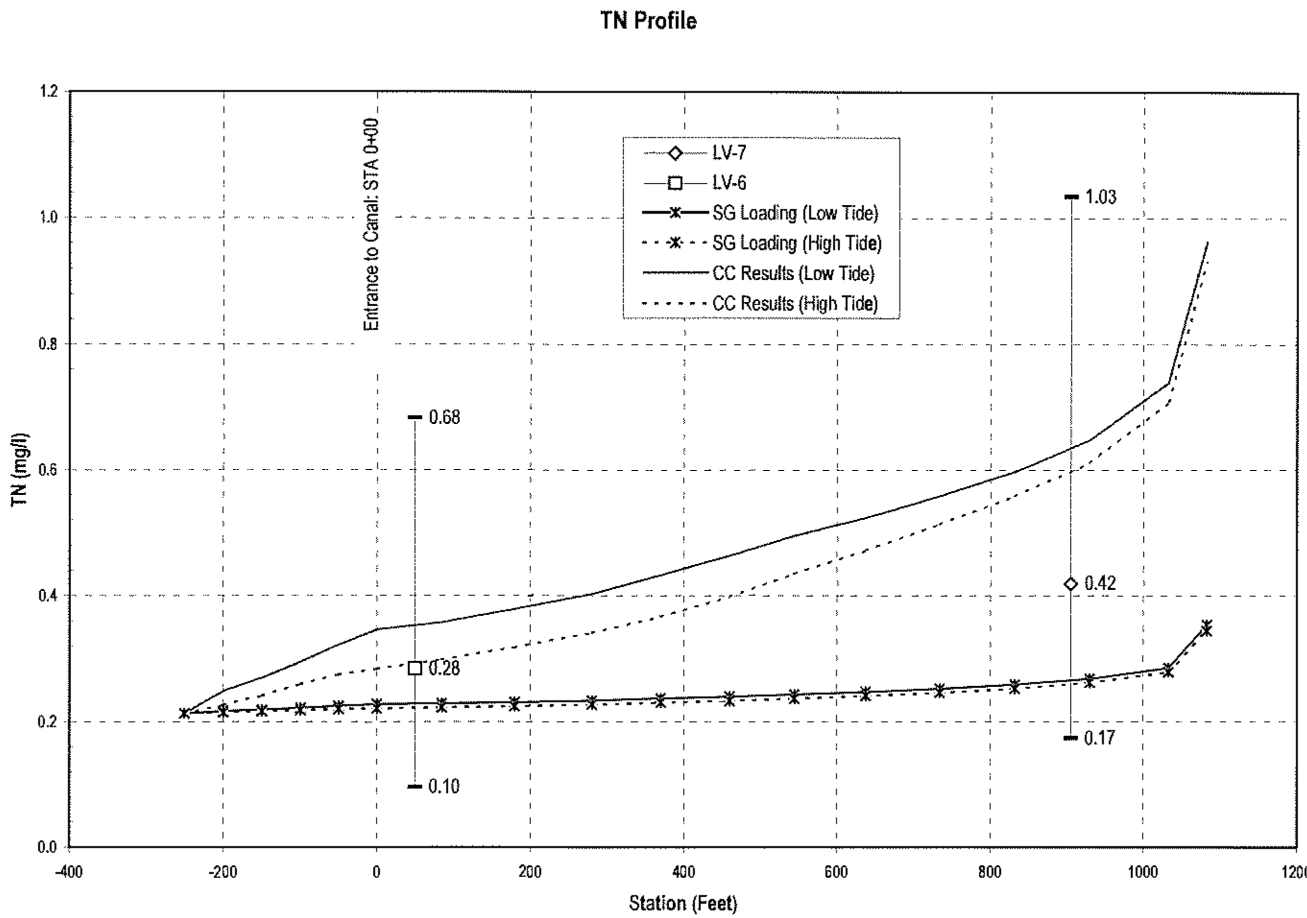
Canal #204, Marathon Model Output: TSS Profile



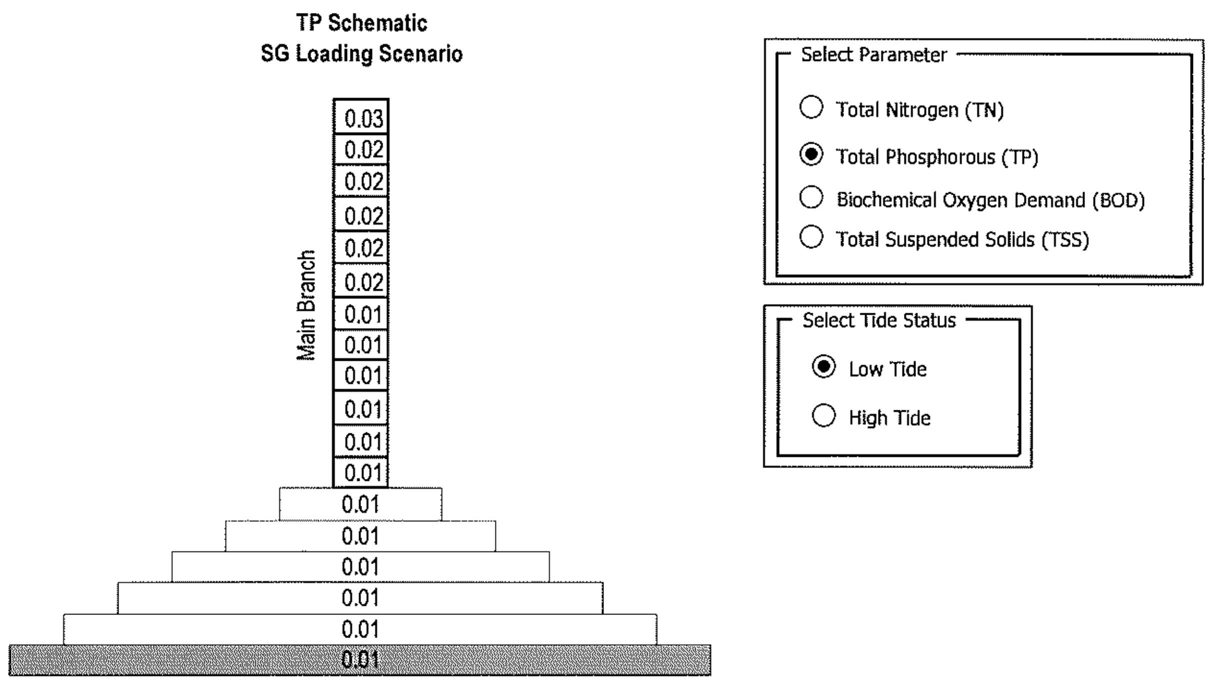
Canal #208, Marathon Model Output: TN, low tide



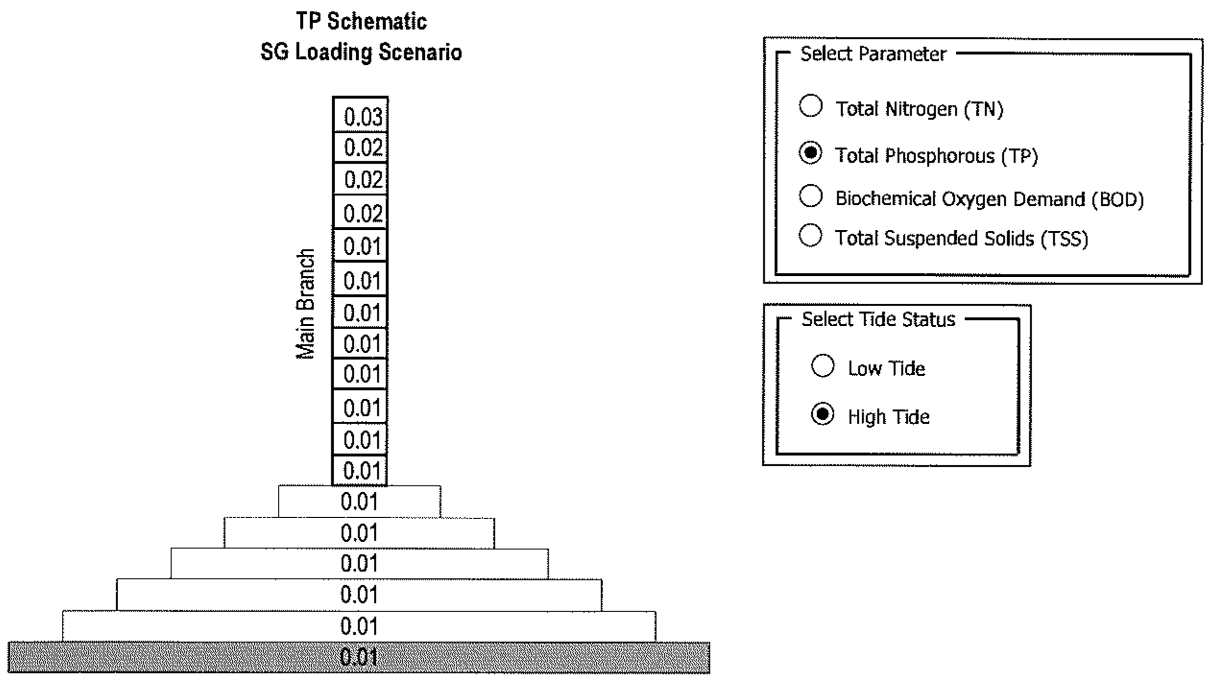
Canal #208, Marathon Model Output: TN, high tide



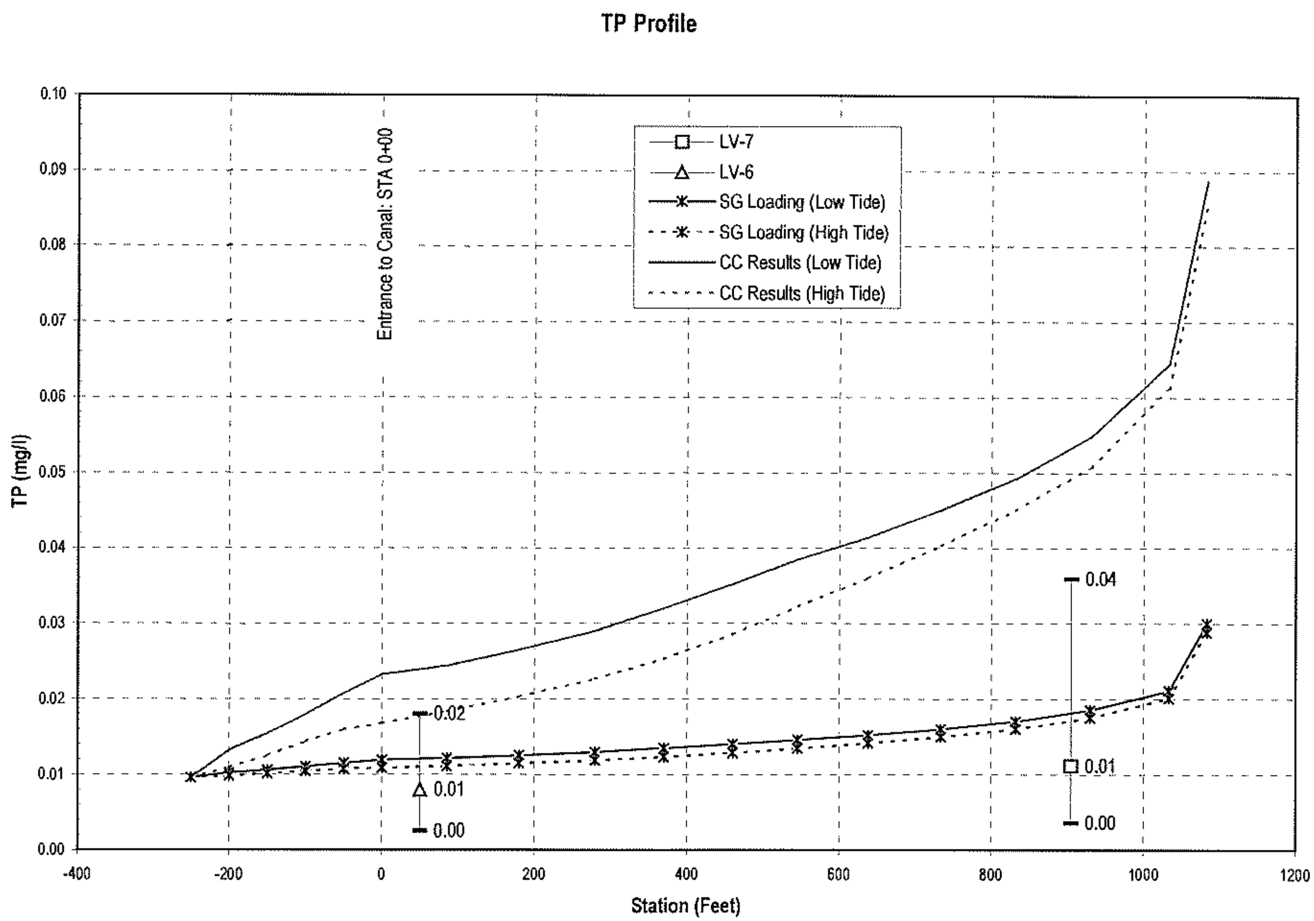
Canal #208, Marathon Model Output: TN Profile



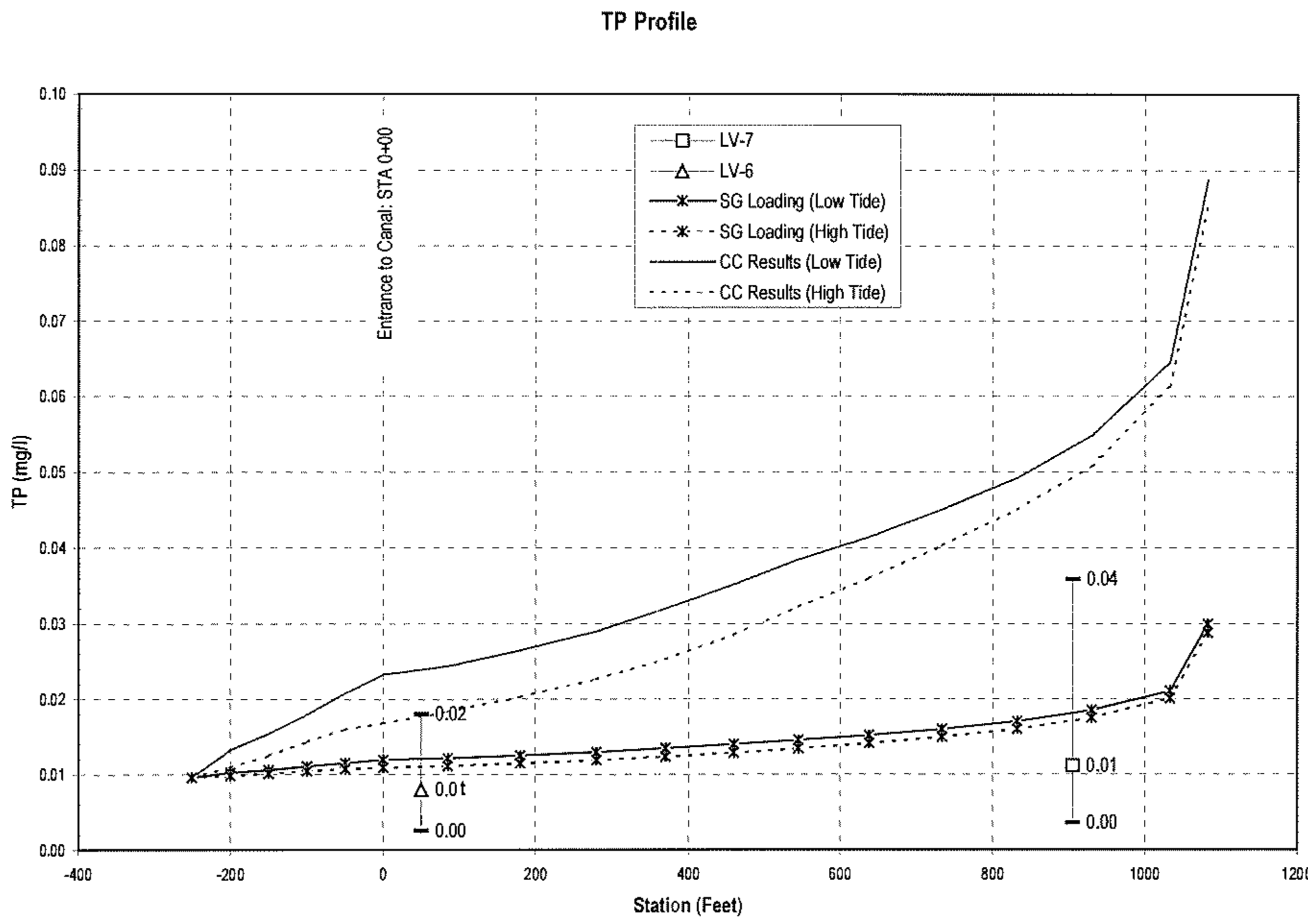
Canal #208, Marathon Model Output: TP, low tide



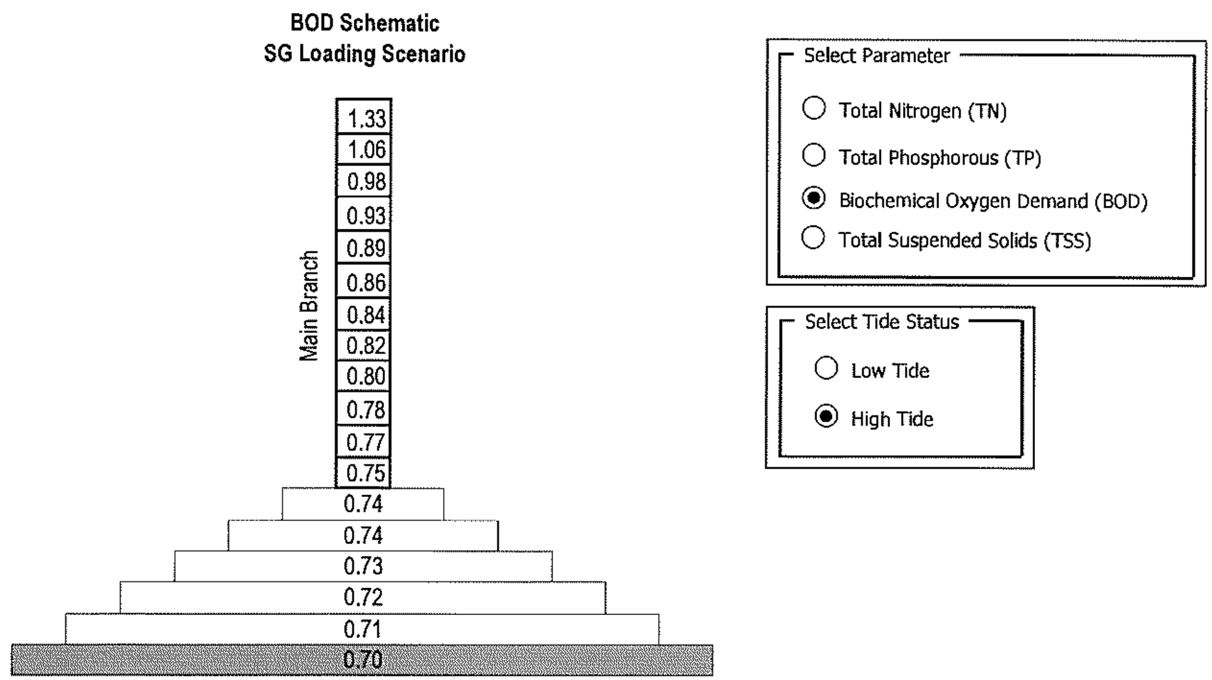
Canal #208, Marathon Model Output: TP, high tide



