December 19, 2000

David Pincumbe
US EPA
Boston, MA 02203

re: CDM June 2000 report on Nitrogen loading in the Wareham River watershed

Dear Mr. Pincumbe:

The Buzzards Bay Project has conducted a review of the June 2000 report titled *Water Quality Investigation of the Wareham River Estuary Complex*, prepared by Dr. Brian Howes of UMass Dartmouth and Camp Dresser and McKee (CDM). We have limited our review at this time to four areas: the validity of flushing rate estimates, nitrogen loading estimates, attenuation coefficient estimates, and application of proposed new BBP standards.

Before addressing these specific areas, we commend the authors for their important contributions in refining estimates of nitrogen loading to the Wareham River Estuary, quantifying attenuation coefficients for the upper watershed, estimating contributions from point and non-point sources of nitrogen, and for more precisely determining flushing rates of the estuary. This new data and information will not only assist the US EPA in determining an appropriate discharge limit for the Wareham Wastewater Treatment Facility, but adds measurably to our understanding of how this estuary ecosystem has responded to existing nitrogen inputs. In particular, the approach for determining an upper watershed nitrogen attenuation coefficient, although we disagree with the final estimated range, will have transferability to other large drainage basins in Buzzards Bay and southern New England. We commend the Town of Wareham for funding this study and showing leadership in better quantifying water quality conditions and nitrogen loading estimates in an estuary so clearly valued by Town officials and residents alike.

While we agree with many of the conclusions and summaries presented in the report, there are some important calculation errors and questionable assumptions that are germane in the establishment of a nitrogen discharge limit for the facility. These issues are summarized below.

Flushing rate analysis

The hydraulic residence time of an estuary is widely believed to have considerable significance to the susceptibility of an estuary to anthropogenic nitrogen inputs. That is to say, given two estuaries of identical volume and bathymetric profiles, the estuary with the longer hydraulic residence time is more prone to eutrophication impacts than an estuary with a shorter hydraulic turnover time. This concept is incorporated in the Buzzards Bay Project's nitrogen loading methodology. As a result, recommended nitrogen loading limits for an estuary are nearly directly inversely proportional to the hydraulic turnover time in days.[1]

While the Buzzards Bay Project specified that "hydraulic turnover time," "residence time," or "flushing rate" of an estuary be considered, no methodology was specified. This was because no single method was appropriate to all estuaries. The choice of method depended upon whether the system was a typical wedge-shaped estuary with high river flows at the head of the estuary or a coastal lagoon with low freshwater inputs. The method also depended upon other factors such as the shape and volume of the estuary, and the locus of nitrogen inputs (e.g., are they primarily from septic systems near a well-flushed mouth of a bay or from an upstream or groundwater source entering the poorly flushed portion of the upper estuary?).

The choice of a flushing rate value is so fundamental to setting a nitrogen loading limit for an estuary. Because there are a number of potential methodologies that could be used, each with inherent weaknesses when applied to the concept of nitrogen impacts in an estuary, the selection of a residence time for an estuary remains one of the most difficult decisions facing coastal managers. For these reasons also, it is important to use salinity data or dye studies to validate any flushing model adopted.

In 1998, the Buzzards Bay Project prepared a preliminary report of nitrogen loading estimates and recommended limits for the Wareham River estuary[2]. In that report, we used a preliminary estimate of 5.75 days as an approximation of flushing for the Wareham River estuary based on other studies. In the 2000 CDM report, CDM recommended the use of a lower flushing rate of 2.33 to 4.13 (56-99 hours). This estimate was based on the Ketchum fractional freshwater method for calculating "freshwater replacement time" for the upper 1/3 of the estuary. The ranges given were equivalent to the observations on two dates, one near spring tide, one near neap tide conditions. In this method, the total volume of freshwater in an estuary is calculated based on salinities, and this total volume of freshwater is divided by the estimate of daily freshwater flows from stream and groundwater discharges into the estuary. Below are our specific comments on how this method was applied to this study.

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[1]The use of the Vollenweider expression, makes this relationship slightly less than a simple direct proportional relationship.

[2]Costa, J. E. A Preliminary Evaluation of Nitrogen Loading and Water Quality of the Wareham River Estuary as it Relates to the Wareham Wastewater Treatment Facility. Joseph E. Costa, Ph.D., Buzzards Bay Project National Estuary Program, June 2, 1998

1) Freshwater replacement time methodology is acceptable

The use of "freshwater replacement time" as a proxy hydraulic turnover time of seawater in an estuary is most valid in wedge shaped, relatively vertically well mixed riverine estuaries like the Wareham River Estuary complex. The method also seems appropriate, because most nitrogen inputs such as the sewage treatment facility and other upper watershed sources, enter the head of the estuary, like most freshwater inputs. Septic system inputs to the lower estuary probably equal less than 20% of all watershed nitrogen inputs. Thus, the modeling of freshwater inputs is also a good proxy for the modeling of nitrogen inputs to the estuary. Moreover, given the size and complexity of the estuary system, the freshwater fraction method may be one of the most reliable methodologies, and this study is the best estimate of Wareham River flushing to date. For these reasons, we do not object to the use of this methodology for the Wareham River, as long as the limitations on the application of the freshwater fraction time are understood.

