Appendix B

MEP Memos

The Massachusetts Estuaries Project has released several documents related to water resources in Harwich, relative to the CWMP planning process. Included in this appendix are the memoranda related to the MEP reports. Full MEP reports are several hundred pages long. These reports have been made available on the Town of Harwich website, and links are provided below.

- MEP Published Reports – draft and Final
  - Pleasant Bay Final Report – May 2006
  - Allen, Wychmere, Saquatucket Report – June 2010
  - Muddy Creek Final Report – November 2008
  - All reports available on Town of Harwich website: http://harwichma.virtualtownhall.net/Public_Documents/HarwichMA_BComm/CWMP/MEP%20Reports/
- Technical Memoranda
  - Nitrogen Loads by TMDL Watershed/Segments to Pleasant Bay – November 2007
  - Water use and Muddy Creek Nitrogen Attenuation – June 2010
  - MEP Scenarios to Evaluate Water Quality Impacts of the Addition of a 24 foot Culvert in Muddy Creek Inlet – October 2010

CAPE COD COMMISSION

3225 MAIN STREET
P.O. BOX 226
BARNSTABLE, MA 02630
(508) 362-3828
FAX (508) 362-3136
E-mail: frontdesk@capecodcommission.org
WATER EMAIL: water@capecodcommission.org

MEMORANDUM

TO: Pleasant Bay Resource Management Alliance, Watershed Working Group
Carole Ridley, Coordinator, Pleasant Bay Resource Management Alliance
Cape Cod Commission members: Brewster, Chatham, Harwich, Orleans

CC: Brian Howes, SMAST, UMASS Dartmouth
Tom Cambareri, CCC
Paul Niedzwiecki, CCC

FROM: Ed Eichner, Water Scientist

DATE: November 28, 2007

RE: Individual town nitrogen loads by TMDL watershed/segments to Pleasant Bay

---

As a follow-up on my September 25 memo detailing each town's nitrogen loading contribution to each of the individual subwatersheds to the Pleasant Bay estuary, the Alliance Watershed Working Group requested additional analysis to aggregate the loads according to the subembayments listed in the MassDEP TMDL for Pleasant Bay (May 2007). As with the September 25 analysis, each town's contribution of attenuated and unattenuated nitrogen loads under existing and buildout conditions were determined beginning with the Massachusetts Estuaries Project watershed model and reworking its results and equations to complete the requested analysis. Funding for this effort was provided by the current Management Challenges for Nitrogen Control grant that the Commission has from the US Environmental Protection Agency.

Table 1 show the results of the analysis with existing and buildout unattenuated loads for each of the 20-listed TMDL segments for Pleasant Bay, as well as the complementary attenuated loads and the TMDL watershed thresholds. This analysis incorporates the results of the analysis completed to breakdown the loads by town for each of the 95 subwatersheds. Total loads from this analysis by town are generally within 1% of the September 25 memo loads. This analysis also incorporates the percentage reductions in nitrogen load for the portion of the loads that flow out of the system at ponds that straddle the overall watershed boundary.

Table 1. Nitrogen Loads by Town for the Pleasant Bay TMDL Segments

All nitrogen loads are in kilograms per year. All loads account for load reductions caused by groundwater flow out of the watershed from ponds that straddle the outer boundary of the Pleasant Bay watershed. Watershed names are based on the segments listed in the MassDEP TMDL document for Pleasant Bay (May 2007). Target watershed loads for each TMDL segment are listed for comparison. No loads are listed for Little Pleasant Bay because the boundaries of this portion of the system are not included in the TMDL or the MEP Technical Report, which is the basis for the TMDL.

	Target Watershed Load from TMDL	EXISTING UNATTENUATED w/outflows included					EXISTING ATTENUATED					% Atten	BUILDOUT UNATTENUATED w/outflows included					BUILDOUT ATTENUATED					% Atten
Watershed Name	Annual Load	ORL	BRE	HAR	CHA	TOTAL	ORL	BRE	HAR	CHA	TOTAL		ORL	BRE	HAR	CHA	TOTAL	ORL	BRE	HAR	CHA	TOTAL	
Meetinghouse Pond	387	2256	0	0	0	2256	2256	0	0	0	2256	0%	3008	0	0	0	3008	3008	0	0	0	3008	0%
The River - upper	635	1174	61	0	0	1235	998	7	0	0	1005	19%	1685	76	0	0	1761	1433	10	0	0	1443	18%
The River - lower	891	1549	107	0	0	1656	1390	16	0	0	1405	15%	2603	117	0	0	2720	2392	19	0	0	2411	11%
Kescayo Gansett Pond	595	1139	248	0	0	1388	838	40	0	0	878	37%	1628	283	0	0	1910	1230	53	0	0	1283	33%
Areys Pond	336	367	282	0	0	650	367	95	0	0	463	29%	636	286	0	0	922	636	96	0	0	732	21%
Namequoit River	631	1034	117	0	0	1151	935	51	0	0	987	14%	1494	167	0	0	1661	1367	98	0	0	1465	12%
Pah Wah Pond	266	679	0	0	0	679	679	0	0	0	679	0%	1023	0	0	0	1023	1023	0	0	0	1023	0%
Pochet Neck	1504	3135	0	0	0	3135	3073	0	0	0	3073	2%	4411	0	0	0	4411	4336	0	0	0	4336	2%
Little Pleasant Bay	2146																						
Quanset Pond	394	723	142	0	0	865	569	72	0	0	641	26%	965	175	0	0	1141	771	89	0	0	859	25%
Round Cove	1080	0	2	1553	0	1554	0	1	1544	0	1545	1%	0	2	1900	0	1901	0	1	1891	0	1892	1%
Muddy Creek - Upper	1683	0	0	2584	1234	3819	0	0	2510	1154	3663	4%	0	0	3501	1373	4874	0	0	3403	1290	4694	4%
Muddy Creek - Lower	781	0	0	1809	1488	3297	0	0	1802	1294	3096	6%	0	0	2421	1501	3922	0	0	2413	1306	3719	5%
Pleasant Bay	7975	4055	6212	2732	1526	14525	3538	6077	2622	1526	13763	5%	6237	7468	3743	2265	19712	5543	7187	3630	2265	18625	6%
Ryder Cove	1632	0	0	0	4054	4054	0	0	0	3613	3613	11%	0	0	0	4559	4559	0	0	0	4424	4424	3%
Frostfish Creek	256	0	0	0	1059	1059	0	0	0	1059	1059	0%	0	0	0	1211	1211	0	0	0	1211	1211	0%
Crows Pond	1540	0	0	0	1542	1542	0	0	0	1537	1537	0%	0	0	0	1699	1699	0	0	0	1694	1694	0%
Bassing Harbor	610	0	0	0	620	620	0	0	0	607	607	2%	0	0	0	730	730	0	0	0	716	716	2%
Chatham Harbor	6242	0	0	0	6377	6377	0	0	0	6309	6309	1%	0	0	0	7106	7106	0	0	0	7030	7030	1%
System TOTAL	29656	16112	7171	8678	17900	49860	14644	6360	8478	17099	46580	7%	23691	8574	11565	20443	64272	21739	7553	11337	19935	60564	6%

Table 2 shows the percentage of the nitrogen loads from this analysis. The load percentages are the same as the September 25 memo results except for the attenuated buildout in Brewster which decreased by 1% due to a slight change in rounding.

Table 2 also shows percentage watershed land area and the watershed including estuary surface areas by town. These comparisons were used in the Popponesset Bay discussions of town fair shares and are provided in anticipation of similar future discussions for Pleasant Bay. The areas that these percentages are based on do not account for the portions of recharge that flow out of the system.

As mentioned above, this effort to determine subwatershed loads by individual town was funded using grant funds from the Commission's Management Challenges for Nitrogen Control grant that the Commission has from the US Environmental Protection Agency. The effort represents approximately $2,000 worth of Cape Cod Commission staff time.