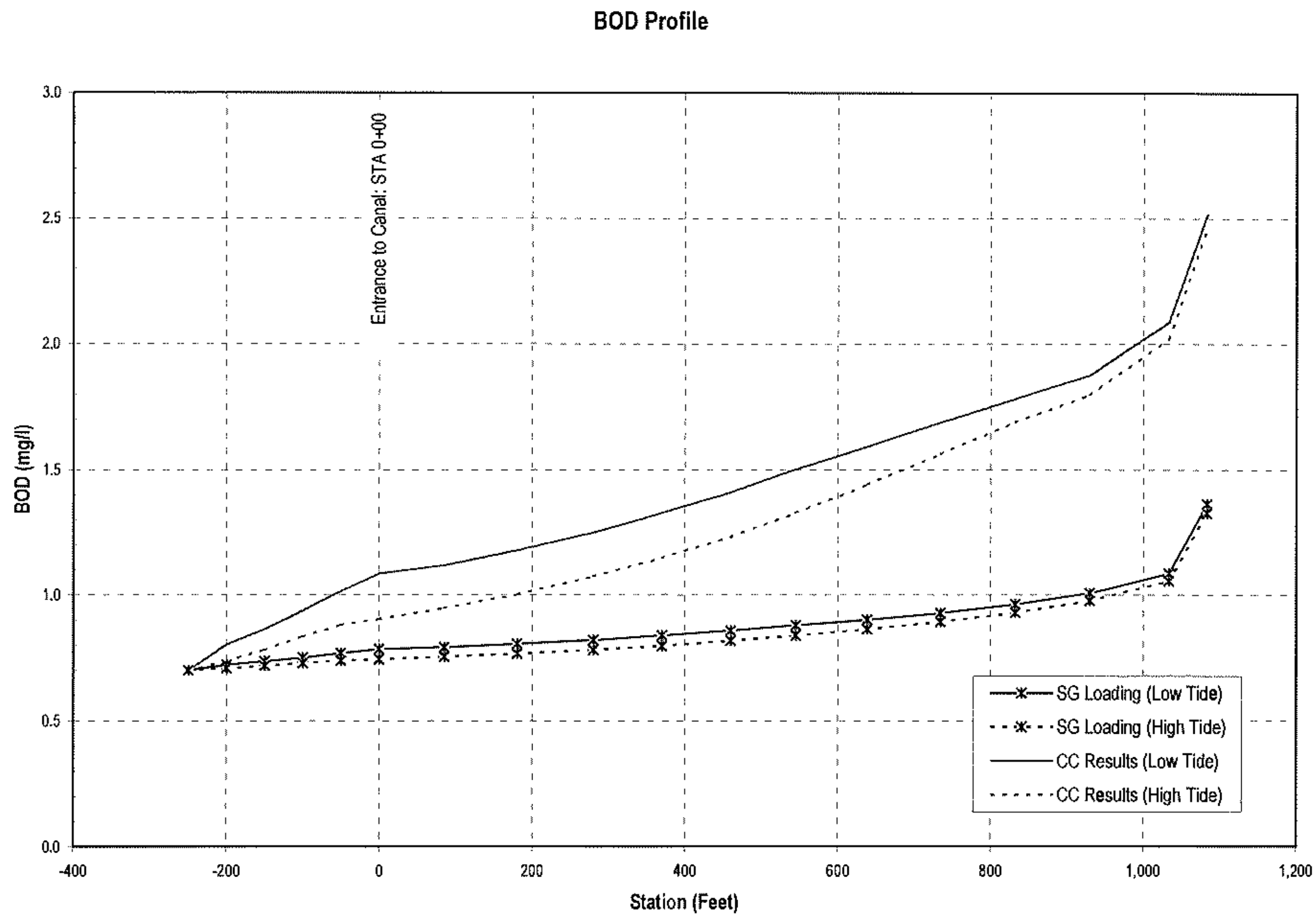
Canal #208, Marathon Model Output: TP Profile



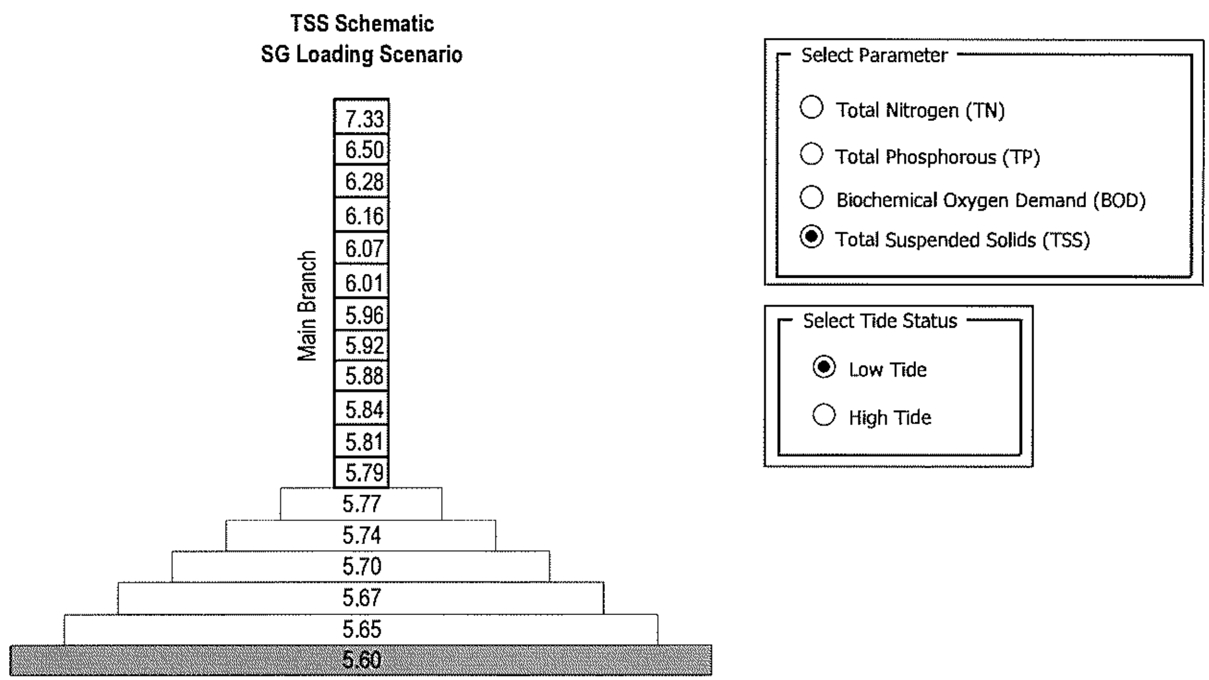
Canal #208, Marathon Model Output: BOD, low tide



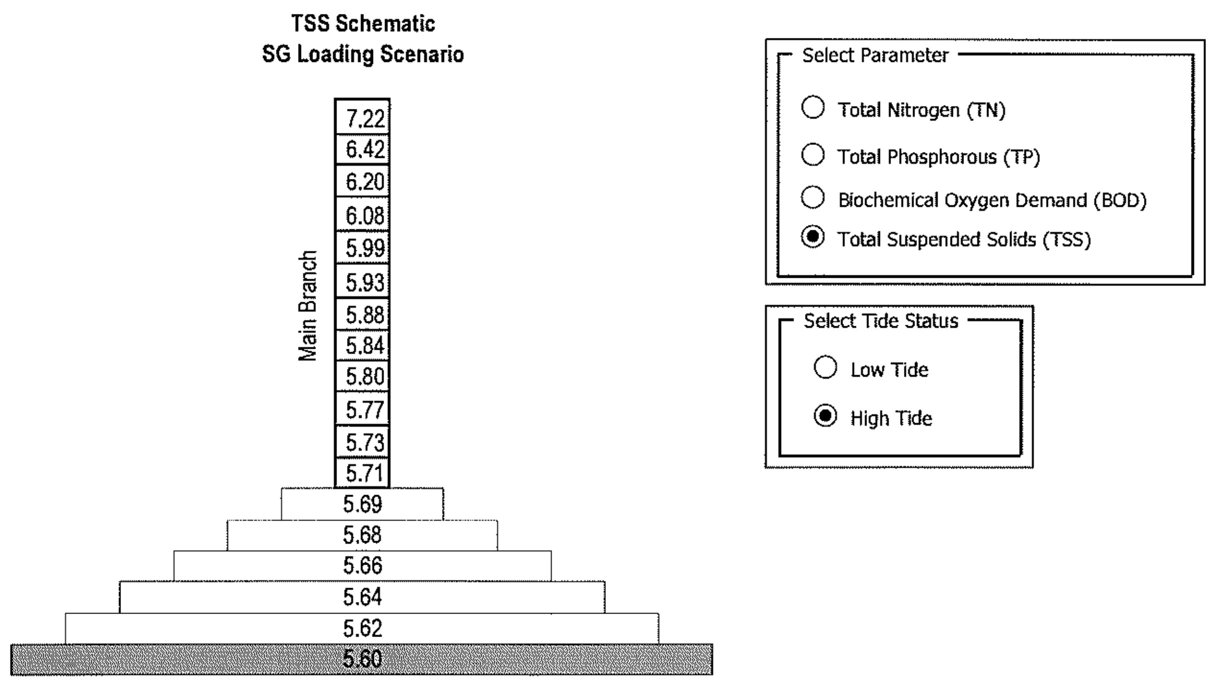
Canal #208, Marathon Model Output: BOD, high tide



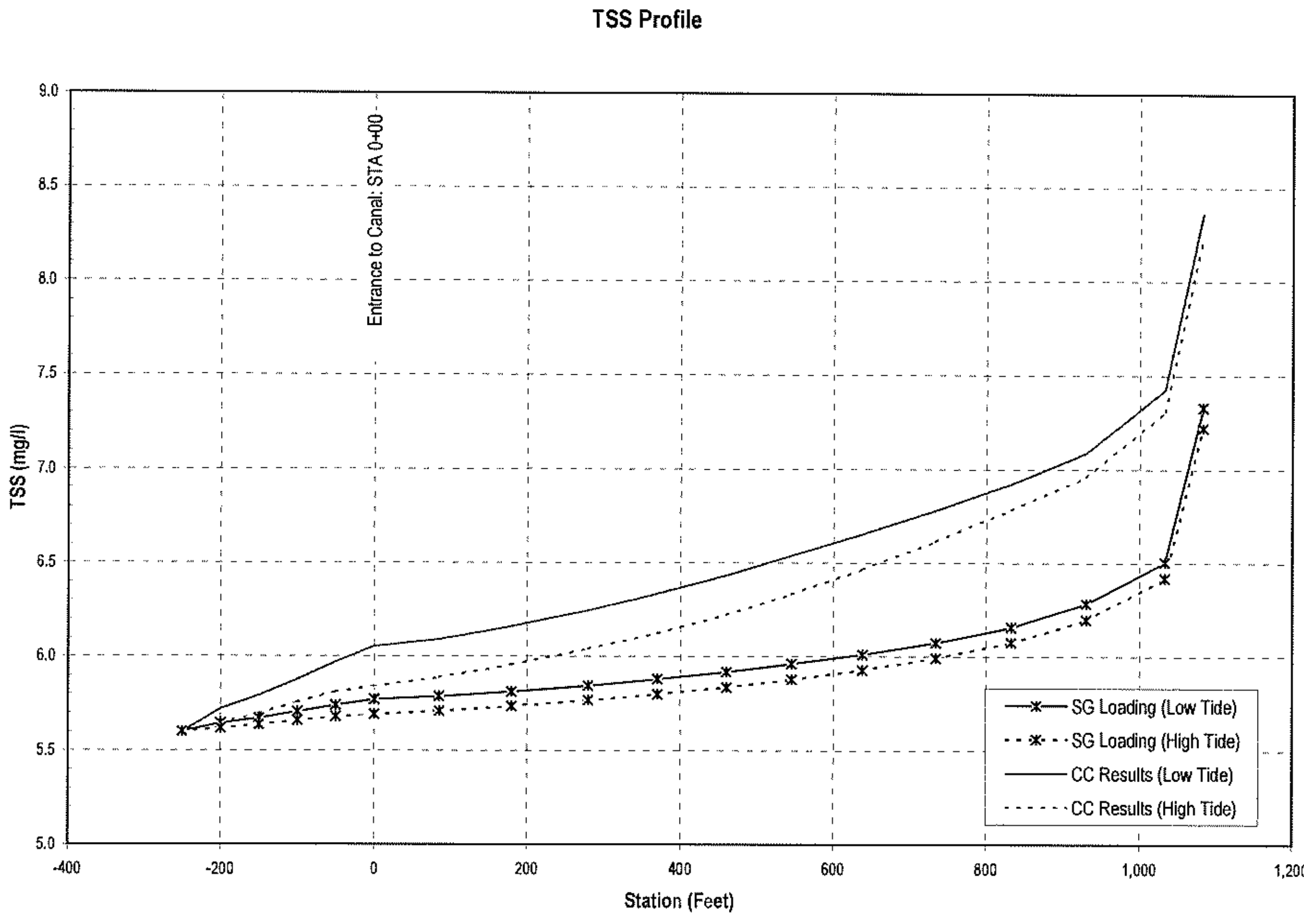
Canal #208, Marathon Model Output: BOD Profile



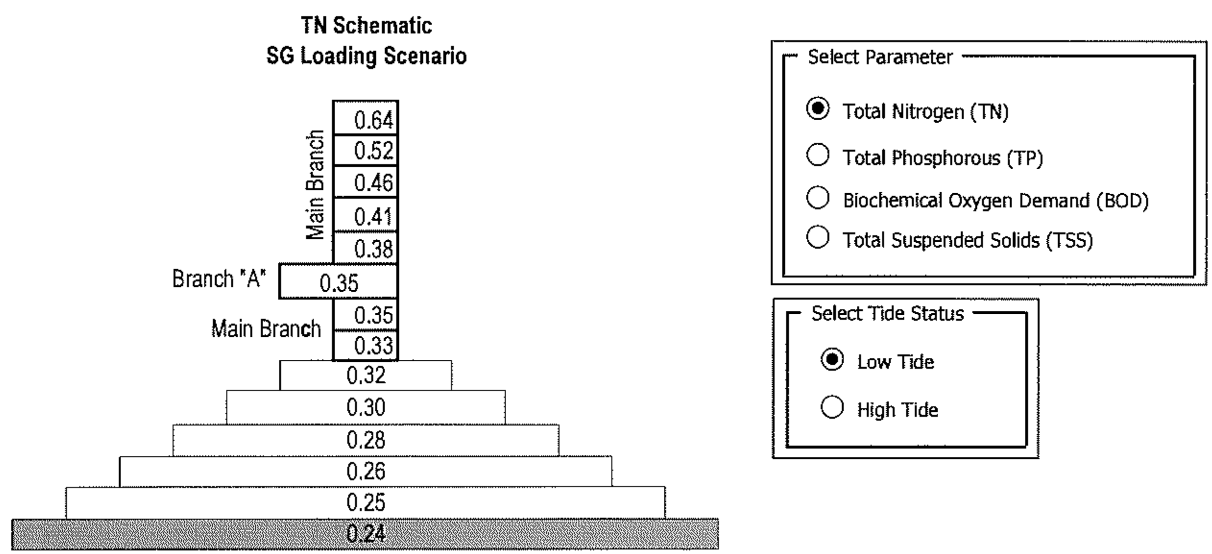
Canal #208, Marathon Model Output: TSS, low tide



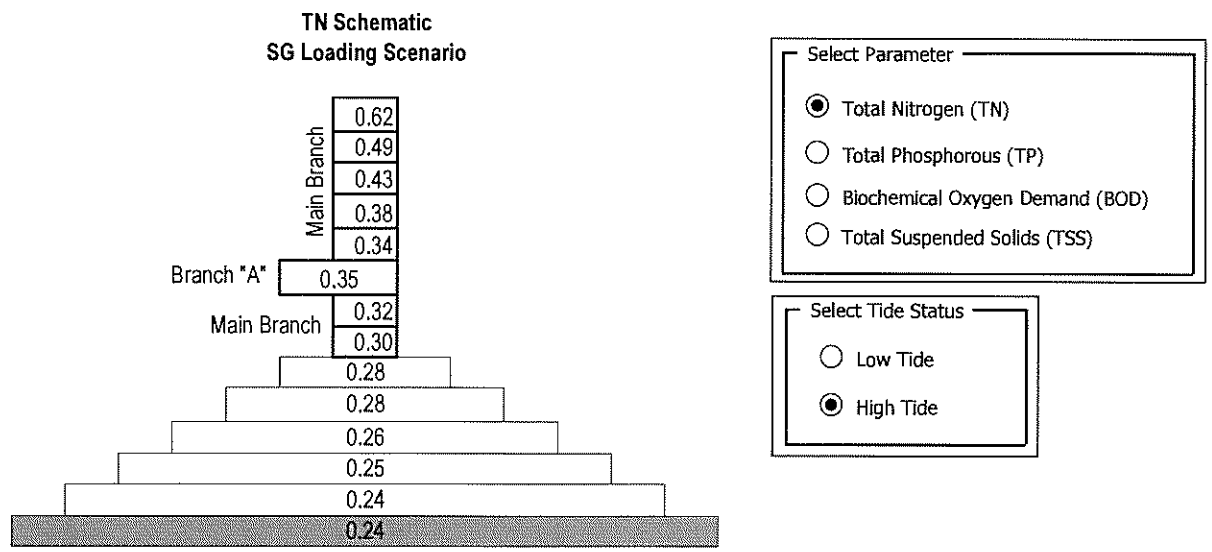
Canal #208, Marathon Model Output: TSS, high tide