2) Calculation errors resulted in underestimates freshwater replacement time

In Table 4-3 and Table 4-4, the salinities of the various segments of the estuary are reported for August 11 and September 26, 2000 respectively. Estimates of MLW volume and half-tide volume of each segment are also reported for calculating freshwater replacement time. In Table 4-4, half tide volume was correctly used in segment 1, but in segments 2 to 21, mean low water segment volume is used. Attached is the corrected Table 4-4. As shown, when half tide volume is correctly used, total system flushing rate is found to be 7.87 days, not 4.43 days as reported. This error was not made in Table 3, where half tide volumes were correctly used to obtain the 5.74 day flushing rate. Thus, the average freshwater replacement time for the two dates is 6.15 days.

In the CDM report, two contradictory boundaries for the estuary are defined. These boundary definitions have important implications for estimating flushing rates. If the whole system is defined as WASP segments 2 to 21, freshwater replacement rates for the two survey dates are 5.68 and 5.68 days respectively. If the whole system is defined as WASP segments 3 to 21, freshwater replacement rates for the two dates are 4.05 and 4.21 days respectively. The implications of these delineations are discussed in a latter section of this comment letter.

3) Calculation method incorrect for upper 1/3 of estuary, may not be applicable

The Buzzards Bay Project recommended that the residence time of water in the upper 1/3 of an estuary be used as the basis of establishing a limit. This recommendation was made in recognition that a parcel of water in the upper 1/3 of an estuary tends to remain longer in an estuary than parcels near the mouth. That is to say, the replacement time or residence time of seawater in the upper estuary is longer. Certain types of models of flushing can demonstrate this.

If it were appropriate for the freshwater fraction for the upper 1/3 of the estuary (for example, for WASP model segment 5-21 as proposed in the report), the appropriate reference salinity is outside of the last segment in the analysis. In this case, segment 4 should be used, not segment 0 as used for the whole estuary calculation. This is because with the freshwater fraction method, freshwater replacement time is measured relative to exchange of salinities outside the last segment, using this salinity as the "background" value for the calculations. If this were not the case, a reference salinity of 31 ppt should be used to evaluate the whole system flushing, because this is the offshore salinity of typical of Buzzards Bay water as noted in the report. If this salinity reference value were used, dramatically longer freshwater replacement times would be reported. For example, on August 11, a value of 28.60 was observed at the mouth of the estuary. If a 31 ppt Buzzards Bay salinity was used as a reference, the whole system freshwater replacement time would be 12.7 days, not 5.7 days as reported. This also illustrates the importance of having a good estimate of salinity just outside the last segment.

When the freshwater fraction method is correctly performed on the upper 1/3 of the estuary using segment 4 as the reference, the fresh water replacement time values are 3.00 and 3.52 days respectively for the August and September Surveys (mean= 3.26 days), not 4.14 and 2.35 (includes calculation error as per comment 2) as reported.

Because of the morphology of the Wareham estuary, which includes some very low salinity segments on the Agawam River, a case could be made for including WASP model segment 4 in the "upper 1/3" analysis. Inclusion of WASP Segment 4 means theses "upper 1/3" of the estuary actually accounts for 43% of all WASP segment areas shown, but WASP segment 4 would have to be included if the Broad Marsh River and Crooked River parts of the Wareham River were included in the calculation, or if the low salinity segments of the upper Agawam were not included as part of the entire surface area of the "estuary." WASP Model segment 4 is an area where eutrophic conditions and loss of eelgrass have been reported. With WASP model segment 4, the upper 1/3 analysis results in upper 1/3 freshwater replacement times of 3.57 and 3.83 days respectively, or 3.7 days for a mean.

However, a more critical issue, is that the freshwater fraction method when applied to smaller upstream areas of an estuary result in shorter freshwater replacement times, not longer times. While this method is an accurate assessment of freshwater replacement times, it may not be appropriate for characterizing seawater residence times in the upper estuary. This contrasts with other types of models that show that a particle of water in the upper portion of an estuary, tends on average to reside longer in an estuary than a particle near the mouth. This nuance of the freshwater fraction model suggests that whole system freshwater replacement times and not upper 1/3 estuary freshwater replacement times be used as the proxy for seawater residence times for the purpose of establishing nitrogen loading limits.

4) Model not robust, results uncertain.
The results of the freshwater fraction method are not particularly robust in this study because out of 21 segments in the WASP model, segments 1 to 3 at the mouth account for 37% of total half-tide volume used in the calculations, and 31% and 46% of total freshwater volume on the two dates. Thus, if salinity values in either of these segments, or the reference salinity were not representative of the average salinity in that segment during the respective tide period, the freshwater replacement times will change considerably.