Table 2. Watershed Nitrogen Load and Watershed Area by Town for Pleasant Bay

NITROGEN LOADS (%)	Orleans	Brewster	Harwich	Chatham
Existing Unattenuated	32%	14%	17%	36%
Existing Attenuated	31%	14%	18%	37%
Buildout Unattenuated	37%	13%	18%	32%
Buildout Attenuated	36%	12%	19%	33%
WATERSHED AREA				
Watershed Land (acres)	5,293	3,527	2,643	3,655
Estuary Surface (acres)	3,528	-	153	2,802
Land and Estuary (acres)	8,822	3,527	2,795	6,456
Watershed Land (%)	35%	23%	17%	24%
Estuary Surface (%)	54%	0%	2%	43%
Land and Estuary (%)	41%	16%	13%	30%

Notes:
1) nitrogen loading percentages based on watershed load only; do not include loads on estuary surfaces
2) all loads adjusted to account for nitrogen loads that flow out of the watershed
3) attenuated loads account for reductions caused by application of multiple attenuation factors in situations where loads flow through multiple ponds
4) watershed land area is not adjusted to account for flow out of the watershed system
5) rounding may cause some totals to appear inaccurate

CAPE COD COMMISSION

3225 MAIN STREET
P.O. BOX 226
BARNSTABLE, MA 02630
(508) 362-3828
FAX (508) 362-3136
E-mail: frontdesk@capecodcommission.org
WATER EMAIL: water@capecodcommission.org

MEMORANDUM

TO: Pleasant Bay Resource Management Alliance, Watershed Working Group
Carole Ridley, Coordinator, Pleasant Bay Resource Management Alliance
Cape Cod Commission members: Brewster, Chatham, Harwich, Orleans

CC: Brian Howes, SMAST, UMASS Dartmouth
Tom Cambareri, CCC
Paul Niedzwiecki, CCC

FROM: Ed Eichner, Water Scientist

DATE: September 25, 2007

RE: Individual town nitrogen loads by individual subwatersheds to Pleasant Bay

---

During past Alliance Watershed Working Group discussions, it was decided that it would be useful to the Alliance and member towns to determine each town's contribution of attenuated and unattenuated nitrogen loads within each individual subwatershed to the Pleasant Bay estuary. Since the Cape Cod Commission had created the Massachusetts Estuaries Project watershed nitrogen loading model, I offered to rework the model's components to determine these nitrogen loads using funding from the current Management Challenges for Nitrogen Control grant that the Commission has from the US Environmental Protection Agency.

The results show that attenuation rates in individual subwatersheds vary between 0 and 79% (Table 1). Attenuated loads account for splitting of downgradient loads among various ponds, as well as application of all the attenuation factors these loads are reduced by prior to discharge into Pleasant Bay or its subestuaries. So, for example, one portion of an upgradient subwatershed load may pass through two ponds and be subject to two 50% reductions, while another portion may pass through only one pond before reaching the estuary. Both attenuated and unattenuated loads also account for portions of nitrogen loads that flow out of the system watershed at ponds that straddle the watershed boundary, such as Cliff Pond in Brewster or Goose Pond in Chatham. Watershed loads do not include any nitrogen loads on the surface of the estuary or subestuaries. The overall system loads are within 0.8% or less of the overall loads presented in the MEP report on Pleasant Bay. Overall attenuation rates for the entire system show that 7% of the load is attenuated under existing conditions, while 6% is projected to be attenuated under buildout conditions.

Table 1. Individual Subwatershed Nitrogen Loads for Pleasant Bay.

All analysis based on Massachusetts Estuaries Project watershed nitrogen loading model, which is documented in the Pleasant Bay MEP Technical Report (Howes, *et al.*, 2006). Loads are adjusted to account for portions of subwatershed loads that leave the system watershed via ponds that straddle the system watershed boundary. Loads include only watershed loads and do not include loads on estuary or subestuary surfaces.