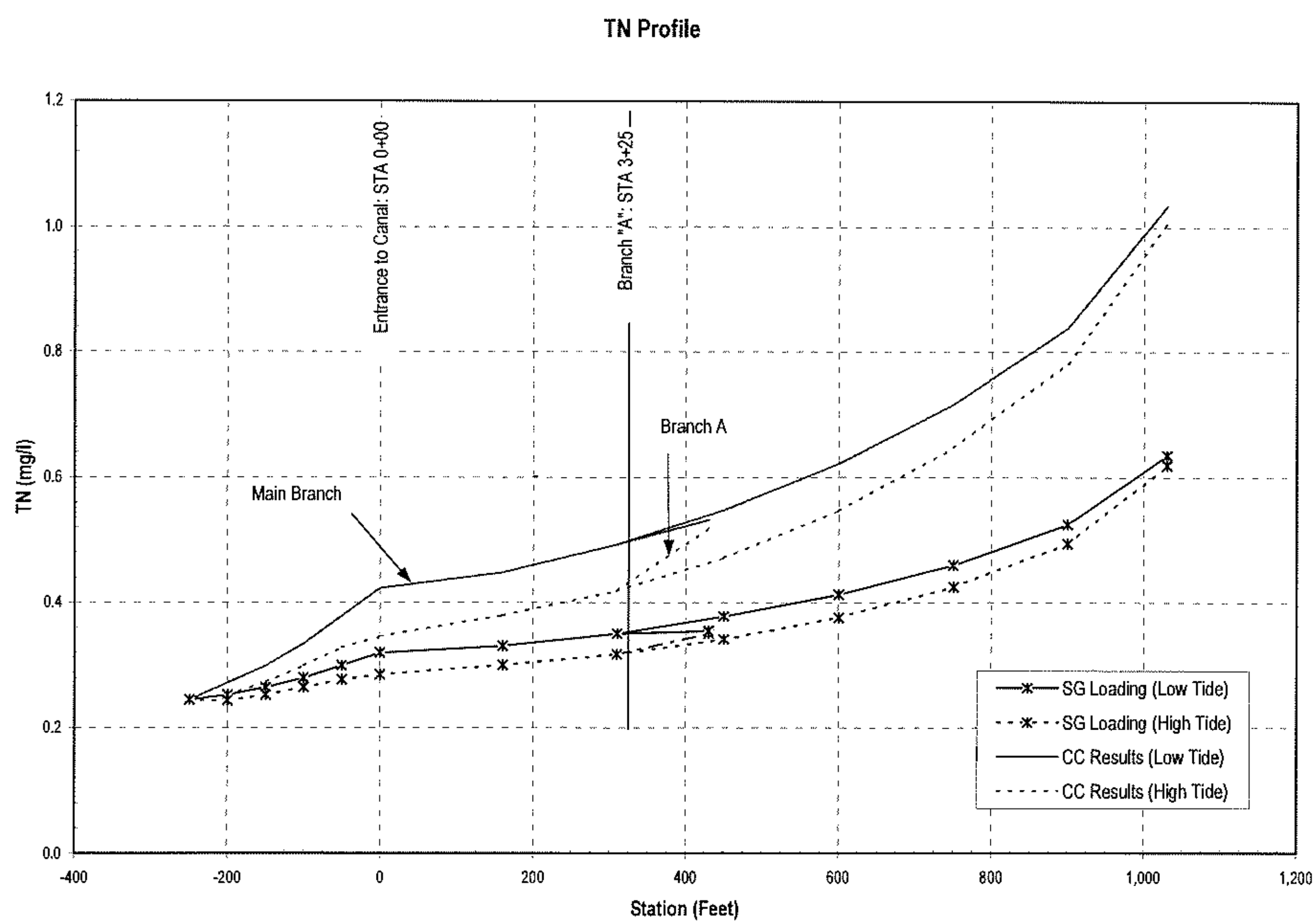
Canal #208, Marathon Model Output: TSS Profile



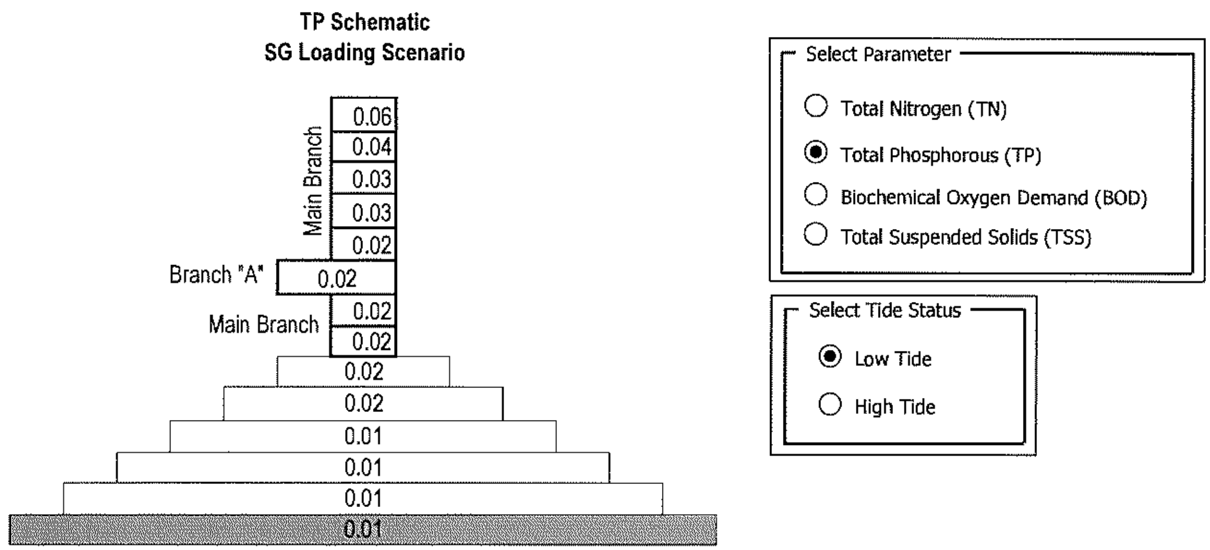
Canal #246, Marathon Model Output: TN, low tide



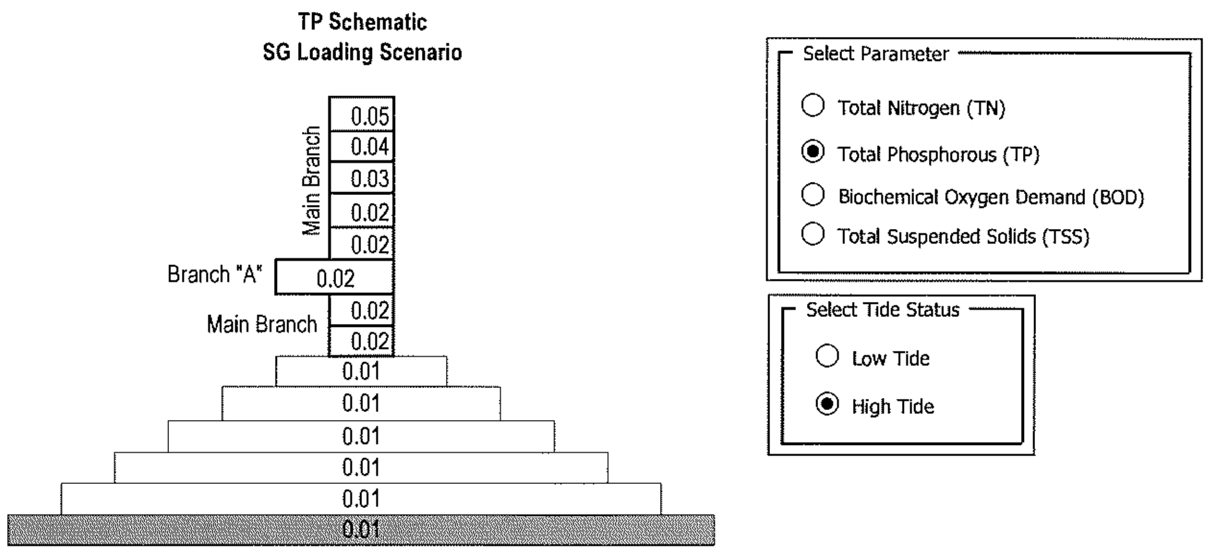
Canal #246, Marathon Model Output: TN, high tide



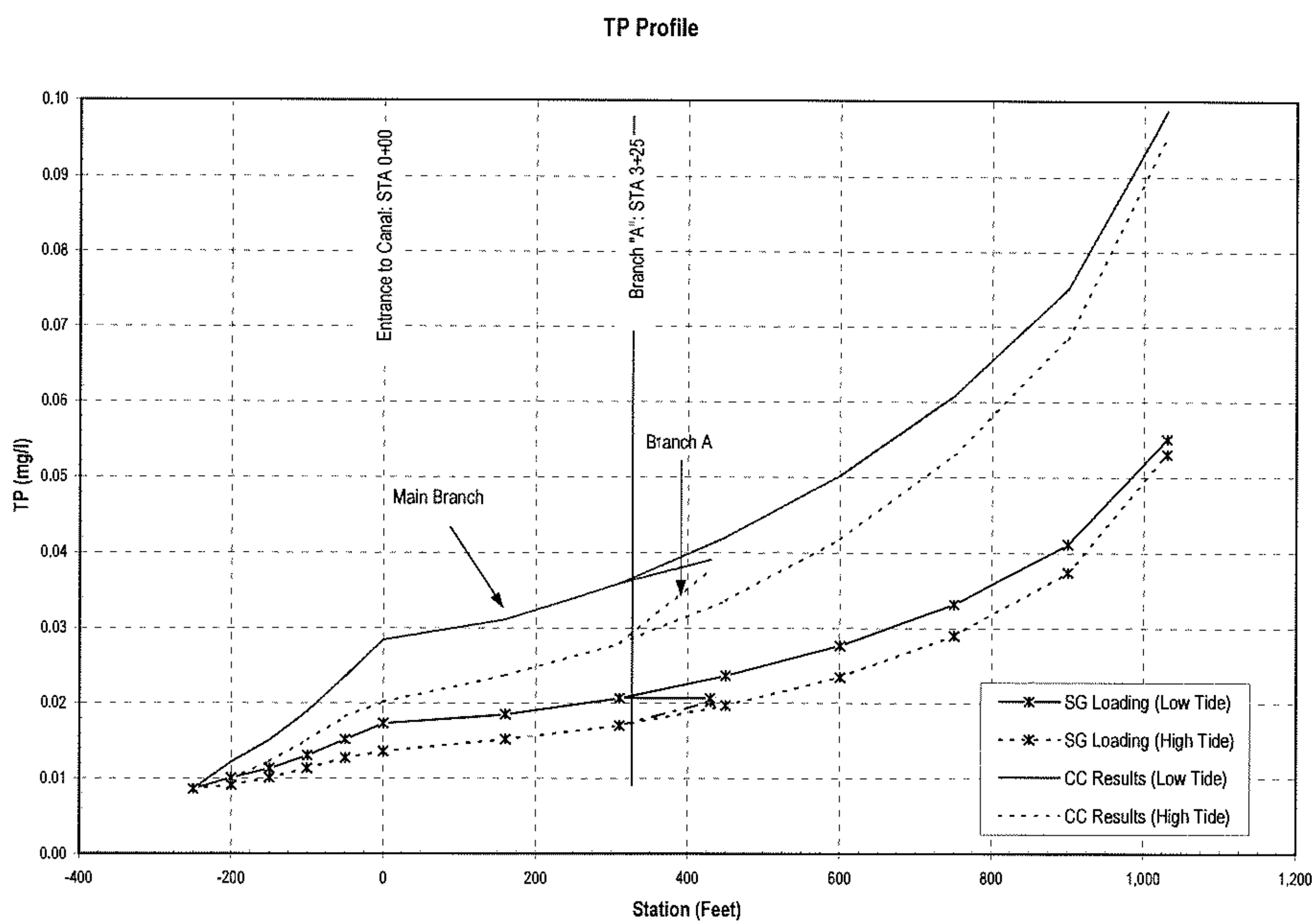
Canal #246, Marathon Model Output: TN Profile



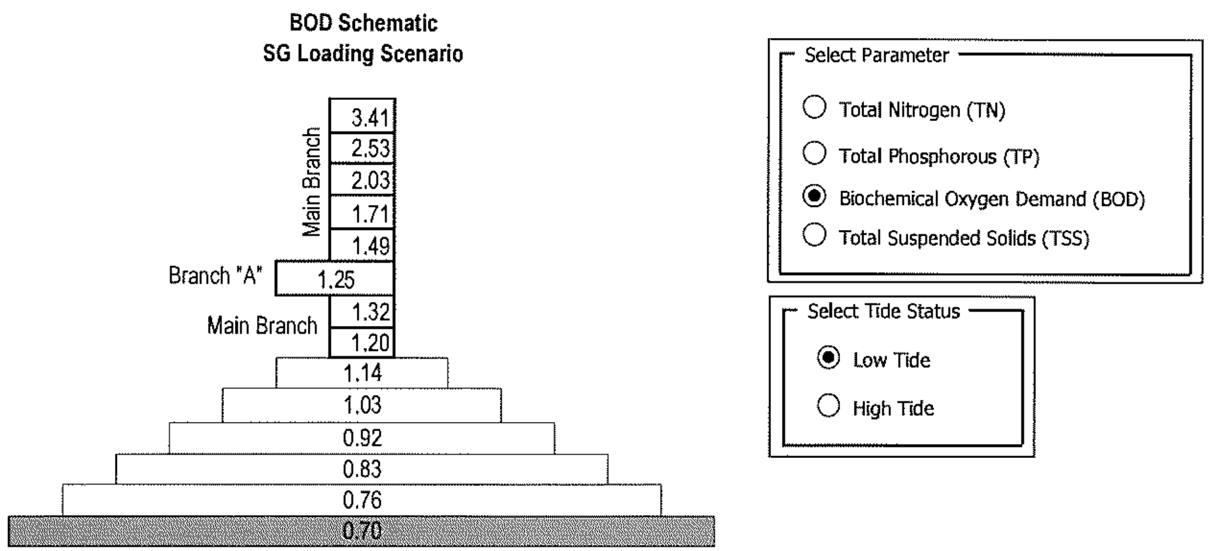
Canal #246, Marathon Model Output: TP, low tide



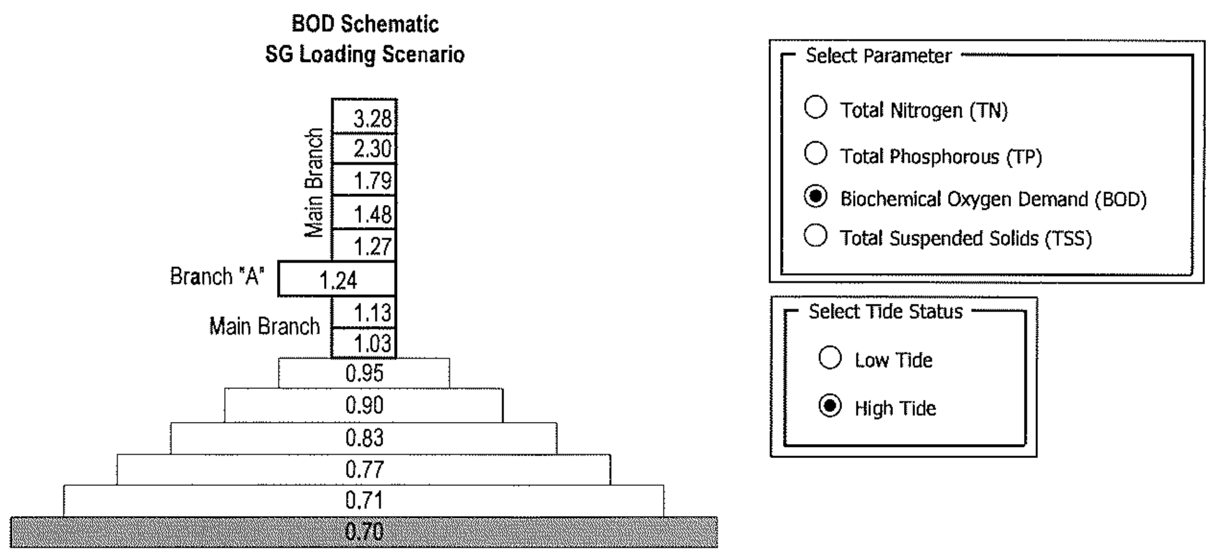
Canal #246, Marathon Model Output: TP, high tide



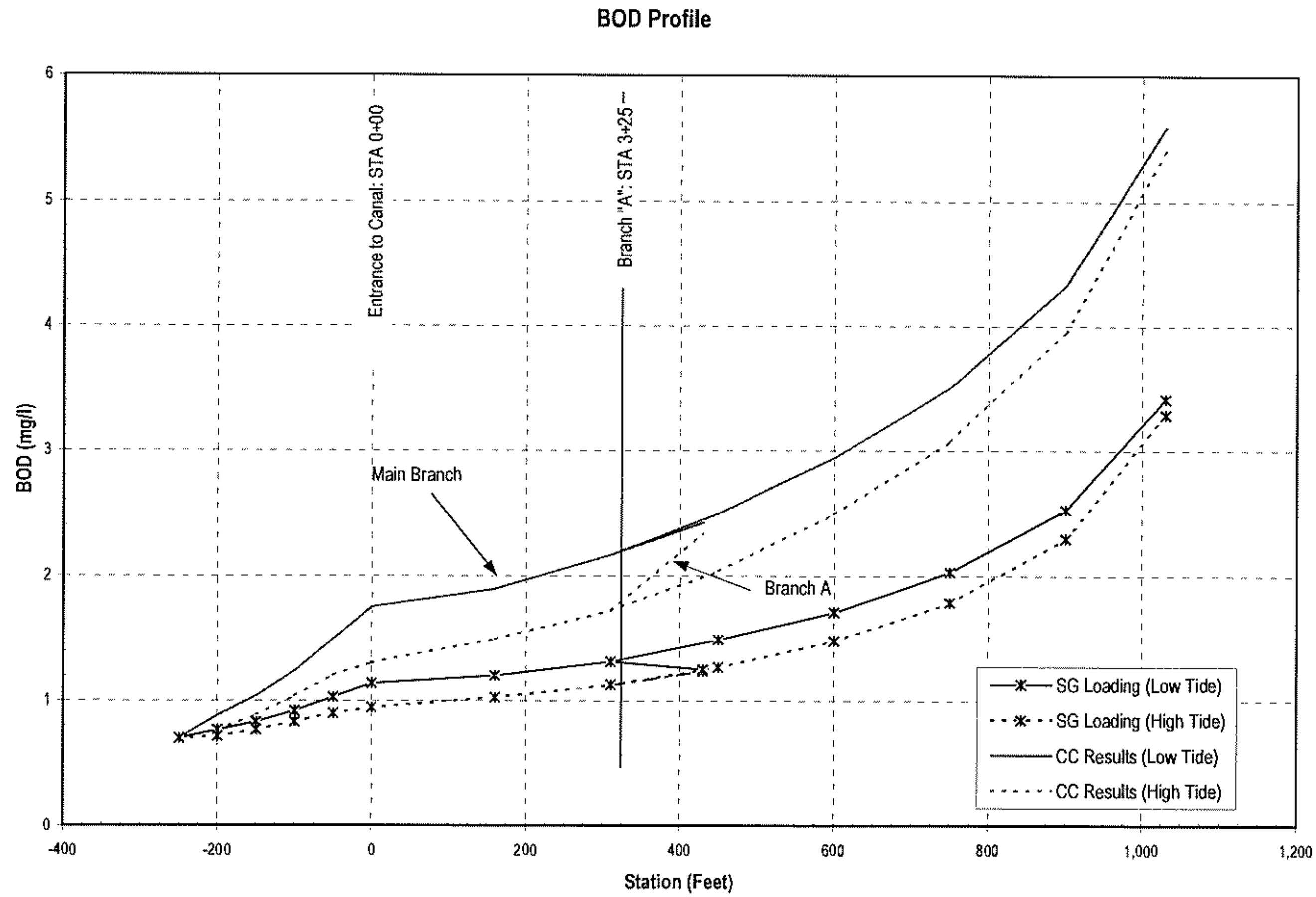
Canal #246, Marathon Model Output: TP Profile



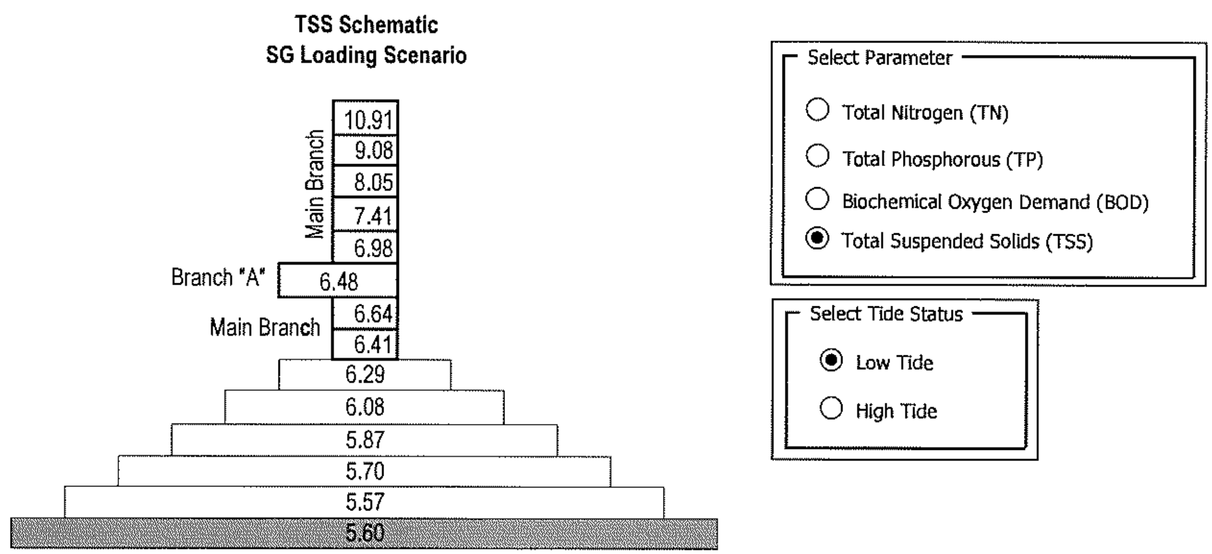
Canal #246, Marathon Model Output: BOD, low tide



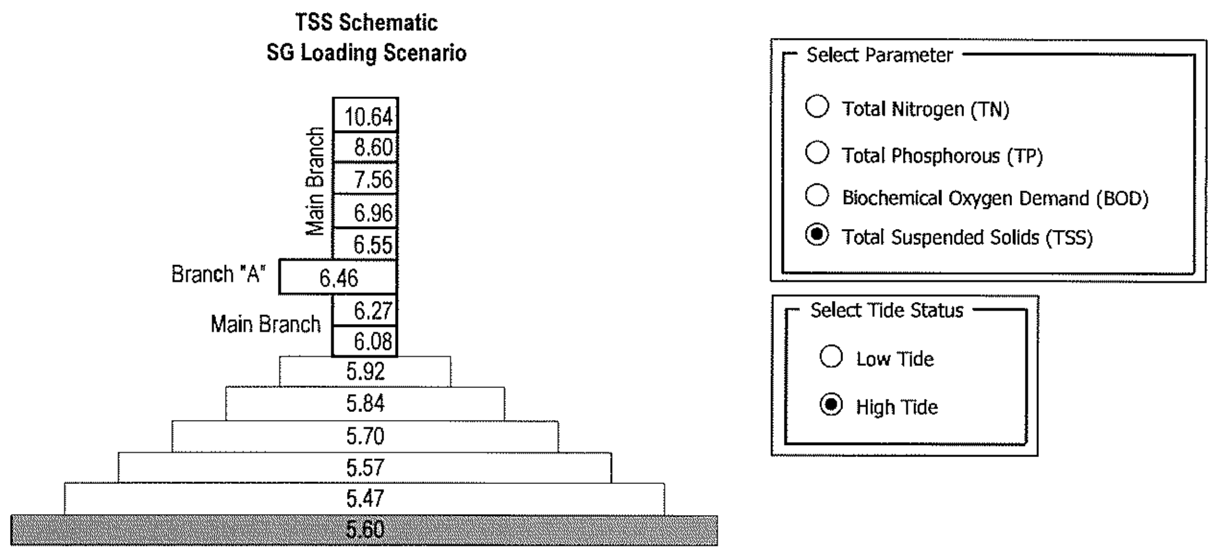
Canal #246, Marathon Model Output: BOD, high tide



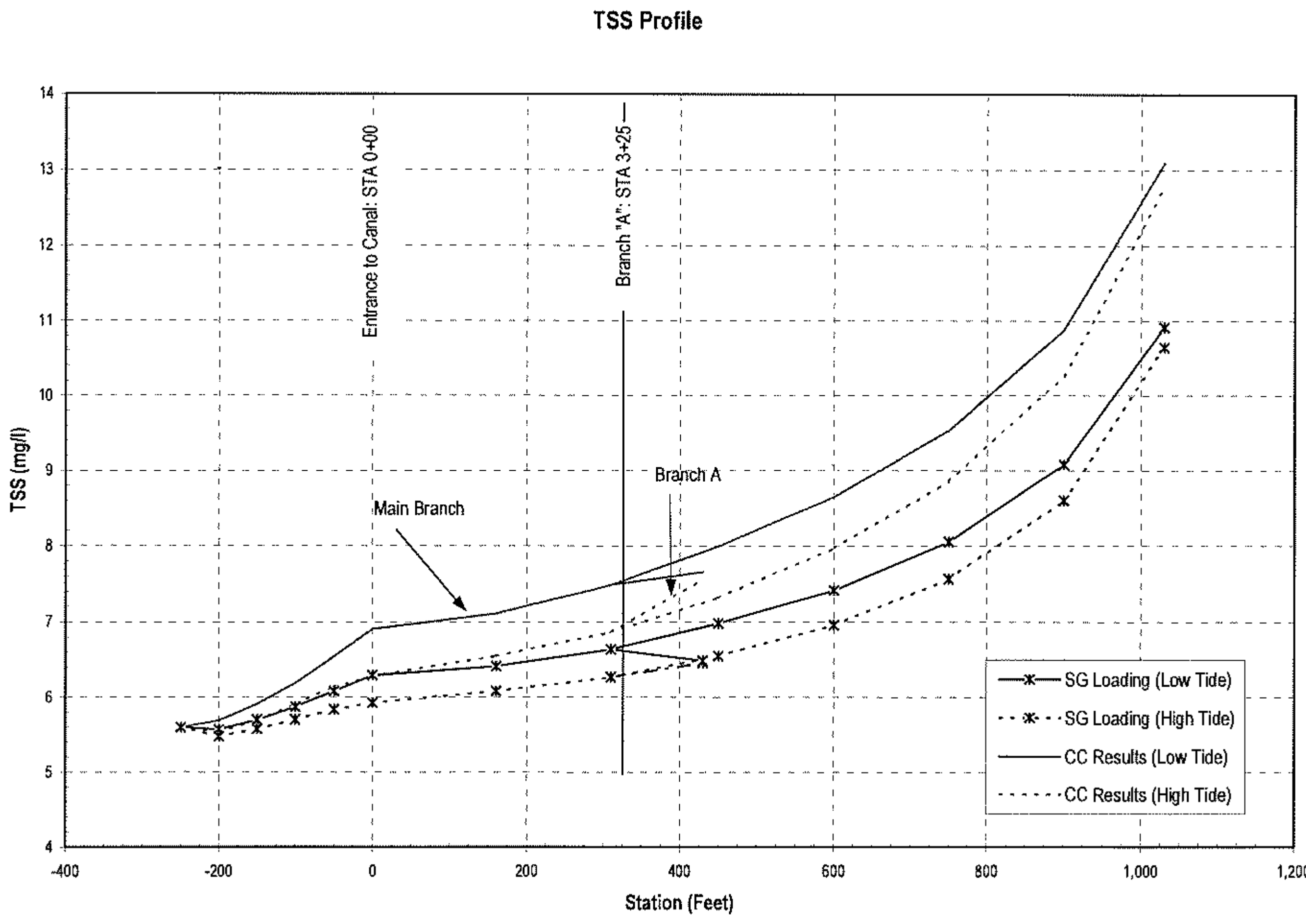
Canal #246, Marathon Model Output: BOD Profile



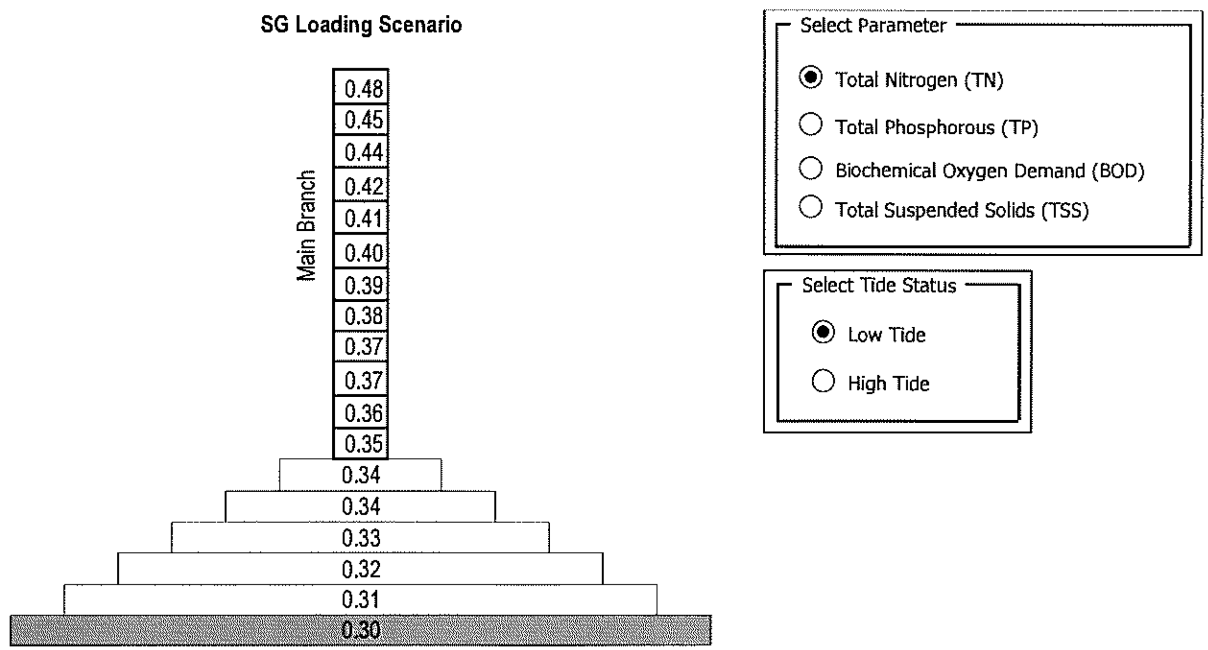
Canal #246, Marathon Model Output: TSS, low tide



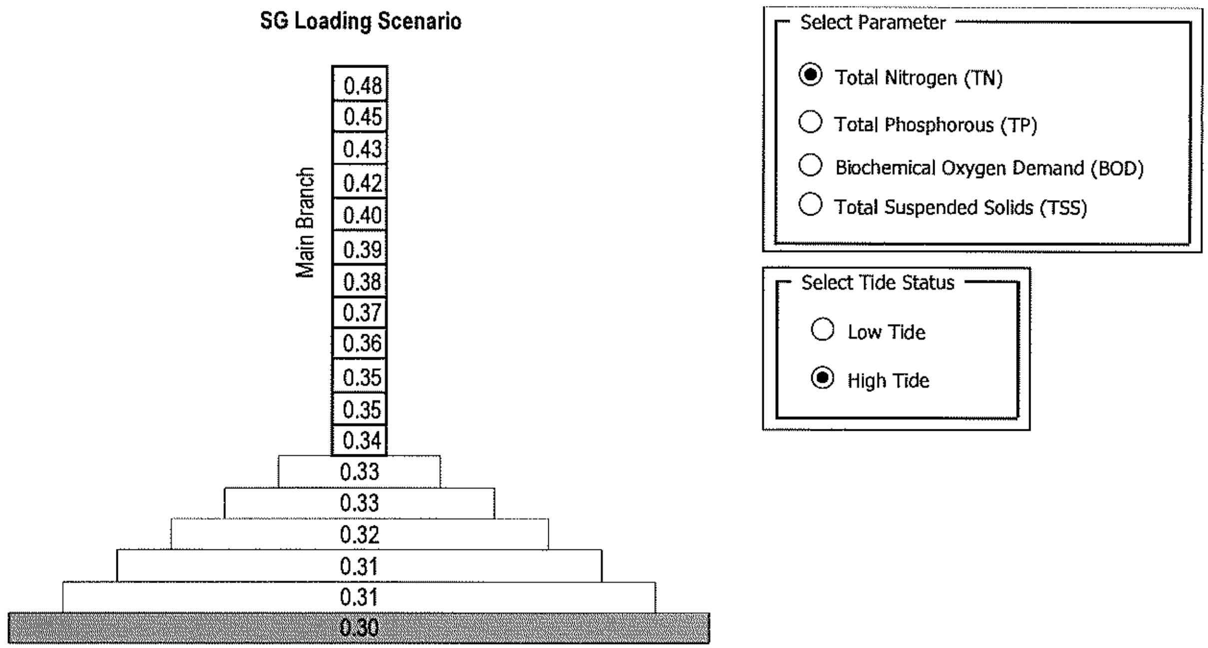
Canal #246, Marathon Model Output: TSS, high tide



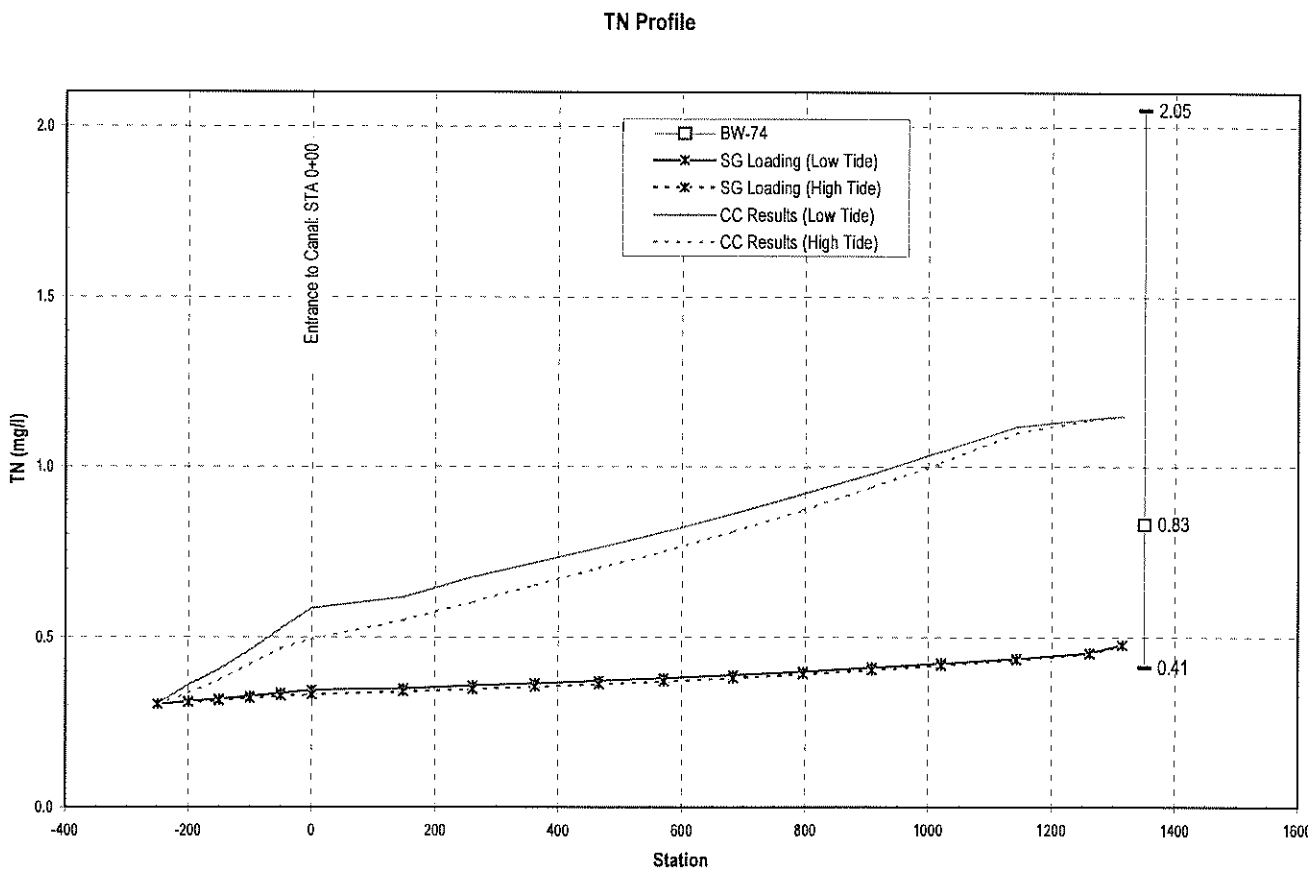
Canal #246, Marathon Model Output: TSS Profile



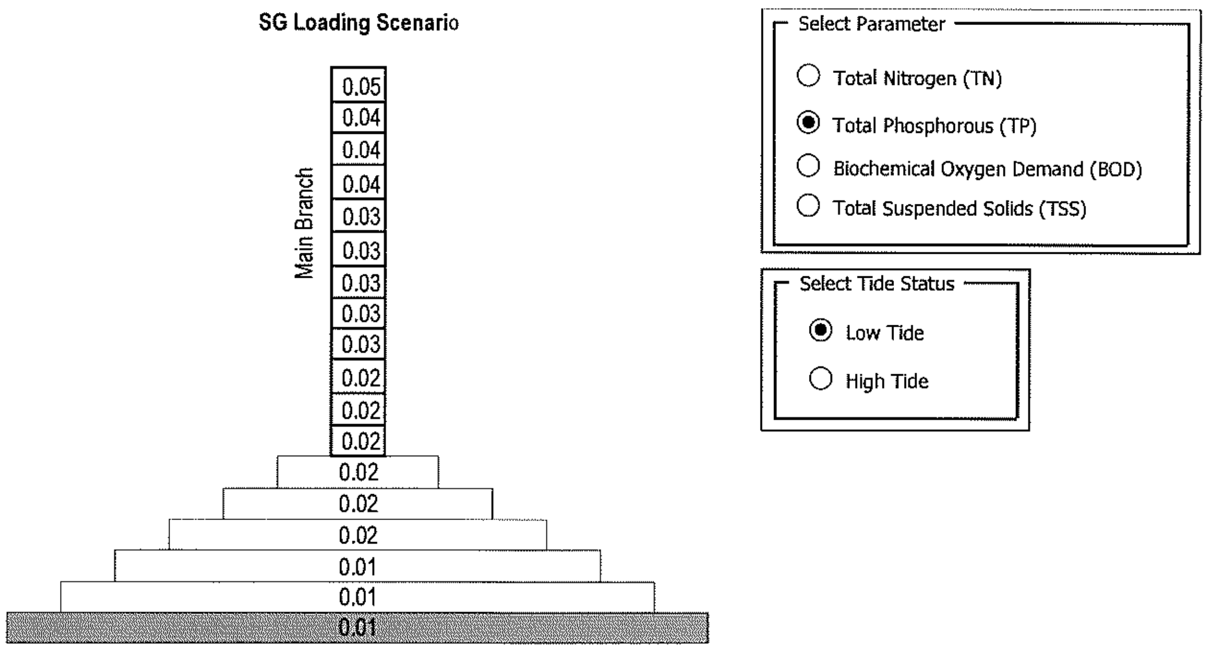
Canal #288, Big Pine Model Output: TN, low tide