		EXISTING UNATTENUATED w/outflows included					EXISTING ATTENUATED						UNATTENUATED BUILDOUT w/outflows included					ATTENUATED BUILDOUT					
Watershed Name	Shed ID#	ORL	BRE	HAR	CHA	TOTAL	ORL	BRE	HAR	CHA	TOTAL	% Atten	ORL	BRE	HAR	CHA	TOTAL	ORL	BRE	HAR	CHA	TOTAL	% Atten
Baker Pond GT 10	1	0	21	0	0	21	0	7	0	0	7	67%	0	34	0	0	34		11			11	67%
Baker Pond LT 10	2	107	23	0	0	130	35	8	0	0	43	67%	118	57	0	0	175	39	19			58	67%
Cliff Pond GT 10	3	0	231	0	0	231	0	48	0	0	48	79%	0	242	0	0	242		50			50	79%
Cliff Pond LT 10	4	0	176	0	0	176	0	36	0	0	36	79%	0	176	0	0	176		36			36	79%
Crystal Lake GT 10	5	128	0	0	0	128	64	0	0	0	64	50%	239	0	0	0	239	120				120	50%
Crystal Lake LT 10	6	388	0	0	0	388	194	0	0	0	194	50%	527	0	0	0	527	263				263	50%
Deep Pond GT 10	7	0	5	0	0	5	0	2	0	0	2	50%	0	173	0	0	173		86			86	50%
Deep Pond LT 10	8	117	53	0	0	171	59	27	0	0	85	50%	165	101	0	0	266	82	51			133	50%
Grassy Pond	9	0	0	183	0	183	0	0	87	0	87	52%	0	0	189	0	189			90		90	52%
Higgins Pond	10	0	134	0	0	134	0	37	0	0	37	72%	0	134	0	0	134		37			37	72%
Little Cliff Pond	11	0	123	0	0	123	0	25	0	0	25	79%	0	123	0	0	123		25			25	79%
Mud Pond	12	0	7	47	0	54	0	3	24	0	27	50%	0	7	47	0	54		3	24		27	50%
Pilgrim Lake LT 10	13	562	0	0	0	562	281	0	0	0	281	50%	730	0	0	0	730	281				281	62%
Rafe Pond	14	0	42	0	0	42	0	21	0	0	21	50%	0	42	0	0	42		21			21	50%
Ruth Pond GT 10	15	0	41	0	0	41	0	8	0	0	8	80%	0	41	0	0	41		8			8	80%
Ruth Pond LT 10	16	0	7	0	0	7	0	1	0	0	1	80%	0	7	0	0	7		1			1	80%
Sarahs Pond GT 10	17	311	0	0	0	311	156	0	0	0	156	50%	420	0	0	0	420	210				210	50%
Sarahs Pond LT 10	18	85	0	0	0	85	43	0	0	0	43	50%	166	0	0	0	166	83				83	50%
Shoal Pond GT 10	19	0	4	0	0	4	0	2	0	0	2	50%	0	4	0	0	4		2			2	50%
Shoal Pond LT 10	20	251	155	0	0	405	125	77	0	0	203	50%	315	177	0	0	492	158	88			246	50%
Twinings Pond GT 10	21	11	69	0	0	80	4	27	0	0	31	61%	22	103	0	0	125	9	40			49	61%
Twinings Pond LT 10	22	298	0	0	0	298	116	0	0	0	116	61%	362	0	0	0	362	141				141	61%
Uncle Harvey Pond	23	123	0	0	0	123	61	0	0	0	61	50%	151	0	0	0	151	75				75	50%
Uncle Seths Pond GT 10	24	0	6	0	0	6	0	3	0	0	3	50%	0	6	0	0	6		3			3	50%
Uncle Seths Pond LT 10	25	179	17	0	0	196	90	9	0	0	98	50%	193	56	0	0	250	97	28			125	50%
Cliff Pond WELL_ORL	26	5	22	0	0	27	5	22	0	0	27	0%	5	22	0	0	27	5	22			27	0%
Freeman's Way WELL_BRE	27	0	1063	0	0	1063	0	1063	0	0	1063	0%	0	1203	0	0	1203		1203			1203	0%
Gould Pond WELL_ORL	28	249	27	0	0	276	124	14	0	0	138	50%	321	38	0	0	360	161	19			180	50%
Pleasant Bay Rd WELL_HAR	29	0	0	331	0	331	0	0	331	0	331	0%	0	0	337	0	337			337		337	0%
Silas Rd Well_BRE	30	0	240	0	0	240	0	221	0	0	221	8%	0	296	0	0	296		273			273	8%
WELL 7 WELL_ORL	31	345	61	0	0	406	345	61	0	0	406	0%	438	139	0	0	577	438	139			577	0%
Arey's Pond GT 10N	32	10	8	0	0	18	10	8	0	0	18	0%	16	8	0	0	24	16	8			24	0%
Arey's Pond GT 10S	33	2	0	0	0	2	2	0	0	0	2	0%	2	0	0	0	2	2				2	0%
Arey's Pond LT 10	34	351	0	0	0	351	351	0	0	0	351	0%	614	0	0	0	614	614				614	0%
Barley Neck GT 10	35	433	0	0	0	433	433	0	0	0	433	0%	517	0	0	0	517	517				517	0%
Barley Neck LT 10	36	456	0	0	0	456	456	0	0	0	456	0%	582	0	0	0	582	582				582	0%
Kescayo Gansett Pond GT 10	37	103	0	0	0	103	103	0	0	0	103	0%	204	0	0	0	204	204				204	0%
Kescayo Gansett Pond LT 10	38	268	0	0	0	268	268	0	0	0	268	0%	405	0	0	0	405	405				405	0%
Kescayo Gansett River	39	132	0	0	0	132	132	0	0	0	132	0%	171	0	0	0	171	171				171	0%
Kescayo Gansett Stream	40	45	0	0	0	45	45	0	0	0	45	0%	65	0	0	0	65	65				65	0%
Lower River LT 10	41	1237	0	0	0	1237	1237	0	0	0	1237	0%	2188	0	0	0	2188	2188				2188	0%
Meetinghouse Pond GT 10	42	953	0	0	0	953	953	0	0	0	953	0%	1278	0	0	0	1278	1278				1278	0%
Meetinghouse Pond LT 10	43	1303	0	0	0	1303	1303	0	0	0	1303	0%	1730	0	0	0	1730	1730				1730	0%
Namequoit River GT 10	44	98	40	0	0	138	98	40	0	0	138	0%	115	84	0	0	199	115	84			199	0%
Namequoit River LT 10	45	741	0	0	0	741	741	0	0	0	741	0%	1127	0	0	0	1127	1127				1127	0%
Pah Wah Pond Bog	46	48	0	0	0	48	48	0	0	0	48	0%	56	0	0	0	56	56				56	0%
Pah Wah Pond GT 10	47	386	0	0	0	386	386	0	0	0	386	0%	484	0	0	0	484	484				484	0%
Pah Wah Pond LT 10	48	246	0	0	0	246	246	0	0	0	246	0%	483	0	0	0	483	483				483	0%
Pleasant Bay GT 10_BREHAR	49	0	1361	395	0	1756	0	1361	395	0	1756	0%	0	1400	513	0	1913		1400	513		1913	0%
Pleasant Bay GT 10_HAR	50	0	0	592	0	592	0	0	592	0	592	0%	0	0	769	0	769			769		769	0%
Pleasant Bay GT 10_ORL	51	642	129	0	0	771	642	129	0	0	771	0%	927	230	0	0	1157	927	230			1157	0%
Pleasant Bay GT 10_ORLBRE	52	0	692	0	0	692	0	692	0	0	692	0%	0	1106	0	0	1106		1106			1106	0%
Pleasant Bay LT 10	53	1883	337	1199	1526	4945	1883	337	1199	1526	4945	0%	3098	388	1904	2265	7655	3098	388	1904	2265	7655	0%
Pochet Neck GT 10	54	787	0	0	0	787	787	0	0	0	787	0%	1037	0	0	0	1037	1037				1037	0%
Pochet Neck LT 10	55	465	0	0	0	465	465	0	0	0	465	0%	633	0	0	0	633	633				633	0%
Pochet Neck Stream GT 10	56	377	0	0	0	377	377	0	0	0	377	0%	478	0	0	0	478	478				478	0%
Pochet Neck Stream LT 10	57	493	0	0	0	493	493	0	0	0	493	0%	1014	0	0	0	1014	1014				1014	0%
Quanset Pond Bog	58	21	0	0	0	21	21	0	0	0	21	0%	47	0	0	0	47	47				47	0%
Quanset Pond GT 10	59	0	6	0	0	6	0	6	0	0	6	0%	0	6	0	0	6		6			6	0%
Quanset Pond LT 10	60	427	0	0	0	427	427	0	0	0	427	0%	592	0	0	0	592	592				592	0%
Round Cove GT 10	61	0	0	772	0	772	0	0	772	0	772	0%	0	0	900	0	900			900		900	0%
Round Cove LT 10	62	0	0	766	0	766	0	0	766	0	766	0%	0	0	984	0	984			984		984	0%
Tar Kiln Stream GT 10	63	0	1413	0	0	1413	0	1413	0	0	1413	0%	0	1464	0	0	1464		1464			1464	0%
Tar Kiln Stream LT 10	64	172	696	0	0	868	172	696	0	0	868	0%	388	746	0	0	1134	388	746			1134	0%
The Horseshoe	65	35	0	0	0	35	35	0	0	0	35	0%	68	0	0	0	68	68				68	0%
Upper River GT 10	66	238	0	0	0	238	238	0	0	0	238	0%	327	0	0	0	327	327				327	0%
Upper River LT 10	67	601	0	0	0	601	601	0	0	0	601	0%	872	0	0	0	872	872				872	0%
Mill Pond Fresh	68	0	0	115	53	168	0	0	54	25	79	53%	0	0	162	56	217			76	26	102	53%
Goose Pond	69	0	0	0	174	174	0	0	0	70	70	59%	0	0	0	176	176				72	72	59%
Trout Pond	70	0	0	0	320	320	0	0	0	160	160	50%	0	0	0	320	320				160	160	50%
Schoolhouse Pond	71	0	0	0	195	195	0	0	0	94	94	52%	0	0	0	200	200				97	97	52%
Stillwater Pond	72	0	0	0	387	387	0	0	0	367	367	5%	0	0	0	415	415				394	394	5%
Lovers Lake	73	0	0	0	559	559	0	0	0	265	265	53%	0	0	0	592	592				281	281	53%
Emery Pond	74	0	0	0	71	71	0	0	0	36	36	50%	0	0	0	78	78				39	39	50%
Bassing Pond	75	0	0	0	160	160	0	0	0	80	80	50%	0	0	0	182	182				91	91	50%
Hawksnest Pond	76	0	0	31	0	31	0	0	16	0	16	47%	0	0	31	0	31			16		16	47%
Muddy Crk WELL	77	0	0	589	0	589	0	0	589	0	589	0%	0	0	734	0	734			734		734	0%
Lower Muddy Crk	78	0	0	384	937	1321	0	0	384	937	1321	0%	0	0	692	937	1629			692	937	1629	0%
Lower Muddy Crk 10E	79	0	0	0	164	164	0	0	0	164	164	0%	0	0	0	175	175				175	175	0%
Lower Muddy Crk 10W	80	0	0	828	0	828	0	0	828	0	828	0%	0	0	984	0	984			984		984	0%
Upper Muddy Crk	81	0	0	1561	952	2513	0	0	1561	952	2513	0%	0	0	1723	1053	2776			1723	1053	2776	0%
Upper Muddy Crk 10E	82	0	0	0	123	123	0	0	0	123	123	0%	0	0	0	157	157				157	157	0%
Upper Muddy Crk 10W	83	0	0	881	0	881	0	0	881	0	881	0%	0	0	1591	0	1591			1591		1591	0%
Ryder Cove	84	0	0	0	1833	1833	0	0	0	1833	1833	0%	0	0	0	2118	2118				2118	2118	0%
Ryder Cove 10S	85	0	0	0	485	485	0	0	0	485	485	0%	0	0	0	558	558				558	558	0%
Ryder Cove 10E	86	0	0	0	167	167	0	0	0	167	167	0%	0	0	0	228	228				228	228	0%
Ryder Cove 10W	87	0	0	0	367	367	0	0	0	367	367	0%	0	0	0	378	378				378	378	0%
Crows Pond	88	0	0	0	882	882	0	0	0	882	882	0%	0	0	0	1005	1005				1005	1005	0%
Crows Pond 10	89	0	0	0	651	651	0	0	0	651	651	0%	0	0	0	685	685				685	685	0%
Bassing Harbor	90	0	0	0	360	360	0	0	0	360	360	0%	0	0	0	394	394				394	394	0%
Bassing Harbor 10	91	0	0	0	234	234	0	0	0	234	234	0%	0	0	0	307	307				307	307	0%
Frostfish Creek	92	0	0	0	432	432	0	0	0	432	432	0%	0	0	0	510	510				510	510	0%
Frostfish Creek 10	93	0	0	0	363	363	0	0	0	363	363	0%	0	0	0	397	397				397	397	0%
Upper Frostfish Crk	94	0	0	0	264	264	0	0	0	264	264	0%	0	0	0	304	304				304	304	0%
Chatham Harbor	95	0	0	0	6242	6242	0	0	0	6242	6242	0%	0	0	0	6953	6953				6953	6953	0%
TOTALS		16112	7209	8673	17900	49894	14655	6404	8478	17079	46616	7%	23691	8612	11560	20443	64306	21679	7598	11338	19583	60197	6%

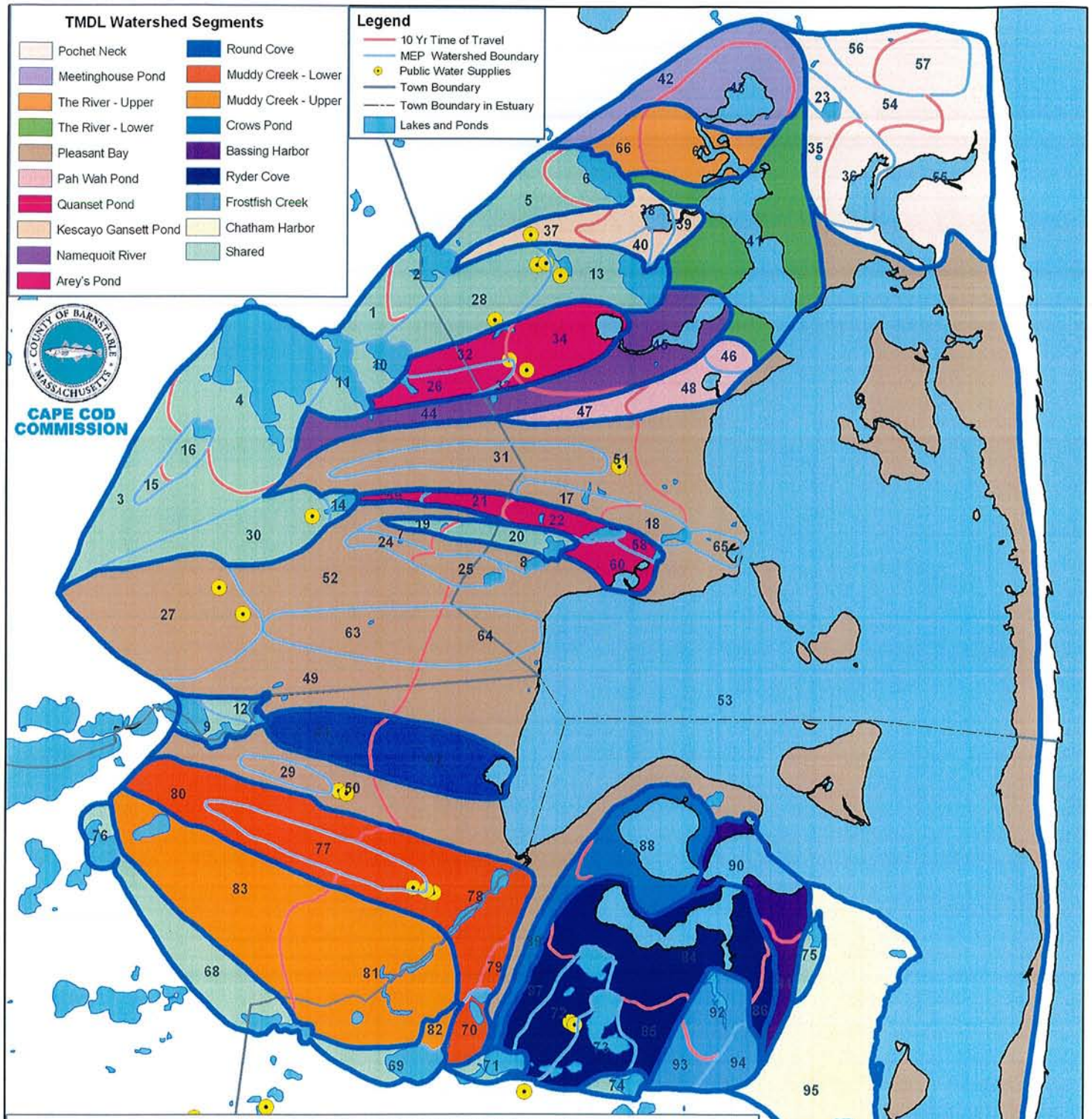
The preparation of these loads also presented the opportunity to re-evaluate the cumulative loads by individual town. Table 1 shows the sum of nitrogen load by town and Table 2 shows the relative percentage by town under existing and buildout conditions for both attenuated and unattenuated loads. Brewster and Harwich contribute a relatively stable percentage of the overall load to Pleasant Bay, while Chatham is the largest percentage under existing conditions and Orleans is the largest percentage under buildout conditions (see Table 2).

As mentioned above, this effort to determine subwatershed loads by individual town was funded using grant funds from the Commission's Management Challenges for Nitrogen Control grant that the Commission has from the US Environmental Protection Agency. The effort represents approximately $2,000 worth of Cape Cod Commission staff time.

Table 2. Percentage Watershed Nitrogen Load by Town for Pleasant Bay

	Orleans	Brewster	Harwich	Chatham
Existing Unattenuated	32%	14%	17%	36%
Existing Attenuated	31%	14%	18%	37%
Buildout Unattenuated	37%	13%	18%	32%
Buildout Attenuated	36%	13%	19%	33%

Notes:
1) percentages based on watershed load only; do not include loads on estuary surfaces
2) all loads adjusted to account for nitrogen loads that flow out of the watershed
3) attenuated loads account for reductions caused by application of multiple attenuation factors in situations where loads flow through multiple ponds



Individual Massachusetts Estuaries Project Subwatersheds

SHED_ID	NAME	SHED_ID	NAME	SHED_ID	NAME	SHED_ID	NAME
1	Baker Pond GT 10	25	Uncle Seths Pond LT 10	49	Pleasant Bay GT 10_BREHAR	73	Lovers Lake
2	Baker Pond LT 10	26	Cliff Pond WELL_ORL	50	Pleasant Bay GT 10_HAR	74	Emery Pond
3	Cliff Pond GT 10	27	Freeman's Way WELL_BRE	51	Pleasant Bay GT 10_ORL	75	Bassing Pond
4	Cliff Pond LT 10	28	Gould Pond WELL_ORL	52	Pleasant Bay GT 10_ORLBRE	76	Hawknest Pond
5	Crystal Lake GT 10	29	Pleasant Bay Rd WELL_HAR	53	Pleasant Bay LT 10	77	Muddy Creek Well
6	Crystal Lake LT 10	30	Silas Rd Well_BRE	54	Pochet Neck GT 10	78	Lower Muddy Creek
7	Deep Pond GT 10	31	WELL 7 WELL_ORL	55	Pochet Neck LT 10	79	Lower Muddy Creek 10 E
8	Deep Pond LT 10	32	Arey's Pond GT 10N	56	Pochet Neck Stream GT 10	80	Lower Muddy Creek 10 W
9	Grassy Pond	33	Arey's Pond GT 10S	57	Pochet Neck Stream LT 10	81	Upper Muddy Creek
10	Higgins Pond	34	Arey's Pond LT 10	58	Quanset Pond Bog	82	Upper Muddy Creek 10 E
11	Little Cliff Pond	35	Barley Neck GT 10	59	Quanset Pond GT 10	83	Upper Muddy Creek 10 W
12	Mud Pond	36	Barley Neck LT 10	60	Quanset Pond LT 10	84	Ryders Cove
13	Pilgrim Lake LT 10	37	Kescayo Gansett Pond GT 10	61	Round Cove GT 10	85	Ryders Cove 10 S
14	Rafe Pond	38	Kescayo Gansett Pond LT 10	62	Round Cove LT 10	86	Ryders Cove 10 E
15	Ruth Pond GT 10	39	Kescayo Gansett River	63	Tar Kiln Stream GT 10	87	Ryders Cove 10 W
16	Ruth Pond LT 10	40	Kescayo Gansett Stream	64	Tar Kiln Stream LT 10	88	Crows Pond
17	Sarahs Pond GT 10	41	Lower River LT 10	65	The Horseshoe	89	Crows Pond 10
18	Sarahs Pond LT 10	42	Meetinghouse Pond GT 10	66	Upper River GT 10	90	Bassing Harbor
19	Shoal Pond GT 10	43	Meetinghouse Pond LT 10	67	Upper River LT 10	91	Bassing Harbor 10
20	Shoal Pond LT 10	44	Namequoit River GT 10	68	Mill Pond Fresh	92	Frostfish Creek
21	Twinings Pond GT 10	45	Namequoit River LT 10	69	Goose Pond	93	Frostfish Creek 10
22	Twinings Pond LT 10	46	Pah Wah Pond Bog	70	Trout Pond	94	Upper Frostfish Creek
23	Uncle Harvey Pond	47	Pah Wah Pond GT 10	71	Schoolhouse Pond	95	Chatham Harbor
24	Uncle Seths Pond GT 10	48	Pah Wah Pond LT 10	72	Stillwater Pond		

Water use and Muddy Creek Nitrogen Attenuation – June 2010

Coastal Systems Program
School for Marine Science and Technology
University of Massachusetts Dartmouth
706 South Rodney French Blvd.
New Bedford, MA 02744-1221

MEP Technical Memo

To: David Young, CDM
Frank Sampson, Chair, Harwich Water Quality Management Task Force

From: Ed Eichner, CSP/SMAST
Brian Howes, CSP/SMAST
Sean Kelley, ACRE
John Ramsey, ACRE

Date: June 25, 2010

Re: Updated water use and Muddy Creek nitrogen attenuation and nitrogen loading to Pleasant Bay

---

On behalf of the Town of Harwich, Camp Dresser & McKee (CDM) requested a scenario using the linked Massachusetts Estuaries Project (MEP) models for Pleasant Bay to assess the impact of updated information on the findings for Round Cove and Muddy Creek. The scenario results documented in this Technical Memo include the inclusion of the following updated information:

- updated average Harwich water use based on 2004 to 2007 data,
- updated Harwich land use coverages from 2006, and
- updated nitrogen attenuation from the 2008 SMAST analysis of Muddy Creek.