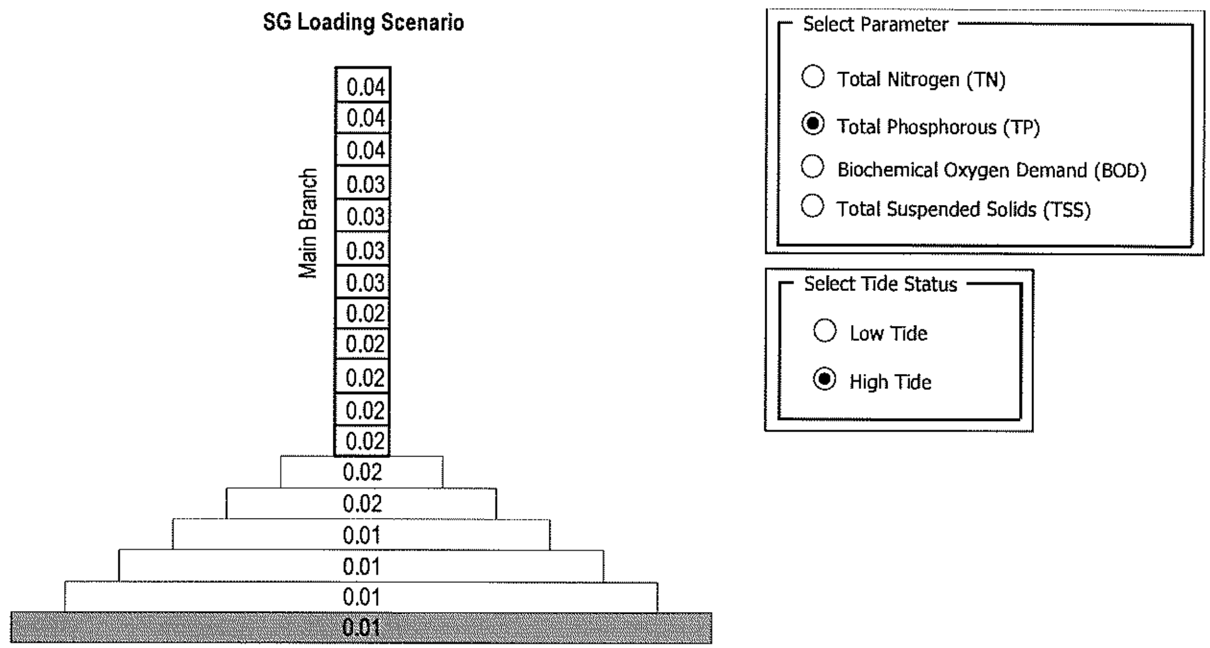
Canal #288, Big Pine Model Output: TN, high tide



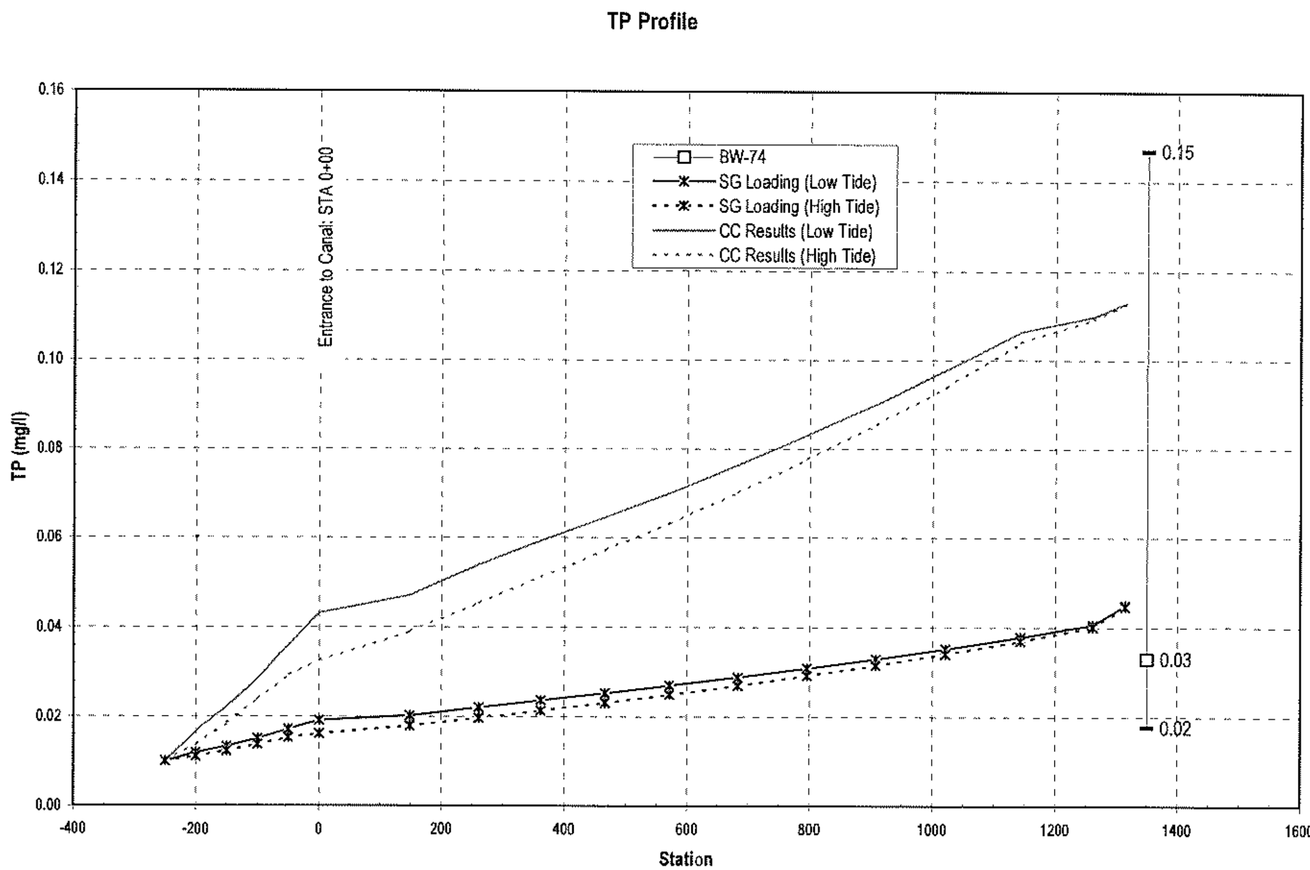
Canal #288, Big Pine Model Output: TN Profile



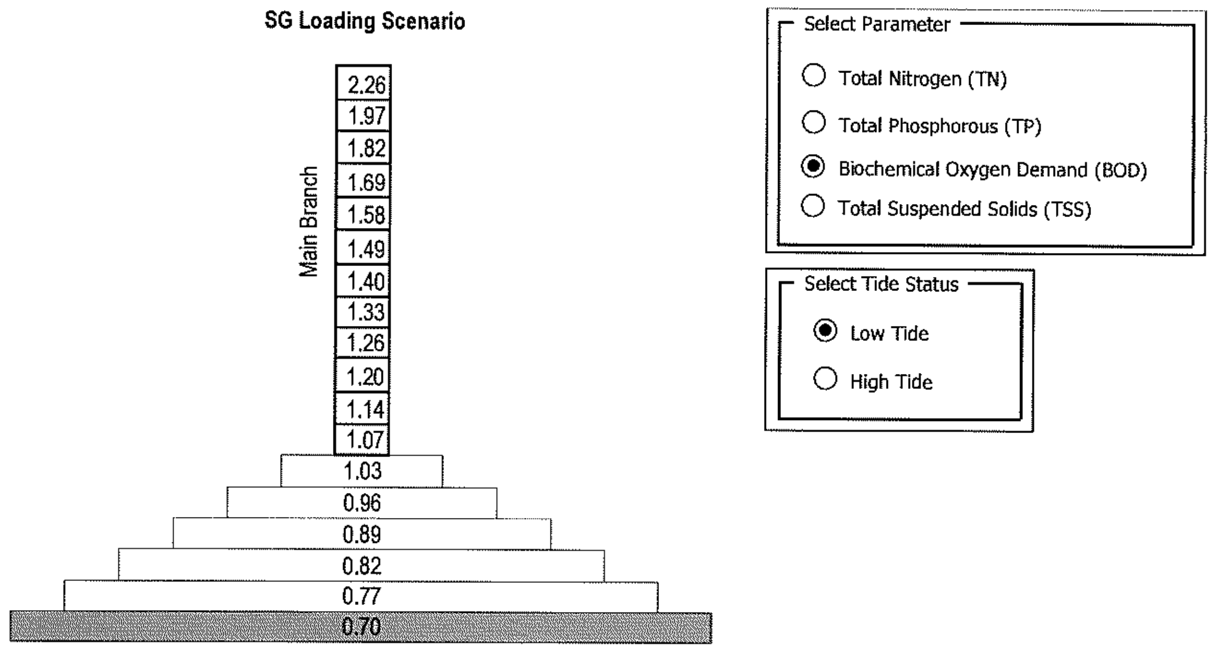
Canal #288, Big Pine Model Output: TP, low tide



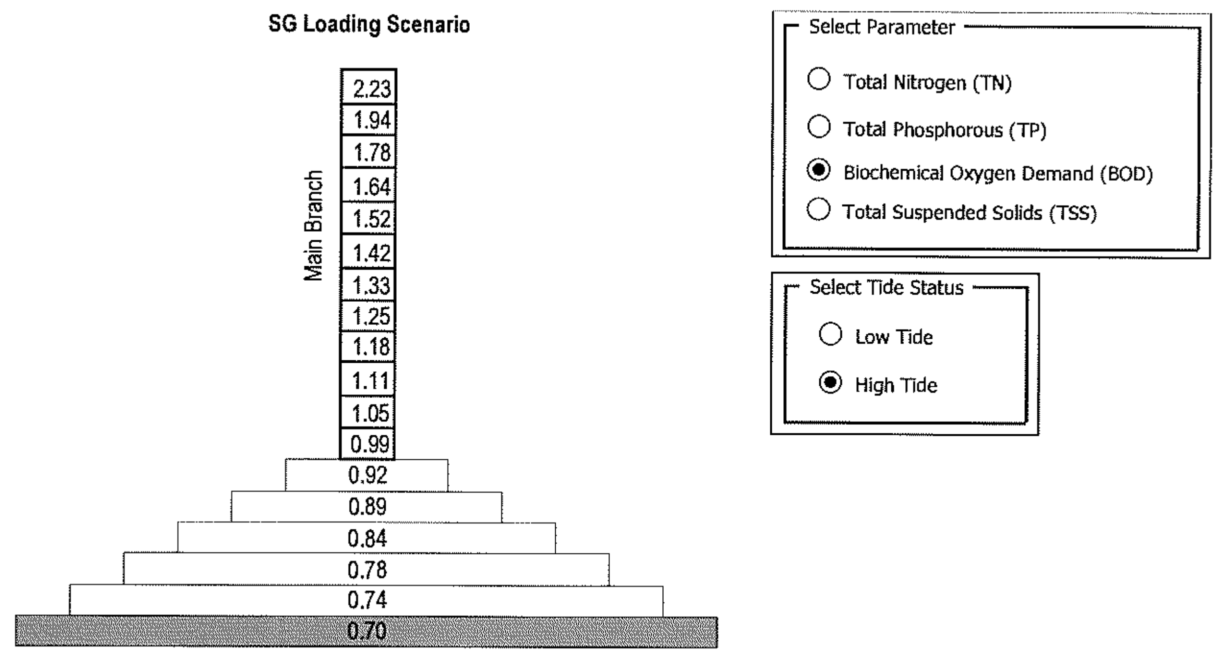
Canal #288, Big Pine Model Output: TP, high tide



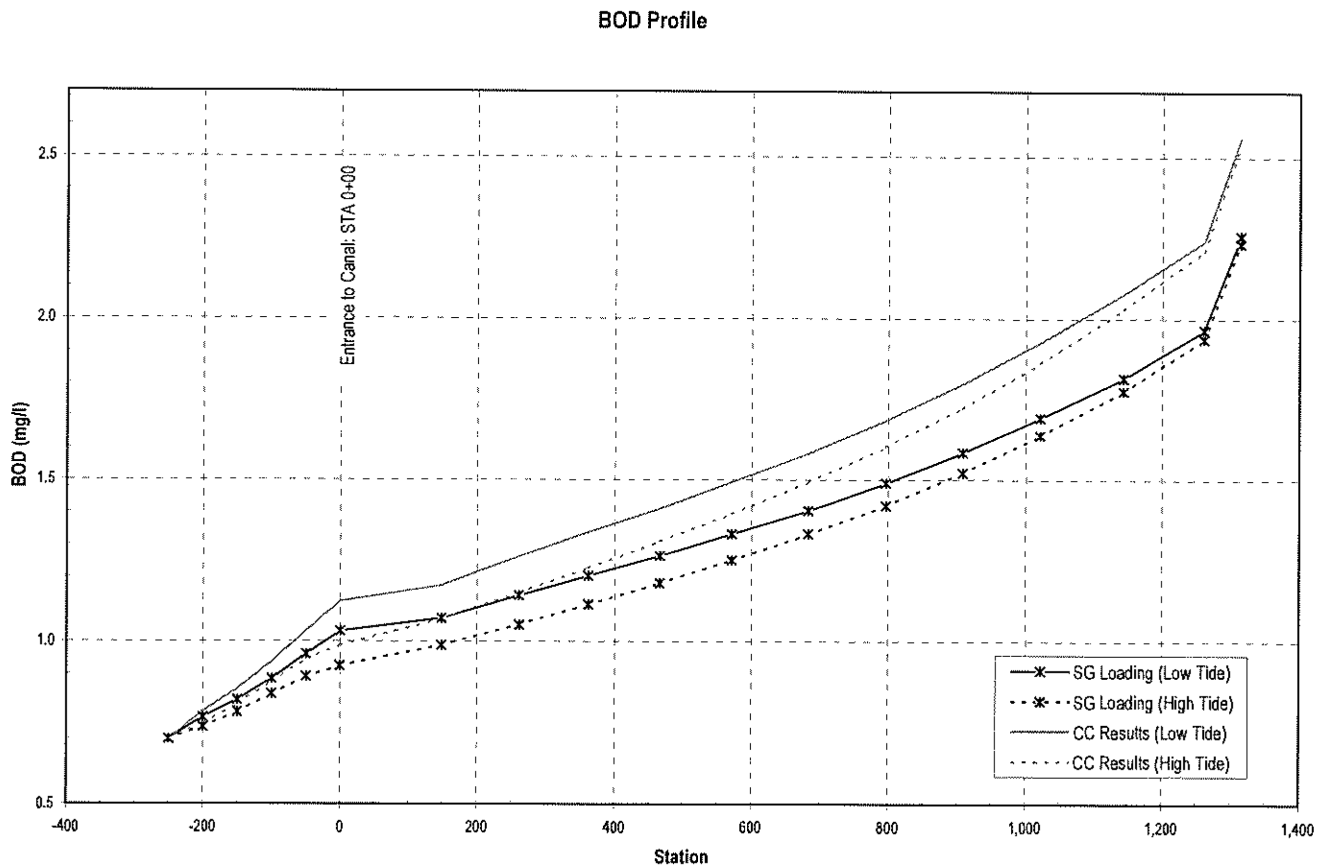
Canal #288, Big Pine Model Output: TP Profile



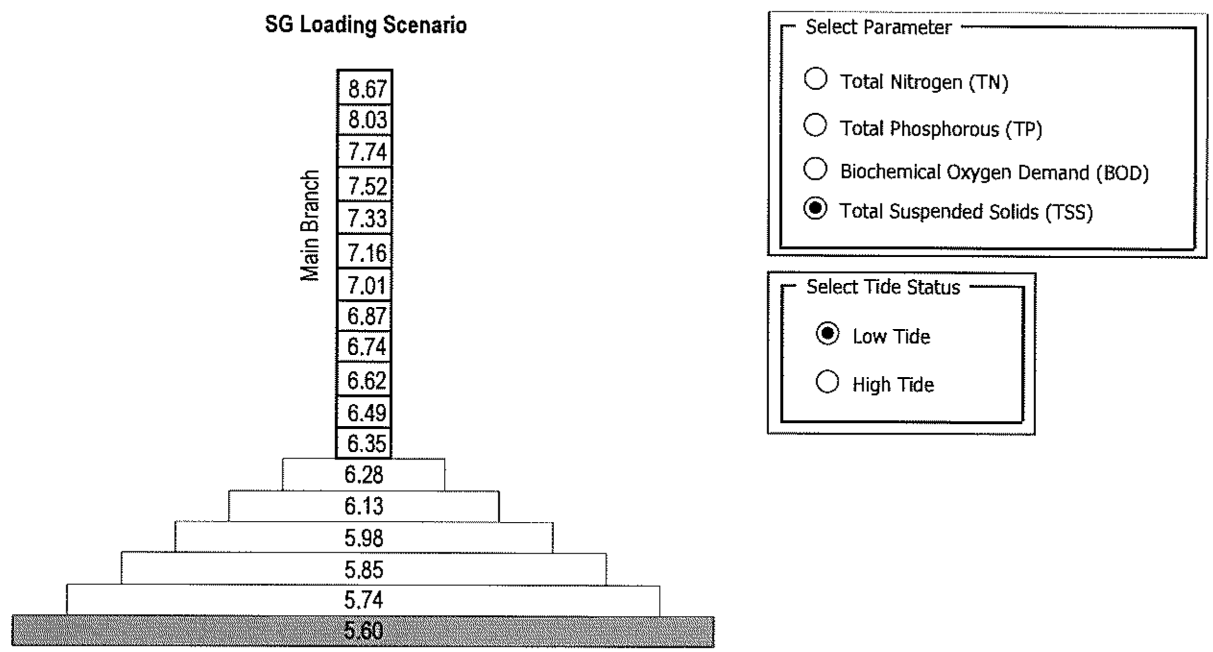
Canal #288, Big Pine Model Output: BOD, low tide



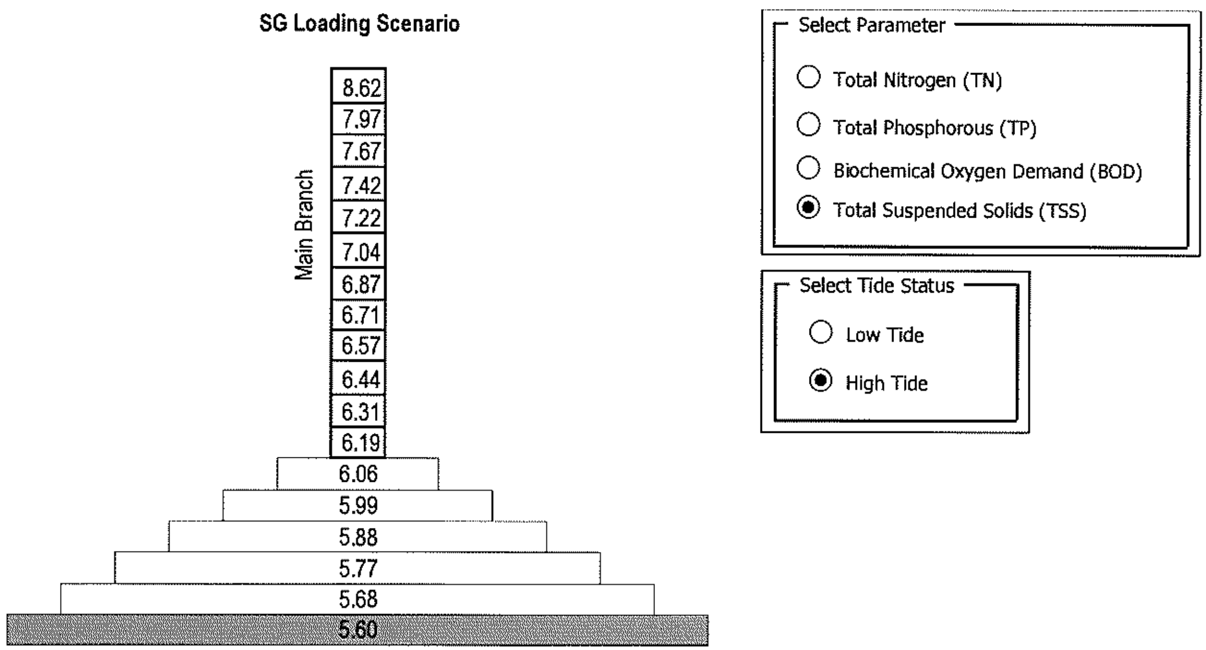
Canal #288, Big Pine Model Output: BOD, high tide



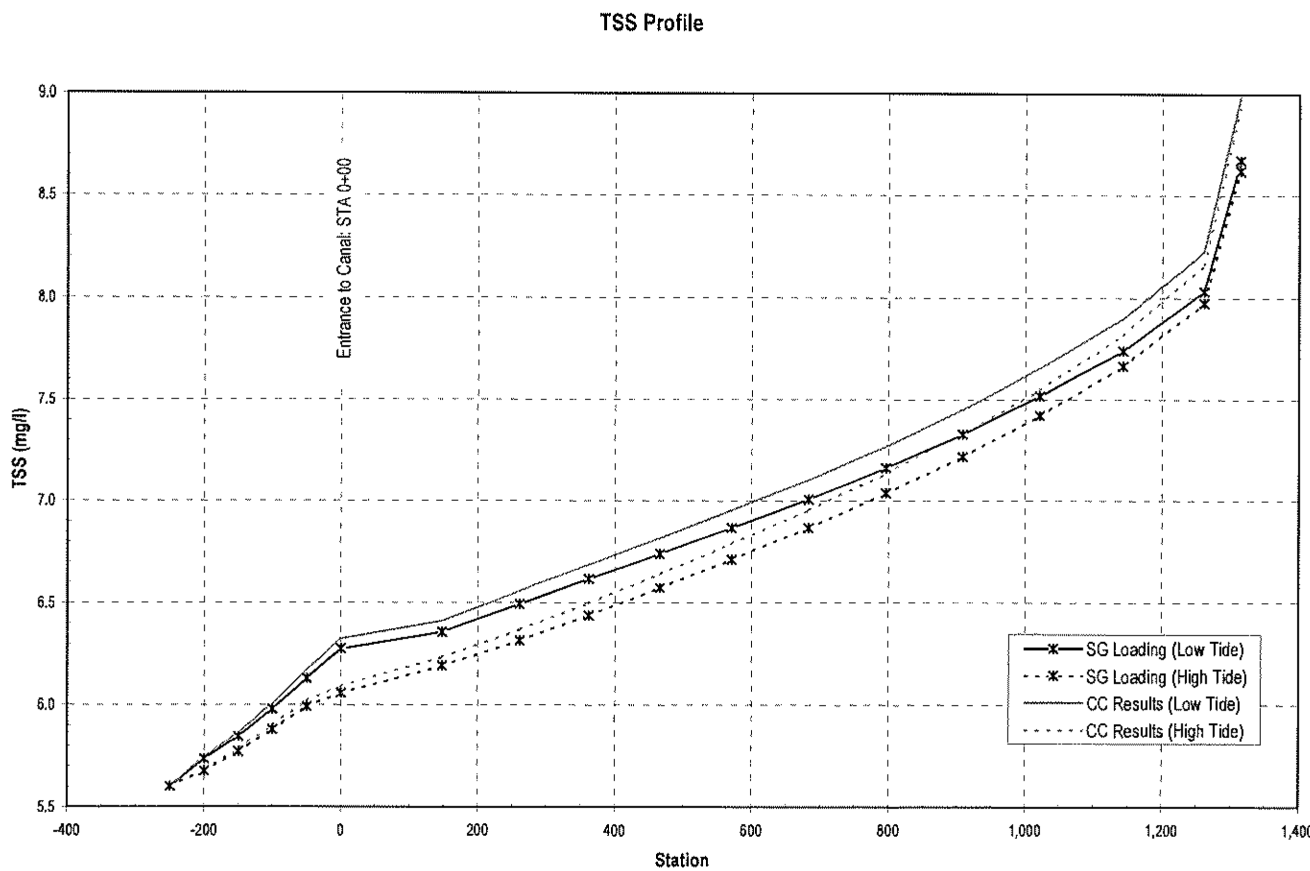
Canal #288, Big Pine Model Output: BOD Profile



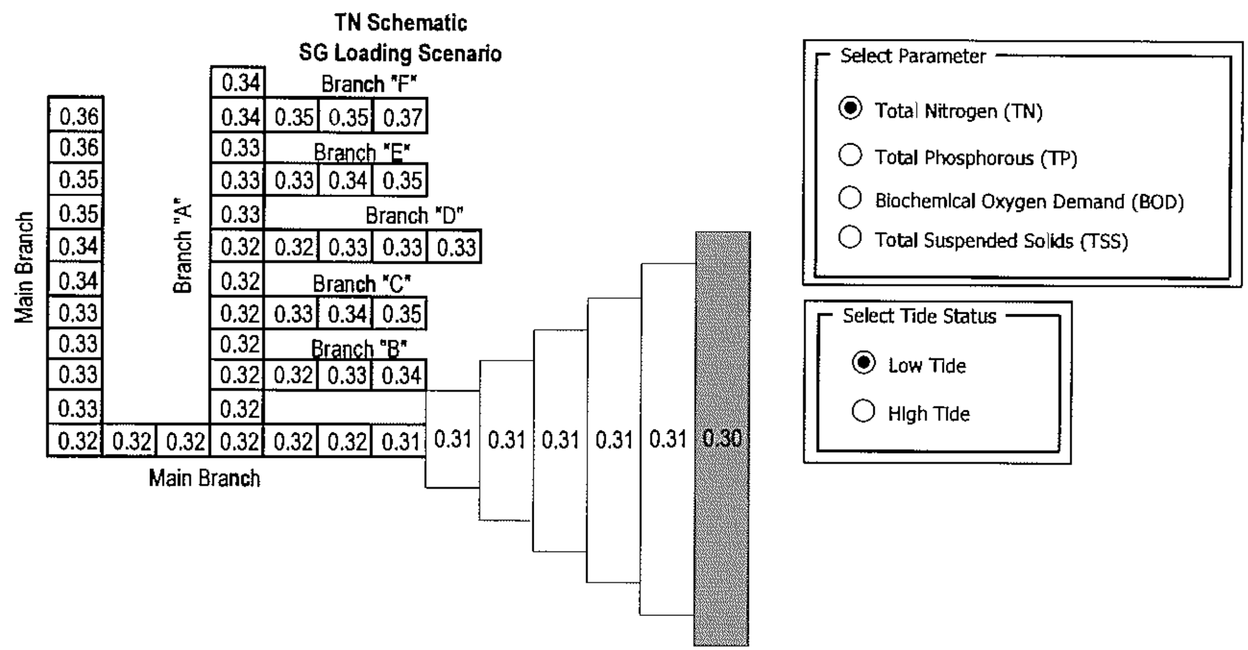
Canal #288, Big Pine Model Output: TSS, low tide



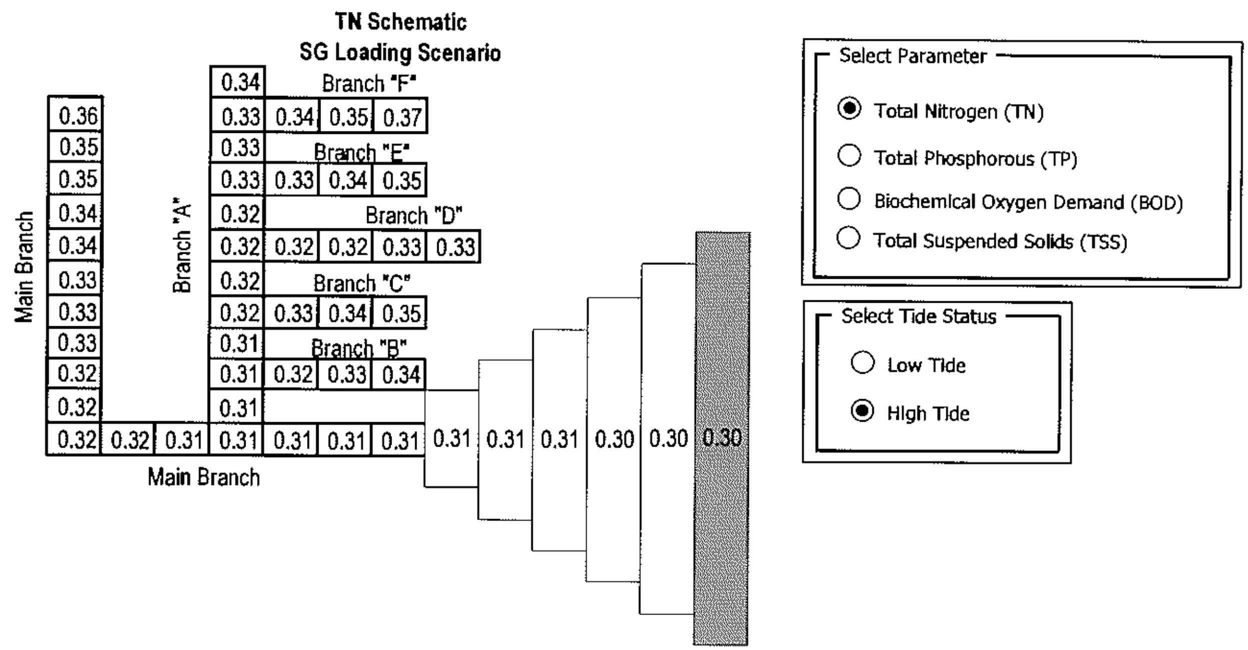
Canal #288, Big Pine Model Output: TSS, high tide



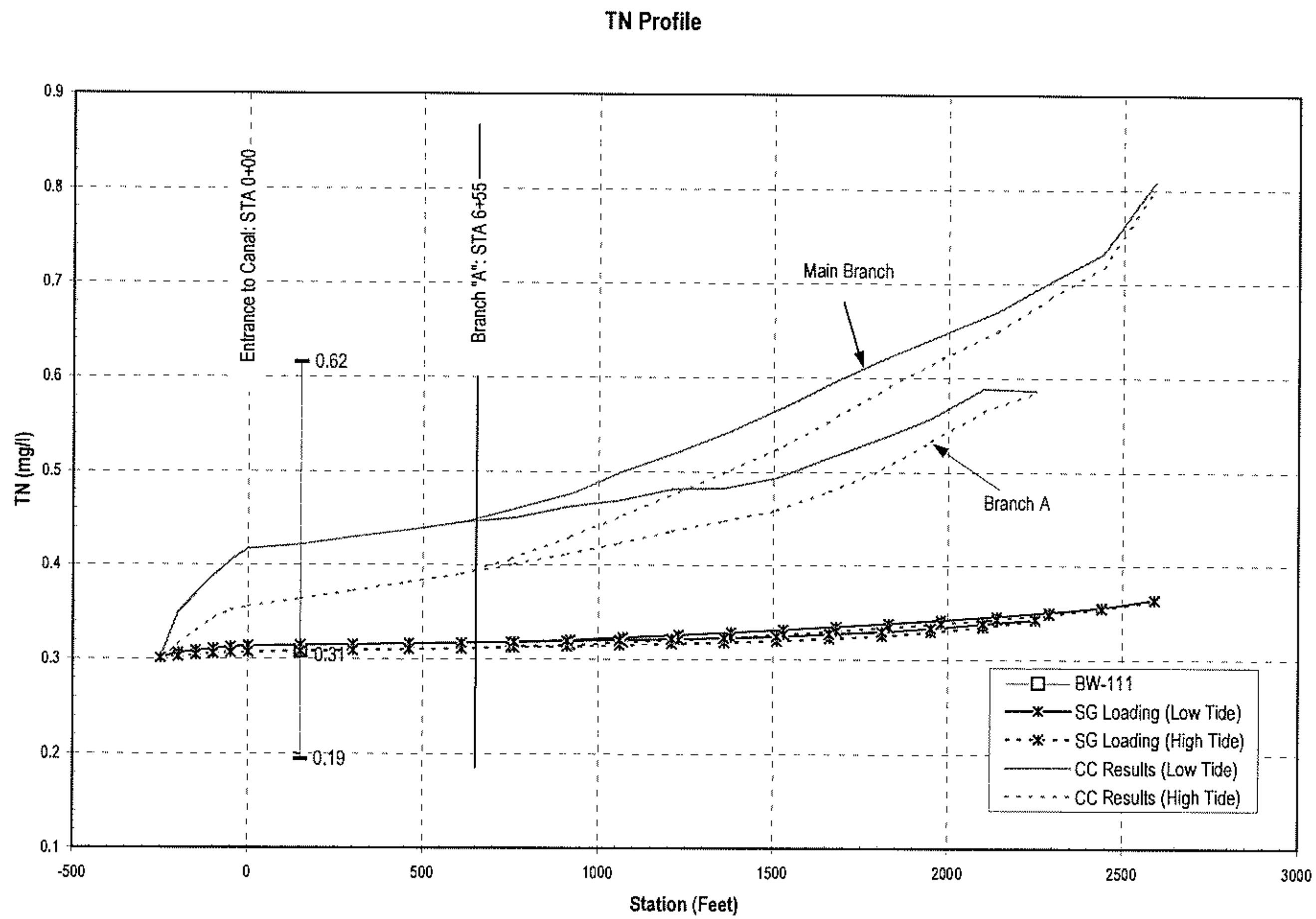
Canal #288, Big Pine Model Output: TSS Profile



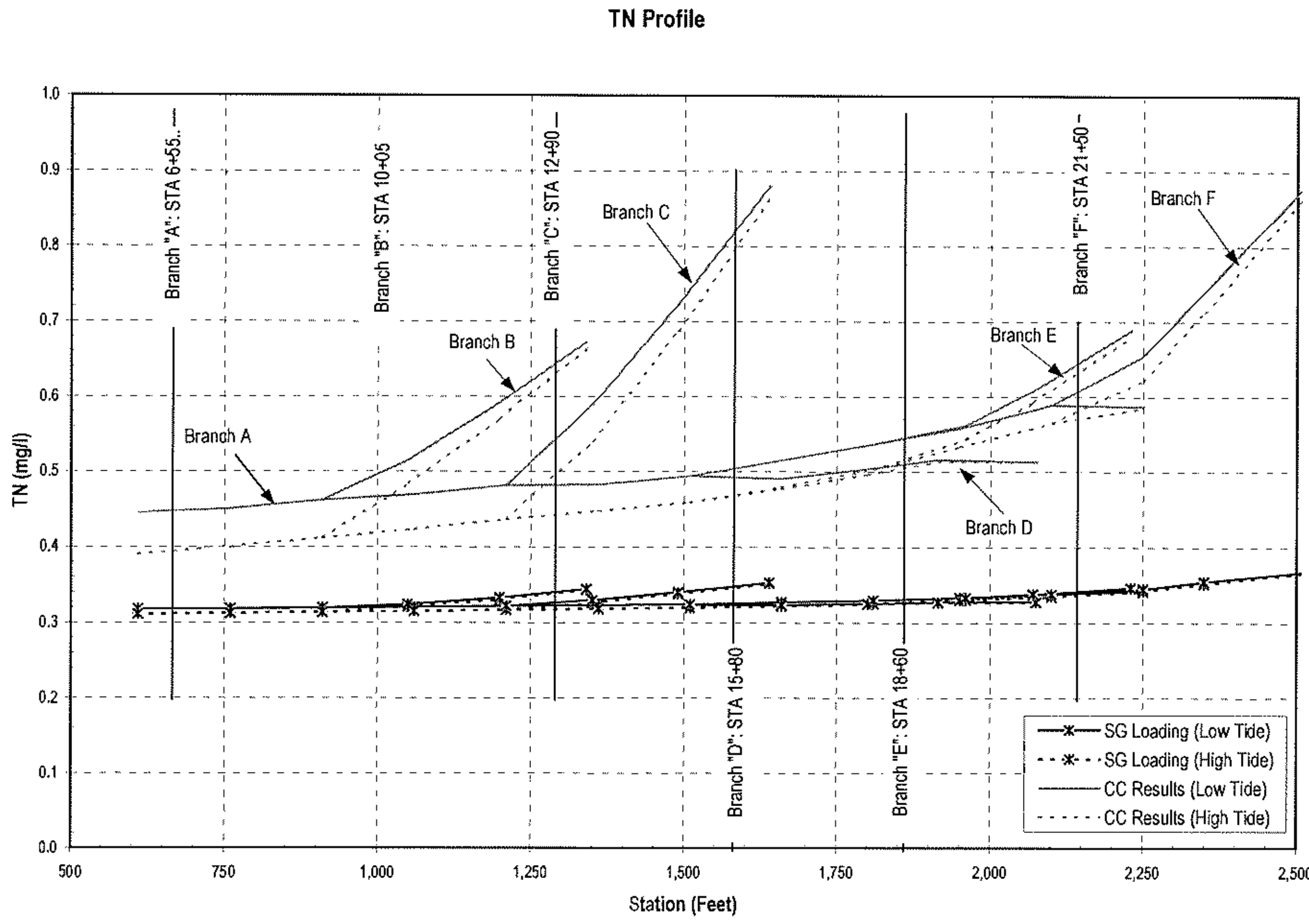
Canal #339, Little Torch Model Output: TN, low tide