A summary of the scenario development and its results are described below.

Scenario Development

During the collection of information for the development of the MEP linked models for Wychmere Harbor, Saquatucket Harbor, Allen Harbor, and the Herring River, MEP staff obtained 2004 to 2007 water use information from the Harwich Water Department for parcels throughout the Town. This enhanced the prior Pleasant Bay nitrogen loading analysis, which had access to only the 2004 water-use data from the Water Department at the time of the development of the Pleasant Bay MEP linked model (Howes, *et al*., 2006)[1]. Similarly, the Town of Harwich provided updated land use information for the review of all systems. The Pleasant Bay MEP assessment is based on 2004 Harwich land use data, while the other MEP systems in town will be based on 2006 land use data. The Town of Harwich and CDM wanted to have a consistent and comprehensive basis for the current Comprehensive Wastewater Management

[1] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

Planning effort and requested that a MEP scenario be completed for Pleasant Bay that uses the 2006 land use base and 2004 to 2007 water use that is used for the assessment of all of the other MEP estuaries within the town.

In addition, MEP Technical Team members completed a 2008 assessment of Muddy Creek (White, *et al*., 2008)[2]. This assessment, which was completed for the Pleasant Bay Alliance, included collection and analysis of sediment nitrogen regeneration, wetland characterization, water quality analysis, and nitrogen exchange measurements between the upper and lower basins of Muddy Creek. This assessment is a much more detailed and comprehensive review of Muddy Creek than was possible during the MEP assessment and allowed for an updated assessment of nitrogen attenuation in the Upper and Lower portions of Muddy Creek. The Town of Harwich and CDM requested that the findings from the 2008 Muddy Creek assessment be incorporated into the scenario with the Town's updated water use and land use. The requested scenario does not modify the inlet to Pleasant Bay to include the 2007 breach nor does it change the inlet culvert configuration or size into Muddy Creek.

In order to integrate the updated information, MEP Technical Team members were required to check the calibration and validation of the MEP Linked Models for Muddy Creek and Pleasant Bay. This step checked the effects of incorporating the new information and compared these results to the available water quality and salinity data to ensure that any significant changes did not cause unacceptable variability in the comparison of model results to collected field data. This step was especially important for the Muddy Creek area where much more refined data were incorporated. These checks showed that modest re-calibration was required in Muddy Creek (mainly as a result of the new attenuation rates) and that validation of the model was sustained.

MEP Scenario Results and Discussion

Based on the incorporation of the new information, watershed nitrogen loads for Muddy Creek and Round Cove increased (Table 1). Aside from the new water use, revised loads also include: a) changes in the treatment of both existing and buildout conditions at the Wequassett Inn (personal communication, Dave Michniewicz, Coastal Engineering, 6/26/08), b) load additions from farm animals, c) inclusion of a cranberry bog in Lower Muddy Creek that was previously excluded, d) inclusion of innovative/alternative septic systems in the Upper Muddy Creek subwatersheds, and e) updated land use coverages from 2006. These changes are consistent with updates provided as a result of data gathering for MEP assessments of other estuaries in Harwich.

After incorporating the revised nitrogen loads, the attenuation factors based on the more refined assessment of Muddy Creek were incorporated (White, *et al*., 2008). The attenuation factor used for watershed nitrogen loading from Upper Muddy Creek is 57%, while the attenuation factor for Lower Muddy Creek is 2%. These attenuation factors are based on the measured water quality in Muddy Creek documented in the 2008 report and the revised watershed nitrogen loads completed for this scenario.

[2] White, D., B. Howes, S. Kelley, J. Ramsey. 2008. Resource Assessment to Evaluate Ecological & Hydrodynamic Responses to Reinstalling a Water Control Structure in the Muddy Creek Dike. Report to the Pleasant Bay Alliance by the Coastal Systems Program-SMAST, University of Massachusetts-Dartmouth, New Bedford MA

The overall attenuated load for the upper Muddy Creek basin decreased (41%) mainly as a result of including the large measured attenuation in the upper basin (2008), while the attenuated watershed load for the lower basin increased by 27% (Table 2). Round Cove attenuated load increased by 48%. Overall, the updated attenuated watershed nitrogen load for the combined Muddy Creek decreases 10% and is similar to the MEP report, 16.59 kg d^{-1} and 18.46 kg d^{-1}, respectively. The net combined result of the changes in the watershed loads, attenuation factors, and more refined sediment characterization is that the overall Muddy Creek nitrogen load changes only very slightly: 2006 MEP Report nitrogen load is 22.16 kg d^{-1}, while the load in this revised scenario is 22.19 kg d^{-1}. The Round Cove overall load increases by 16% (from 12.82 to 14.83 kg d^{-1}).

It is also notable that the 2008 study found that Upper Muddy Creek sediments serve as a net nitrogen sink during summer conditions, while Lower Muddy Creek sediments are a net nitrogen source (see Table 2). The 2006 MEP report included the reverse assessment of the sediments in Upper (net source) and Lower Creeks (net sink). The main difference found in the more detailed 2008 assessment is due mostly to the very large nitrogen uptake in the uppermost brackish wetland, which was previously not measured. The 2006 MEP upper basin analysis was based upon measurement at a single location near this wetland.

Incorporation of the increased natural nitrogen attenuation in Upper Muddy Creek decreases the wastewater nitrogen that must be removed from its watershed to meet its threshold if wastewater is the only nitrogen source that is reduced (Table 3). The percentage of wastewater nitrogen that must be removed to meet the threshold decreases from 75% in the 2006 MEP analysis to 66% in this revised scenario. Lower Muddy Creek remains at 100% wastewater removal under the revised scenario and Round Cove increases from 40% wastewater removal to 64% removal. Round Cove's increase is largely due to an increase in the septic load based on the incorporation of the water use revisions.

When all loads, including septic wastewater, fertilizer, and stormwater runoff, are considered as sources for nitrogen removal to meet the threshold, the necessary percentage reductions in attenuated watershed nitrogen loads are different (Table 4) than if only septic loads are considered (see Table 3), but the relative relationships among the estuaries are essentially the same. Lower Muddy Creek has the highest required removal, which increased slightly in the requested scenario (from 75% to 80%), while Upper Muddy Creek has a slight drop in required removal (from 54% removal to 52% removal) and Round Cove has an increase in the required removal (from 30% to 53%). Although Upper Muddy Creek has an increase in the watershed load (see Table 1), this increase is largely offset by the better documented increase in system nitrogen attenuation. The opposite effect is seen in Lower Muddy Creek and Round Cove where the increased total watershed load increases the percentage of watershed load that must be removed.

Table 5 compares the threshold loads for bioactive nitrogen (DIN+PON) under the 2006 MEP Report and this updated scenario. As also shown in Table 4, the watershed threshold loads for Lower Muddy Creek and Round Cove generally did not change, but the watershed threshold load for Upper Muddy Creek decreased due to the increased attenuation in the system. The changes in the benthic fluxes due to the 2008 study also are noted.

In interpreting the results, it is important to consider that Muddy Creek is a heavily altered system, which previously was divided by a dike, and has a large restriction of tidal exchange at its outlet to Pleasant Bay due to a small culvert under Rt. 28. Tributary estuaries with large restrictions to tidal exchange (reduced flushing) have increased nitrogen levels over the similar systems with unrestricted tidal exchange. Extreme examples of the effect of tidal exchange on nitrogen levels can be seen in West End Pond (Gosnold) and Rushy Marsh (Barnstable), where removing all anthropogenic watershed nitrogen loading is insufficient to meet water quality restoration goals. The flushing rates in these systems are so low that even small amounts of entering nitrogen accumulate to produce high water column nitrogen levels and low oxygen conditions. While Muddy Creek is not at this level of restriction, it is virtually certain that much of its nitrogen related water quality "problem" results from its restricted tidal circulation.

The overall impact of incorporating all the Harwich changes, including updated land use and water use, incorporation of monitoring from innovative/alternative septic systems, loading from farm animals, Wequassett Inn wastewater clarifications, and the better characterization of Muddy Creek, is summarized as:

1) Lower Muddy Creek is not changed; the watershed threshold load remains the same and the required septic removal to meet the threshold remains at 100%.
2) Upper Muddy Creek has a slight improvement in nitrogen removal to meet the threshold. Incorporation of the better documented natural nitrogen attenuation in the Creek largely balances watershed nitrogen loading increases. The net result is that the watershed threshold load is reduced and the required septic removal to meet the threshold also decreases to 66%.
3) Round Cove watershed threshold load remains the same, but the addition of the modified water use has increased the watershed nitrogen load. The net result is that in order to meet the watershed threshold load, the required septic removal within the watershed increases to 64%.

Table 1. Comparison of Watershed Nitrogen Loads for Round Cove and Muddy Creek. A) Watershed nitrogen loads from Table IV-5 of the Massachusetts Estuaries Project Technical Report for Pleasant Bay (Howes, *et al*., 2006). B) Watershed nitrogen loads prepared for this scenario including the incorporation of updated water use and land use from the Town of Harwich. Muddy Creek attenuated loads do not include attenuation assigned to within the wetlands and sediments of the Muddy Creek.

A) 2006 MEP Pleasant Bay Technical Report Nitrogen Loads for Round Cove and Muddy Creek

		Pleasant Bay N Loads by Input (kg/yr):							***Present N Loads***		
Name	**Watershed ID#**	**Wastewater**	**Fertilizers**	**Impervious Surfaces**	**Water Body Surface Area**	**"Natural" Surfaces**	**Buildout**	**% of Pond Outflow**	**UnAtten N Load**	**Atten %**	**Atten N Load**
Round Cove	**61,62 + MP**	**1157**	**175**	**154**	**77**	**54**	**347**		**1616**		**1607**
Round Cove Estuary surface deposition					62				62		62
Muddy Creek	**77, 78, 79, 80, 81, 82, 83 + MPF, GOP, HWP, TTP**	**5275**	**612**	**776**	**400**	**332**	**1946**		**7395**		**7027**
Upper Muddy Creek	81,82,83 + MPF,GOP,HWP	2839	344	395	247	189	1322		4014		3860
Upper Muddy Creek Estuary surface deposition					59				59		59
Lower Muddy Creek	77,78,79,80 + TTP	2436	268	381	153	143	624		3381		3167
Lower Muddy Creek Estuary surface deposition					75				75		75

B) 2008 MEP Technical Memo Nitrogen Loads with updated Harwich water use and land use for Round Cove and Muddy Creek

		Pleasant Bay N Loads by Input (kg/yr):							***Present N Loads***		
Name	**Watershed ID#**	**Wastewater**	**Fertilizers**	**Impervious Surfaces**	**Water Body Surface Area**	**"Natural" Surfaces**	**Buildout**	**% of Pond Outflow**	**UnAtten N Load**	**Atten %**	**Atten N Load**
Round Cove	**61,62 + MP**	**1884**	**175**	**162**	**77**	**53**	**263**		**2350**		**2341**
Round Cove Estuary surface deposition					62				62		62
Muddy Creek	**77, 78, 79, 80, 81, 82, 83 + MPF, GOP, HWP, TTP**	**7321**	**685**	**781**	**398**	**331**	**2235**		**9516**		**9086**
Upper Muddy Creek	81,82,83 + MPF,GOP,HWP	4088	351	402	245	189	1543		5276		5066
Upper Muddy Creek Estuary surface deposition					59				59		59
Lower Muddy Creek	77,78,79,80 + TTP	3233	333	379	153	143	692		4241		4020
Lower Muddy Creek Estuary surface deposition					75				75		75

Table 2. Nitrogen loads (attenuated) under existing conditions for Harwich subestuaries of the Pleasant Bay system. Existing nitrogen loads for the watersheds to Round Cove and Muddy Creek are compared for the scenario discussed in this Technical Memo and the MEP report (Howes, *et al*., 2006). The requested scenario includes the incorporation of revised information gathered in Harwich into the 2006 MEP Linked Models for Pleasant Bay including: 1) average Harwich water use based on 2004 to 2007 data, 2) updated Harwich land use coverages from 2006, and 3) updated nitrogen attenuation from the 2008 SMAST assessment of Muddy Creek (White, *et al*., 2008). All values have been rounded.

Sub-embayment	Revised Harwich scenario				MEP Report				% change
	Attenuated watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)	Total Load (kg/d)	Attenuated watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)	Total Load (kg/d)	Total Load
Round Cove	6.24	0.17	8.42	14.83	4.23	0.17	8.42	12.82	+16%
Muddy Creek - upper	5.85	0.16	-0.64	5.37	9.98	0.16	4.56	14.70	-63%
Muddy Creek - lower	10.74	0.21	5.87	16.82	8.48	0.21	-1.23	7.46	+125%
Muddy Creek - total	16.59	0.37	5.23	22.19	18.46	0.37	3.33	22.16	0%

Table 3. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios for Harwich subestuaries in the current requested scenario. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms. All values have been rounded.

Sub-embayment	Revised Harwich scenario			MEP Report			change		
	Attenuated Septic load (kg/day)	Threshold septic load (kg/day)	septic load reduction to attain threshold % change	Attenuated Septic load (kg/day)	Threshold septic load (kg/day)	septic load reduction to attain threshold % change	Attenuated Septic load (kg/day)	Threshold septic load (kg/day)	septic load reduction to attain threshold % change
Round Cove	5.18	1.865	-64%	3.16	1.897	-40%	+2.02	-0.03	-24%
Muddy Creek - upper	4.72	1.603	-66%	7.16	1.789	-75%	-4.13	-1.79	+9%
Muddy Creek - lower	8.6	0	-100%	6.34	0	-100%	+2.26	0	0%

Table 4. Comparison of sub-embayment ***total watershed loads*** (attenuated, including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios for Harwich subestuaries in the current Harwich-requested scenario and the 2006 MEP Technical Report. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms. All values have been rounded.

Sub-embayment	Revised Harwich scenario			MEP Report			change		
	Attenuated total load (kg/day)	Threshold total load (kg/day)	load reduction to attain threshold % change	Attenuated total load (kg/day)	Threshold total load (kg/day)	load reduction to attain threshold % change	Attenuated total load (kg/day)	Threshold total load (kg/day)	load reduction to attain threshold % change
Round Cove	6.24	2.93	-53%	4.23	2.96	-30%	+2.019	-0.03	-23%
Muddy Creek - upper	5.85	2.82	-52%	9.98	4.61	-54%	-4.134	-1.79	+2%
Muddy Creek - lower	10.74	2.14	-80%	8.48	2.14	-75%	+2.26	0	-5%

Table 5. Threshold sub-embayment loads used for bioactive nitrogen (DIN+PON) modeling of the Harwich subestuaries in the current Harwich-requested scenario and the 2006 MEP Technical Report, with threshold loads for total attenuated watershed N loads, atmospheric N loads, and benthic flux. All values have been rounded.

Sub-embayment	Revised Harwich scenario				MEP Report				% change
	Attenuated watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)	Total Load (kg/d)	Attenuated watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)	Total Load (kg/d)	Attenuated Watershed load (kg/d)
Round Cove	2.93	0.17	5.59	8.69	2.96	0.17	6.74	9.87	-1%
Muddy Creek - upper	2.82	0.16	-0.37	2.61	4.61	0.16	2.7	7.47	-40%
Muddy Creek - lower	2.14	0.21	2.92	5.27	2.14	0.21	-0.71	1.64	0%
Muddy Creek - total	4.96	0.37	2.55	7.88	6.75	0.37	1.99	9.11	-27%

Coastal Systems Program
School for Marine Science and Technology
University of Massachusetts Dartmouth
706 South Rodney French Blvd.
New Bedford, MA 02744-1221

MEP Technical Memo

To: Carole Ridley, Pleasant Bay Alliance, Coordinator
Bob Duncanson, Chair, Technical Resource Committee, Pleasant Bay Alliance

From: Ed Eichner, Coastal Systems Program/SMAST/UMassD
Brian Howes, Coastal Systems Program/SMAST/UMassD
Sean Kelley, Applied Coastal Research and Engineering
John Ramsey, Applied Coastal Research and Engineering

Date: October 5, 2010

Re: MEP Scenarios to evaluate water quality impacts of the addition of a 24 ft culvert in Muddy Creek inlet

---

The Pleasant Bay Alliance (PBA) requested two (2) scenarios, one under existing conditions and another under buildout conditions using an updated version of the Massachusetts Estuaries Project (MEP) model for Pleasant Bay that incorporates recent updates requested by the Town of Harwich.[1] The PBA scenarios are designed to evaluate potential changes in water quality throughout the Pleasant Bay System resulting from reducing the tidal restriction caused by the current culvert at the outlet of Muddy Creek (under Route 28) by installing a 24-foot wide culvert.