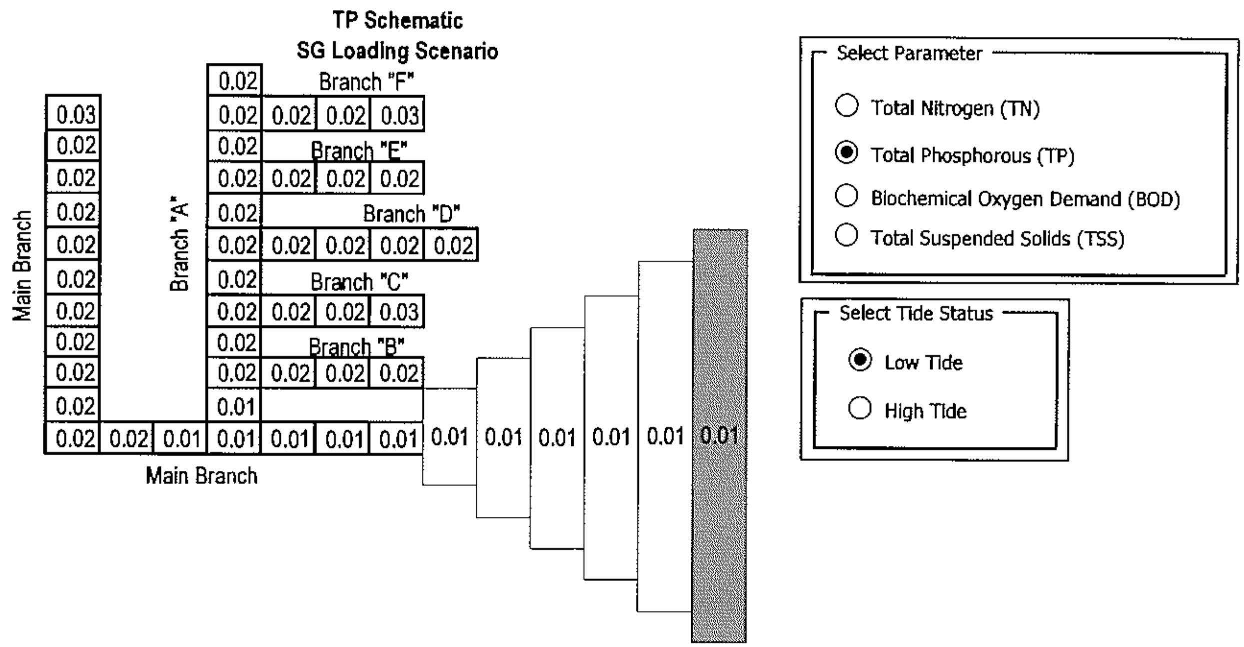
Canal #339, Little Torch Model Output: TN, high tide



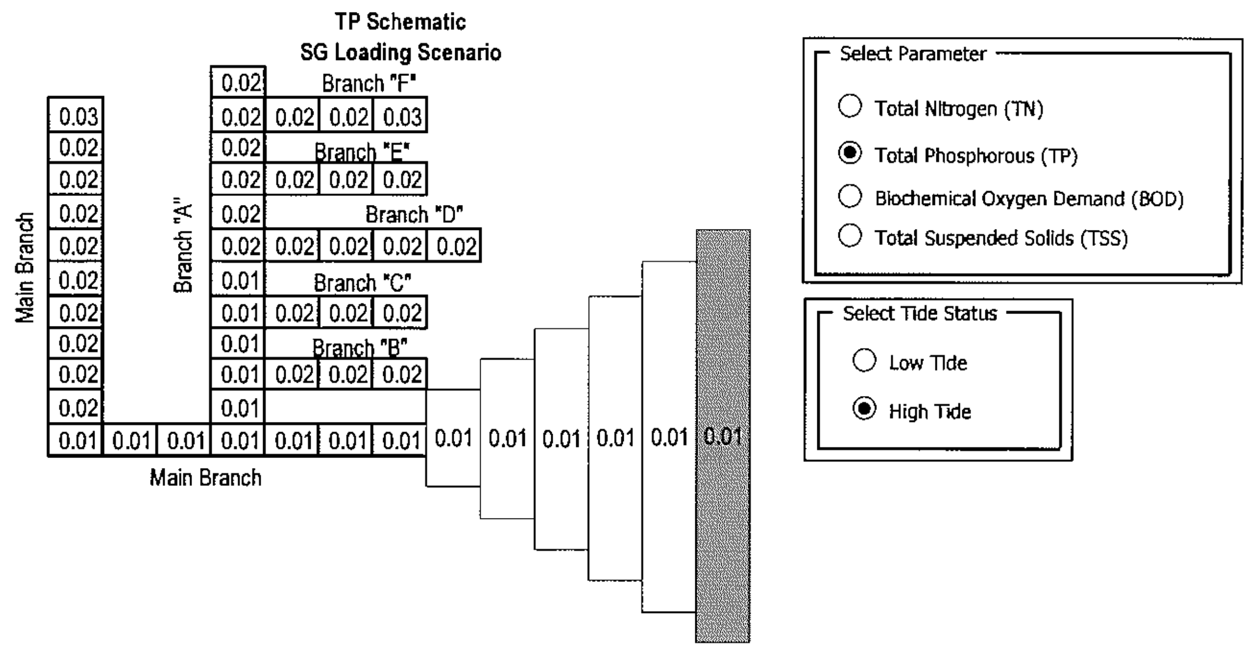
Canal #339, Little Torch Model Output: TN Profile



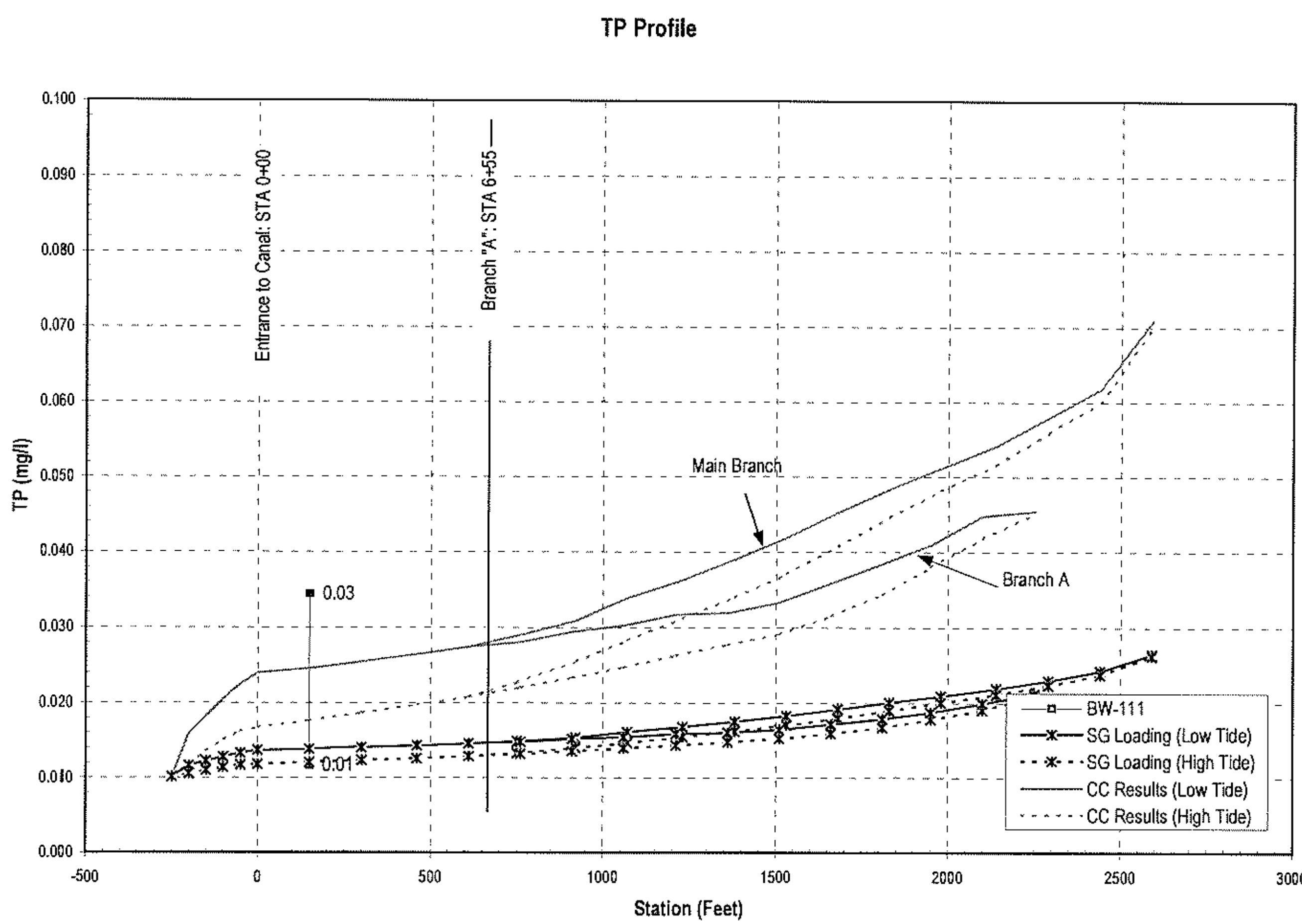
Canal #339, Little Torch Model Output: TN Profile



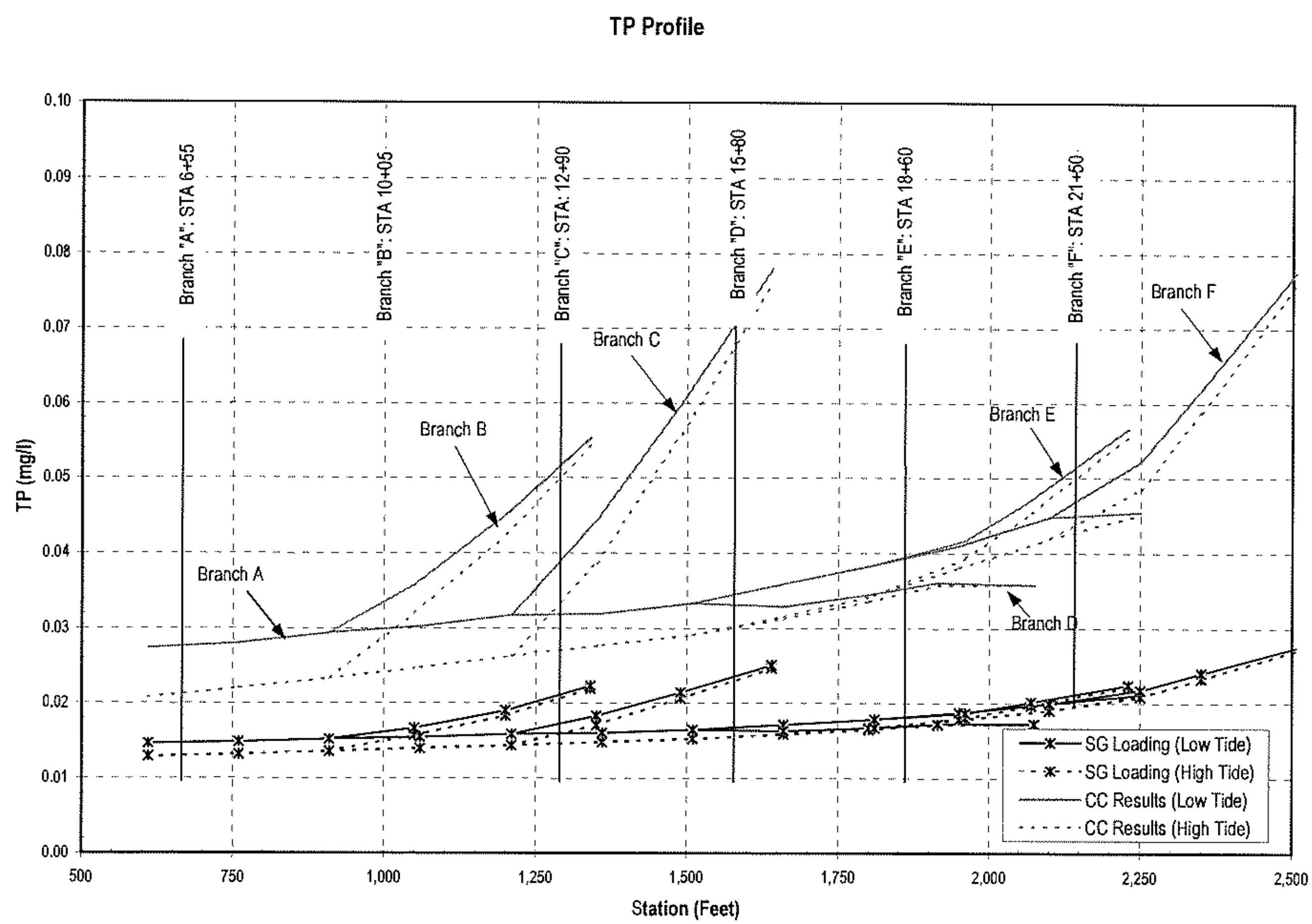
Canal #339, Little Torch Model Output: TP, low tide



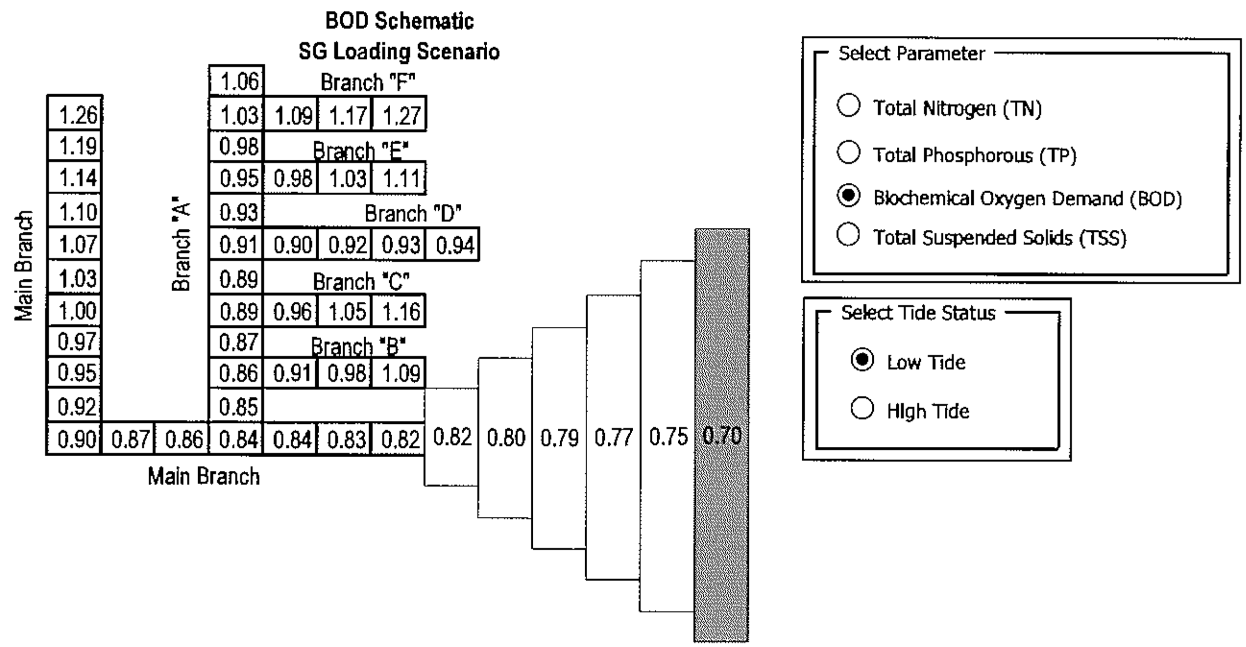
Canal #339, Little Torch Model Output: TP, high tide



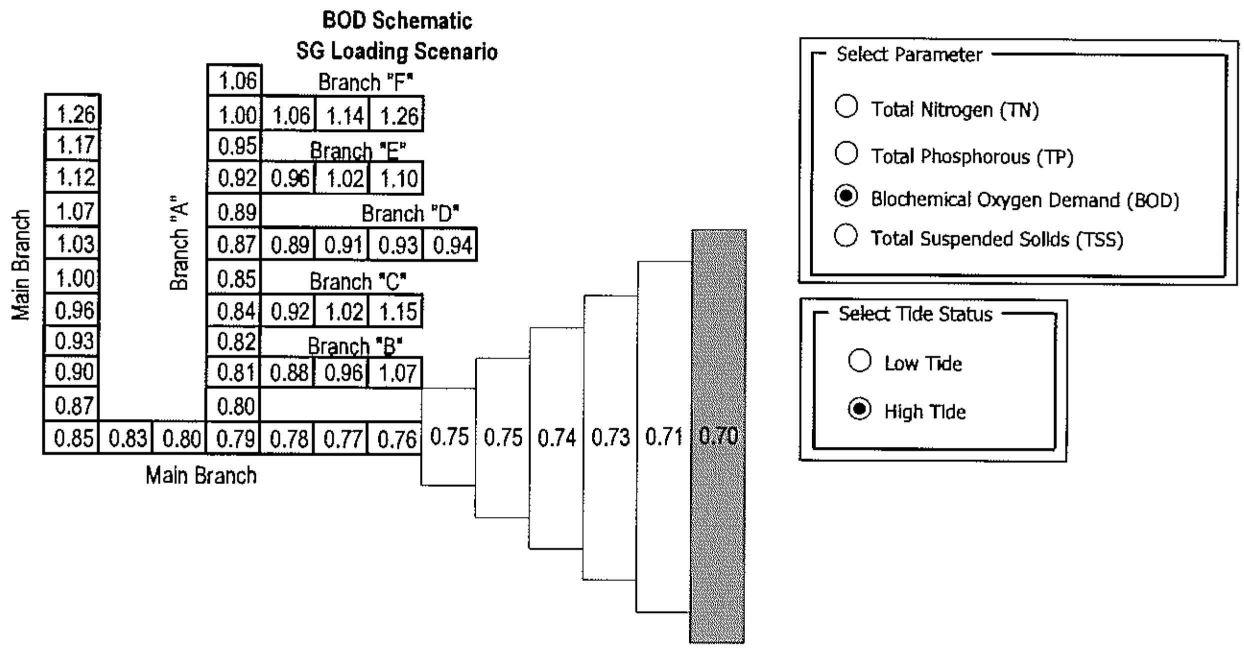
Canal #339, Little Torch Model Output: TP Profile