The updates in the MEP Pleasant Bay model that were requested by the Town of Harwich focused on Muddy Creek and Round Cove. The updates are documented in a June 25, 2010 MEP Technical Memo and include the additions of the following information:

- updated average Harwich water use based on 2004 to 2007 data,
- updated Harwich land use coverages from 2006, and
- updated nitrogen attenuation from the 2008 SMAST analysis of Muddy Creek.[2]

Incorporating these updates required a check of the calibration and validation of the MEP Linked Model for Pleasant Bay.[3] This step checked the effects of incorporating the new information and

---

[1] CSP/SMAST and ACRE. MEP Technical Memo. June 25, 2010. Updated water use and Muddy Creek nitrogen attenuation and nitrogen loading to Pleasant Bay. Completed for Camp Dresser McKee and Town of Harwich Water Quality Management Task Force.

[2] White, D., B. Howes, S. Kelley, J. Ramsey. 2008. Resource Assessment to Evaluate Ecological & Hydrodynamic Responses to Reinstalling a Water Control Structure in the Muddy Creek Dike. Report to the Pleasant Bay Alliance by the Coastal Systems Program-SMAST, University of Massachusetts-Dartmouth, New Bedford MA

compared these results to the available water quality and salinity data to ensure that any significant changes did not cause unacceptable variability in the comparison of model results to collected field data. This step was especially important for the Muddy Creek area where much more refined data were incorporated. These checks showed that modest re-calibration was required in Muddy Creek (mainly as a result of the new attenuation rates) and that validation of the overall Pleasant Bay model was sustained.

For the assessment of the Pleasant Bay-wide water quality changes of installing a 24-foot culvert at the outlet of Muddy Creek, PBA requested two (2) scenarios:

1) Scenario 1 - Existing watershed N loading and updated N Muddy Creek attenuation with the addition of a single 24-foot culvert.
2) Scenario 2- same as #1 above, except that the build-out N load will be used as the watershed N load.

Requested outputs from the scenarios are: a) modeled N concentrations at the TMDL sentinel and check water quality stations throughout the Pleasant Bay System and b) required N load reductions from watershed septic loads to meet the nitrogen TMDL for Pleasant Bay. PBA specified that model modifications should not include changes to the inlet to Pleasant Bay to include the impacts of the 2007 breach, so as to allow comparison of these results to the existing USEPA/MassDEP TMDL for this system.

MEP Technical Team members from the Coastal Systems Program/SMAST and Applied Coastal Research and Engineering, completed the development of the scenarios and prepared the following summary of the scenario results.

MEP Scenario Results and Discussion: Pleasant Bay Alliance updates

The changes requested by the Town of Harwich, including the changes in the attenuation of nitrogen by Muddy Creek ecological systems, resulted in small, generally insignificant increases in watershed nitrogen loads throughout the Pleasant Bay watershed with the most significant changes within watersheds of sub-embayments predominantly within Harwich (Table 1). Changes occurred throughout the Bay watershed because the changes in the Harwich water use increased the average water use for the Pleasant Bay System. The change in the average water use also impacted the buildout loads since these rely extensively on this value.

Evaluation of the effect of installing the 24 ft culvert can be conducted by comparing the needed reduction in septic loads based upon the updated septic thresholds for both attenuated existing and buildout nitrogen loads relative to the MEP Technical Report[4]. This comparison shows that the necessary percent reductions to meet the thresholds are generally the same throughout most of the system with and without the new culvert; percent removals generally increase by ~1% (Table 2). Muddy Creek and Round Cove, however, show notable changes due to the updates to the Harwich water use, the refinements in the Muddy Creek N attenuation and the association with the new culvert. Given that the new culvert directly effects Muddy Creek, the decreased percent removal of existing septic watershed loads to meet threshold in Upper Muddy Creek (from 75% removal to 45% removal) and Lower Muddy Creek (from 100% removal to 50%

---

[3] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.
[4] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006).

removal) was expected. Round Cove's increased percent removal from 40% to 64% primarily results from changes in watershed loading.

In addition to evaluating loadings, the affect of adding the 24 ft culvert at the inlet to Muddy Creek on bioactive N concentrations throughout Pleasant Bay was evaluated using the updated model, incorporating the updates requested by the Town of Harwich. This evaluation was conducted under both existing (Table 3) and buildout (Table 4) watershed loadings. It appears that replacing the existing inlet to Muddy Creek with a 24-foot culvert has little effect on the nitrogen levels throughout the Pleasant Bay System. This is not surprising as Muddy Creek represents only about 12% of the watershed load to the overall system and the inlet has little effect on the amount of nitrogen leaving Muddy Creek, but reduces the build-up in concentration, so the concentration in ebb waters will be lower. A small, but insignificant, lowering of concentrations can be seen system-wide likely resulting from this lower Muddy Creek ebb concentration and the small increase in total system tidal prism (flushing) that will result from the larger tide range in Muddy Creek with the new inlet.

While there is a clear reduction in the bioactive nitrogen level at the Muddy Creek check station, due to the wider culvert, there is little or no change in bioactive N concentrations at the other check stations and sentinel stations. The wider culvert results in a 20% drop in the difference between the existing conditions modeled N concentration and the threshold concentration (0.21 mg/l) at the Lower Muddy Creek check station (PBA-05). Additional N reductions are necessary in the Muddy Creek watershed to meet the threshold concentration in Lower Muddy Creek, but the magnitude of the reductions are reduced through the installation of the wider culver. All other stations throughout Pleasant Bay have insignificant changes in concentration, *i.e.*, less than one percent. These results suggest that addition of a 24-foot culvert at the head of Muddy Creek will improve water quality in Muddy Creek and will not result in any significant changes in the rest of the Pleasant Bay system.

It should be noted that the attenuation rate in Upper Muddy Creek was not adjusted based on the addition of the wider culvert. MEP Technical Team members reviewed the modeled increase in Mean High Water (MHW) elevation (+1.2 ft) due to the wider culvert and compared it to the wetland elevation data indicated in the Muddy Creek study.[5] This comparison found that it was likely that the MHW increase would expand the salt marsh area significantly in the uppermost wetland basin, but not really change the area in the larger open water upper basin (above the former dike but below the marsh basin). This increase in salt marsh area would cause an inward/upward shift of fringing freshwater vegetation in the uppermost wetland basin to an undetermined higher elevation based on the change in tide height and how the marsh adapted to the surrounding land elevation. Since salt marsh is nitrogen limited and tends to hold or denitrify nitrogen, it is thought that this expansion of salt marsh area might increase the nitrogen attenuation in Upper Muddy Creek above the attenuation measured in the Muddy Creek study. However, given that the wetland elevation contours are in two foot increments and the change in MHW fits within this increment, it was thought that any attenuation estimate above that assigned in the Muddy Creek study would not have been properly derived and constrained. With that in mind, MEP Technical Team used the nitrogen attenuation determined in the Muddy Creek Study for the analysis with the installation of the 24-foot culvert.

[5] White, D., B. Howes, S. Kelley, J. Ramsey. 2008..

As additional nitrogen sources are added to the watershed through buildout development, these loads will need to be offset to meet the bioactive nitrogen threshold for Pleasant Bay determined in the USEPA/MassDEP TMDL (Table 4). These greater loads increase the percent reductions in N concentrations to meet the N thresholds at the sentinel and check stations throughout the Pleasant Bay System. However, the necessary percentage reduction to meet the N concentrations at the Lower Muddy Creek station at buildout with the 24-foot culvert is less than the percent reduction required at buildout with the existing culvert. It should also be noted that all Pleasant Bay water quality and sentinel stations exceed their MEP N thresholds under buildout conditions with or without the proposed culvert.

In conclusion, the addition of a 24-foot culvert at the outlet of Muddy Creek without accounting for any impacts of the 2007 Pleasant Bay breach will:

1) reduce nitrogen concentrations at the Lower Muddy Creek check/benthic infauna water quality station (PBA-05) to within 23% of its MEP threshold concentration with current watershed development (an improvement from a required 43% reduction to meet the threshold without the widened culvert),
2) reduce nitrogen concentrations at the Lower Muddy Creek check/benthic infauna water quality station (PBA-05) to within 36% of its MEP threshold concentration with buildout watershed development, and
3) not significantly impact nitrogen concentrations elsewhere in the Pleasant Bay estuary.