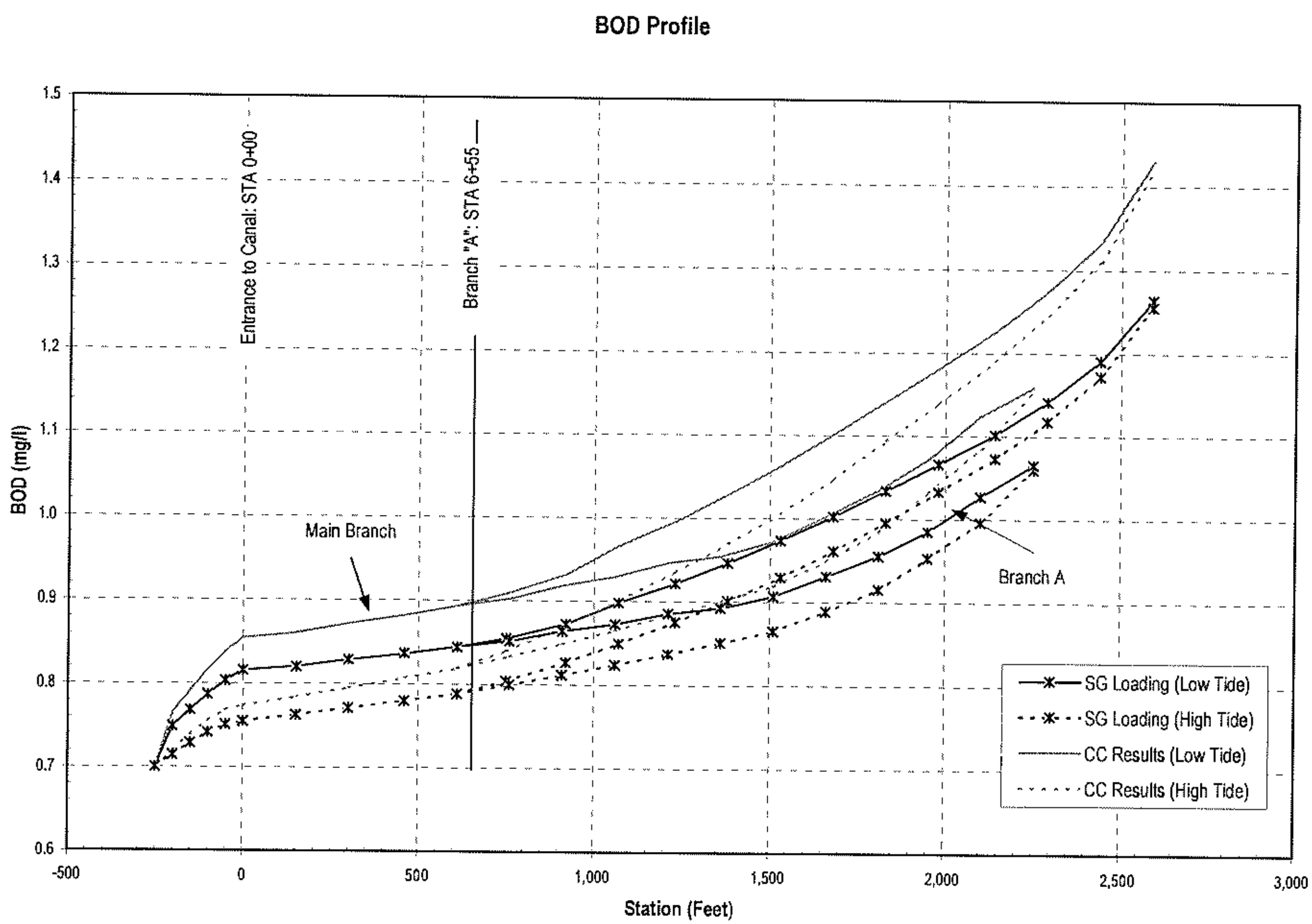
Canal #339, Little Torch Model Output: TP Profile



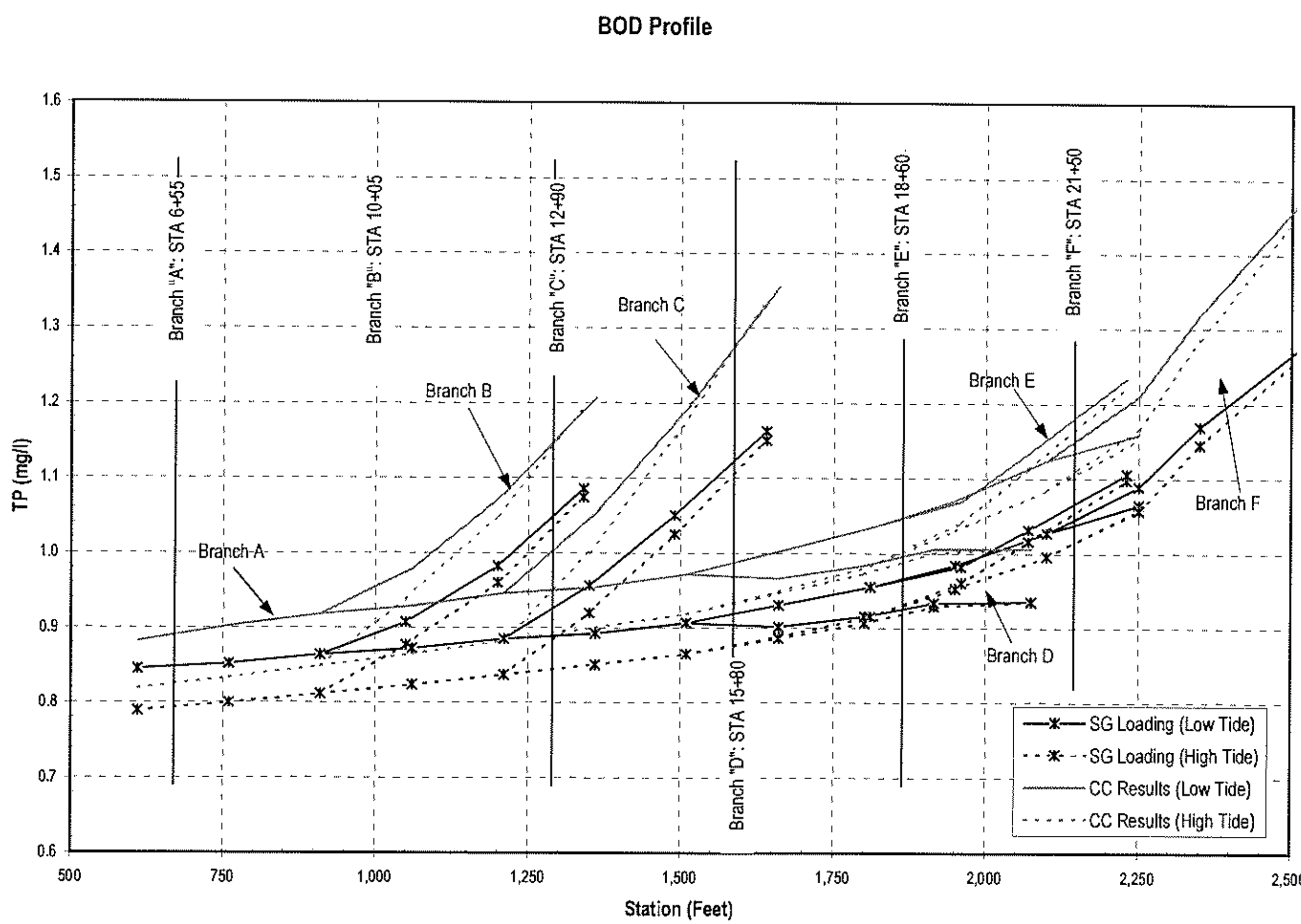
Canal #339, Little Torch Model Output: BOD, low tide



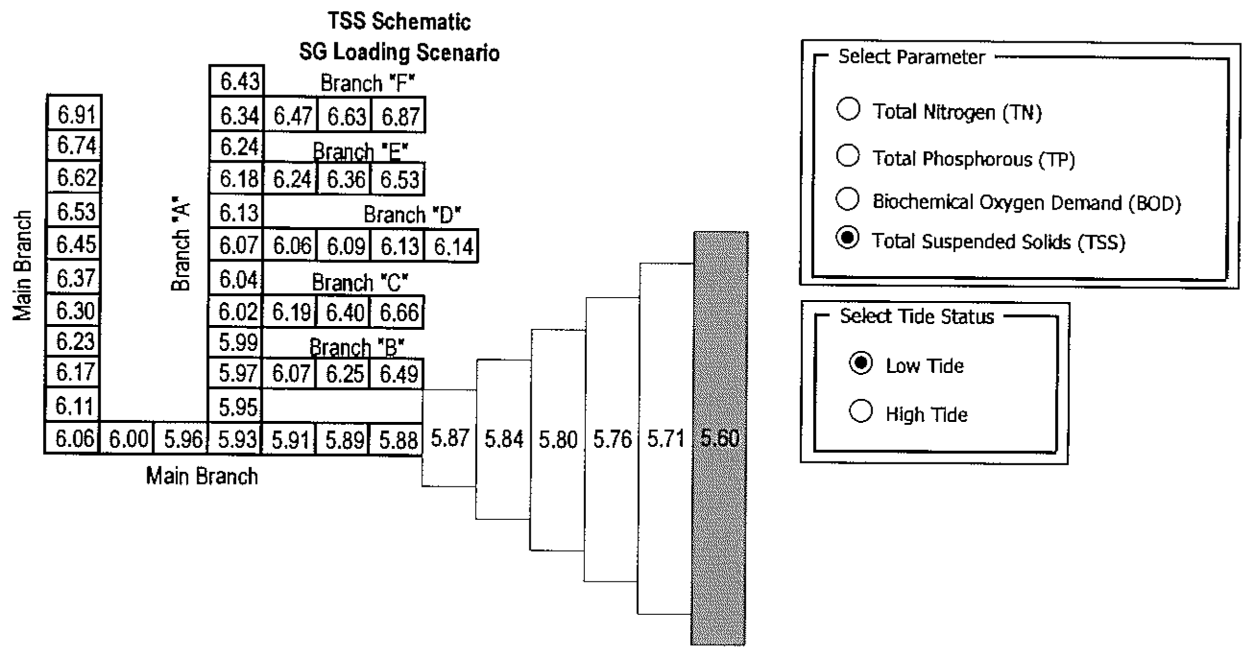
Canal #339, Little Torch Model Output: BOD, high tide



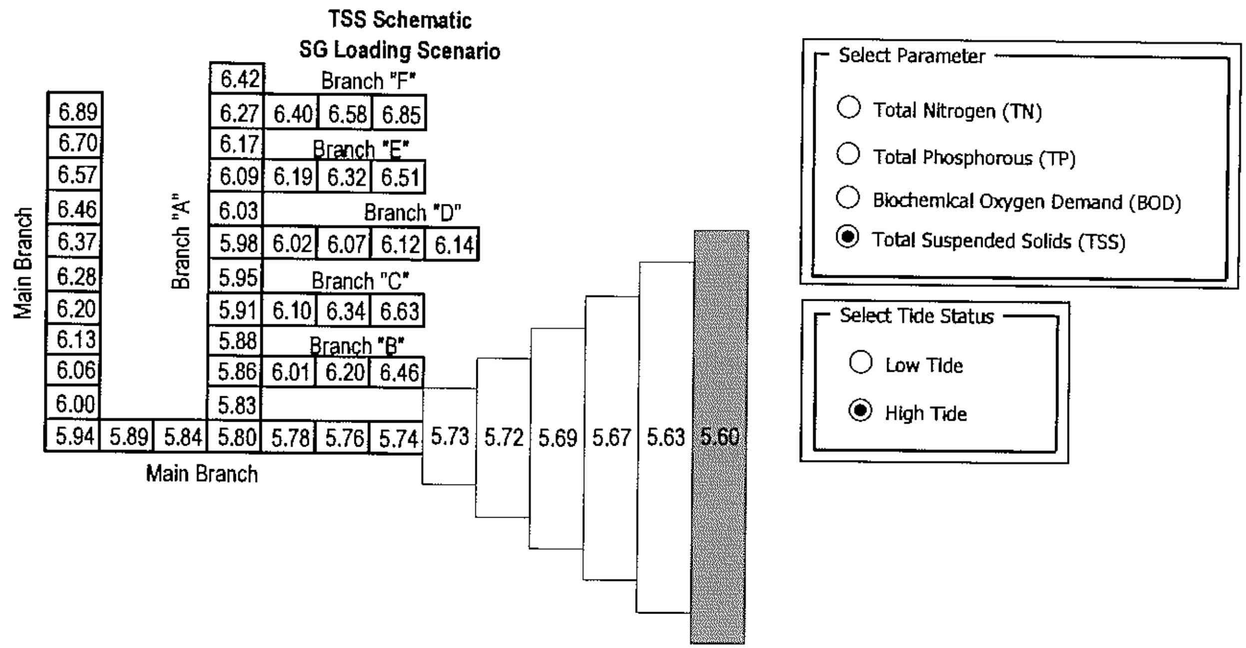
Canal #339, Little Torch Model Output: BOD Profile



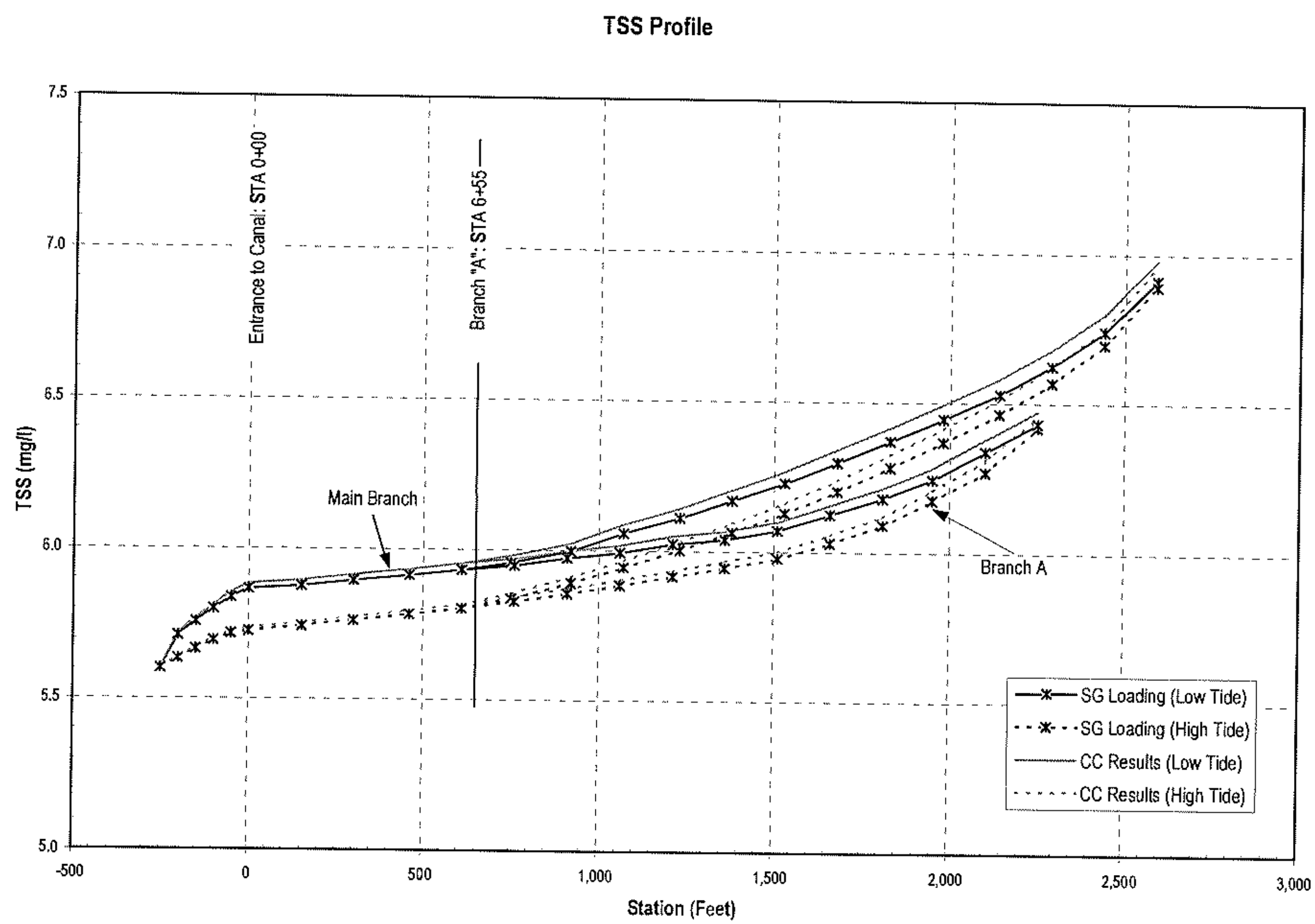
Canal #339, Little Torch Model Output: BOD Profile



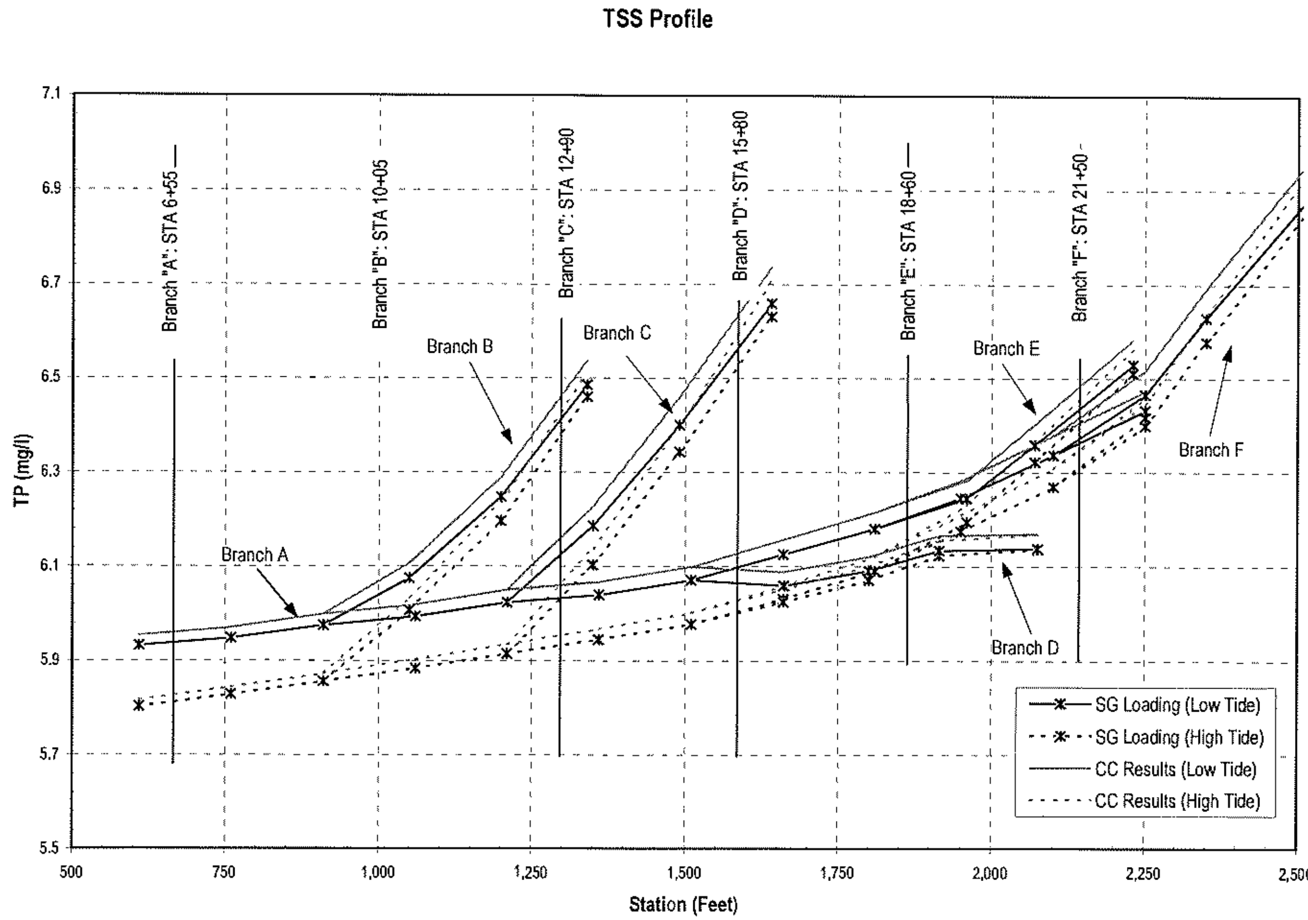
Canal #339, Little Torch Model Output: TSS, low tide



Canal #339, Little Torch Model Output: TSS, high tide



Canal #339, Little Torch Model Output: TSS Profile



Canal #339, Little Torch Model Output: TSS Profile