Table 1. Total existing and buildout watershed N loads for current Pleasant Bay Alliance Scenario and 2006 MEP Technical Report (Howes, *et al.*) (including septic, runoff, and fertilizer) used for modeling of present conditions. These loads reflect updates in the Harwich water use and Muddy Creek nitrogen attenuation. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	Existing PBA scenario watershed load (kg/day)	Existing 2006 MEP Report watershed load (kg/day)	Buildout PBA scenario watershed load (kg/day)	Buildout 2006 MEP Report watershed load (kg/day)
Meetinghouse Pond	6.197	6.197	8.48	8.26
The River – upper	2.803	2.773	4.12	3.98
The River – lower	3.942	3.879	6.99	6.65
Lonnies Pond	2.471	2.441	3.69	3.56
Areys Pond	1.318	1.304	2.13	2.05
Namequoit River	2.767	2.737	4.22	4.05
Paw Wah Pond	1.882	1.860	2.93	2.81
Pochet Neck	8.468	8.422	12.29	11.89
Little Pleasant Bay	9.430	7.496	14.26	12.03
Quanset Pond	1.786	1.781	2.46	2.39
Tar Kiln Stream	6.142	6.123	7.10	6.99
Round Cove	6.244	4.225	6.96	5.18
The Horseshoe	0.647	0.638	1.04	0.99
Muddy Creek - upper	5.937	9.981	7.71	13.96
Muddy Creek - lower	10.737	8.477	12.69	10.19
Pleasant Bay	26.767	23.159	35.03	31.03
Pleasant Bay/Chatham Harbor Channel	-	-	-	
Bassing Harbor - Ryder Cove	10.063	9.819	11.50	11.14
Bassing Harbor - Frost Fish Creek	2.912	2.904	3.37	3.32
Bassing Harbor - Crows Pond	4.282	4.219	4.76	4.65
Bassing Harbor	1.707	1.668	2.02	1.97
Chatham Harbor	17.175	17.099	19.33	19.05
TOTAL - Pleasant Bay System	133.679	127.203	173.085	166.14

Table 2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present, buildout, and threshold loading scenarios of the Pleasant Bay system in the PBA Alliance scenarios. These loads include the updated attenuation in Muddy Creek (White, *et al.*, 2008) and the **24 foot-wide culvert at Muddy Creek**. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms. MEP report present threshold septic load % changes are also presented for comparison.

sub-embayment	Present PBA scenario septic load (kg/day)	Buildout PBA scenario septic load (kg/day)	Threshold PBA scenario septic load (kg/day)	Present Threshold PBA scenario septic load % change	Buildout Threshold PBA scenario septic load % change	MEP Report Present Threshold septic load % change
Meetinghouse Pond	5.14	7.03	0.00	-100%	-100%	-100%
The River – upper	2.10	3.09	1.03	-51%	-67%	-50%
The River – lower	2.93	5.20	1.44	-51%	-72%	-50%
Lonnies Pond	1.66	2.48	0.81	-51%	-67%	-50%
Areys Pond	0.79	1.28	0.39	-51%	-70%	-50%
Namequoit River	2.04	3.11	1.00	-51%	-68%	-50%
Paw Wah Pond	1.53	2.39	0.37	-76%	-85%	-75%
Pochet Neck	6.66	9.67	2.33	-65%	-76%	-65%
Little Pleasant Bay	6.45	9.75	2.26	-65%	-77%	-50%
Quanset Pond	1.41	1.94	0.70	-50%	-64%	-50%
Tar Kiln Stream	1.82	2.10	0.89	-51%	-58%	-50%
Round Cove	5.18	5.78	1.87	-64%	-68%	-40%
The Horseshoe	0.48	0.77	0.48	0%	-38%	0%
Muddy Creek - upper	4.72	6.12	2.59	-45%	-58%	-75%
Muddy Creek - lower	8.60	10.16	4.30	-50%	-58%	-100%
Pleasant Bay	16.69	21.84	6.51	-61%	-70%	-50%
Pleasant Bay/Chatham Harbor Channel	-	-	-	-		-
Bassing Harbor - Ryder Cove	7.38	8.44	1.77	-76%	-79%	-75%
Bassing Harbor - Frost Fish Creek	2.21	2.56	0.00	-100%	-100%	-100%
Bassing Harbor - Crows Pond	3.39	3.77	3.39	0%	-10%	0%
Bassing Harbor	1.44	1.70	1.44	0%	-15%	0%
Chatham Harbor	14.27	16.06	14.27	0%	-11%	0%
TOTAL - Pleasant Bay System	96.88	125.23	47.84	-50%	-62%	-52%

Table 3. Comparison of model average bioactive N (DIN+PON) concentrations from present watershed loading with the **existing Muddy Creek culvert and the 24-foot wide alternative culvert**, with percent change, for the threshold and benthic infauna restoration (check) stations in the Pleasant Bay system. The modeled conditions are based on 2004 hydrodynamic conditions (pre-2007 breach of north inlet). The threshold stations for **eelgrass restoration are shown in bold print** (0.16 mg/L at PBA-12 and the average of PBA-03 and CM-13) and the rest of the listed stations are for benthic infauna restoration (0.21 mg/L at WMO-10, PBA-15, WMO-6, WMO-5, PBA-11, WMO-12, PBA-09 and PBA-05).

Installation of the 24-foot culvert reduces the bioactive N concentration at the Lower Muddy Creek station and has insignificant changes in concentration at the other stations in Pleasant Bay.

Sub-Embayment	monitoring station	present existing culvert (mg/L)	present 24-foot culvert (mg/L)	Threshold (mg/L)	% change to meet threshold - existing	% change to meet threshold – 24-foot culvert
Meetinghouse Pond	WMO-10	0.264	0.264	0.207	-28%	-28%
Lonnies Pond (Kescayo Gansett Pond)	PBA-15	0.251	0.251	0.208	-21%	-21%
Namequoit River - upper	WMO-6	0.240	0.239	0.206	-17%	-16%
Pochet – upper	WMO-05	0.270	0.270	0.211	-28%	-28%
Little Pleasant Bay - head	**PBA-12**	**0.178**	**0.178**	**0.160**	**-11%**	**-11%**
Paw Wah Pond	PBA-11	0.258	0.258	0.209	-23%	-23%
Little Quanset Pond	WMO-12	0.233	0.231	0.194	-20%	-19%
Round Cove	PBA-09	0.255	0.253	0.207	-23%	-22%
Muddy Creek - lower	PBA-05	0.298	0.255	0.208	-43%	-23%
Ryders Cove - upper	**PBA-03**	**0.252**	**0.252**	**0.190**	**-33%**	**-33%**
Ryders Cove - lower	**CM-13**	**0.160**	**0.159**	**0.138**	**-16%**	**-15%**

Table 4. Comparison of model average bioactive N (DIN+PON) concentrations from **existing and buildout watershed loading with the installation of a 24-foot alternative**, with MEP threshold concentrations for the Pleasant Bay system and the percent changes in concentrations to meet the threshold concentrations. The modeled conditions represent 2004 hydrodynamic conditions (pre 2007 breach of north inlet). The threshold stations for **eelgrass restoration are shown in bold print** (0.16 mg/L at PBA-12 and the average of PBA-03 and CM-13) and the rest of the listed stations are for benthic infauna restoration (0.21 mg/L at WMO-10, PBA-15, WMO-6, WMO-5, PBA-11, WMO-12, PBA-09 and PBA-05). Buildout watershed nitrogen loading increases bioactive N concentrations and increases the percent reductions in nitrogen concentrations to meet the MEP threshold concentrations.

Sub-Embayment	monitoring station	Existing PBA scenario watershed loading - 24-foot culvert (mg/L)	Buildout PBA scenario watershed loading - 24-foot culvert (mg/L)	Threshold (mg/L)	% change to meet threshold Existing – 24-foot culvert	% change to meet threshold Buildout - 24-foot culvert
Meetinghouse Pond	WMO-10	0.264	0.300	0.207	-28%	-45%
Lonnies Pond (Kescayo Gansett Pond)	PBA-15	0.251	0.289	0.208	-21%	-39%
Namequoit River - upper	WMO-6	0.239	0.271	0.206	-16%	-32%
Pochet – upper	WMO-05	0.270	0.321	0.211	-28%	-52%
Little Pleasant Bay - head	**PBA-12**	**0.178**	**0.193**	**0.160**	**-11%**	**-21%**
Paw Wah Pond	PBA-11	0.258	0.307	0.209	-23%	-47%
Little Quanset Pond	WMO-12	0.231	0.263	0.194	-19%	-36%
Round Cove	PBA-09	0.253	0.277	0.207	-22%	-34%
Muddy Creek - lower	PBA-05	0.255	0.283	0.208	-23%	-36%
Ryders Cove - upper	**PBA-03**	**0.252**	**0.273**	**0.190**	**-33%**	**-44%**
Ryders Cove - lower	**CM-13**	**0.159**	**0.168**	**0.138**	**-15%**	**-22%**