For example, on the August data set, using a salinity reference of 28.6 ppt for "outside" the estuary, a whole system freshwater replacement rate of 5.74 days was calculated. If the reference salinity were actually 29.0 ppt (a 1.4 % increase), calculated freshwater replacement time would be 6.98 days, a 22% increase in flushing time. A 5% increase in the reference salinity would increase freshwater replacement time 10.0 days, a 75% increase.

It is difficult to evaluate whether the reference salinities used in this study are appropriate. The location of the sampling stations differ on the two sampling dates. It appears that a single station 13 at the boundary of segment 1 was used as the reference station in Survey 2 in September. This left a single station 13A to characterize salinity in segment 1, which was 0.66 ppt higher in salinity than segment 2. In the Survey 1sampling in August, all the "outside" stations were near the mouth of the Weweantic River, and could have resulted in a somewhat lower reference salinity than appropriate. Presumably stations 13A and 13 were used on that date for the reference salinity. The complexities of characterizing a reference salinity using these locations are illustrated by the salinity profiles in figures 4-1 and 4-2. Station 13A, closer than 13 to the Weweantic mouth, is slightly higher in salinity than station 13. Moreover, in absolute value, station 13A is lower in salinity, especially near the surface during flood tides. Other problems include the fact that most of Broad Marsh River was not included in the model, and the portion that was included had no sampling station or data. These observations, together with the fact that the model is very sensitive to slight changes in reference salinity values suggest that estimates of freshwater replacement time in this study have wide confidence limits.

If the whole system estuary is defined as WASP model segments 2-21 or segments 3-21, the calculation is more robust because the first few segments have a lesser percent volume of the whole system, and replacement time is less sensitive to small changes in reference salinities. Also the adjoining "outside" segments used as a reference appears better sampled. This is illustrated by the reduced differences between the two sampling dates.

5) Summary of freshwater replacement times

A summary of the freshwater replacement times in the CDM study, corrected for calculation errors are as follows:

Table 1. Summary of flushing time calculations.

	Freshwater replacement time in days		
Area	survey 1	survey 2	mean
whole system (WASP segments 1-21)	5.74	7.87	6.81
whole system, defined as segs 2-21	5.68	5.68	5.68
whole system, defined as segs 3-21	4.05	4.21	4.13
upper 1/3, using segments 4-21	3.57	3.83	3.70
upper 1/3, using segments 5-21	3.00	3.52	3.26

Note: survey 1 was at neap tide, survey 2 was at spring tide.

Estimates of nitrogen loading

In 1998, the Buzzards Bay Project estimated that loading to the Wareham River estuary was 67,900 kg per year. In the current report, CDM estimates nitrogen load to the estuary to be 78,250 kg per year. This higher estimate by CDM was due to a number of factors, such as somewhat higher loadings for some types of land use, and inclusion of some new development. Most importantly, however, it was due to the fact that he lower watershed boundary now includes an additional highly developed area near the mouth of the Wareham River. In the CDM report, the Wareham estuary entrance is defined as a line between the tip of Cromset Point and an area near Swifts Beach, instead of the more inward natural constriction defined by the spit of land at Swifts Beach across the entrance as used by the Buzzards Bay Project in its 1998 report. As a result, the CDM report now includes densely developed areas around Marks Cove, including all of the Swifts Beach area, and additional areas of Great Neck. While the increased nitrogen loading rate caused by this more expansive watershed may at first suggest that more restrictive nitrogen limits may apply to the estuary, the inclusion of the large deep area at the entrance of the Wareham River has important effects on establishing a nitrogen limit as discussed below.

Other watershed boundary differences exist in the CDM report which appears to be based on land surface topography. In 1990, the Buzzards Bay project rejected this delineation and instead worked with USGS to develop a watershed boundary based on groundwater elevation. However, the differences in nitrogen loading resulting from these different upper watershed boundaries are probably modest, because the upper watershed is largely undeveloped, and because inclusions or omissions in one upper watershed boundary appear offset by comparable omissions or inclusions in the other upper watershed boundary.

The additional loading projections in the CDM report are partly offset by a higher assumed attenuation rate for the upper watershed. CDM estimated that upper watershed attenuation is between 53% and 61% of land use loads. In the 1998 Buzzards Bay Project report, a preliminary upper watershed attenuation of 30% was adopted until specific data could be collected for this watershed. The CDM approach used in this study, namely comparing stream loads (concentration times flow) to land use loading estimates, is a sound one. However, several confounding variables could have contributed to an overestimate of attenuation. First, stream flow was lower during the period studied because of drought conditions. Lower flow would have lead to lower stream load compared to average land use loading contributions. During a wetter year, stream flow would have been high, and nitrogen concentrations at least as high resulting in a better agreement between annual loading by the stream and expected annual loading from land use.

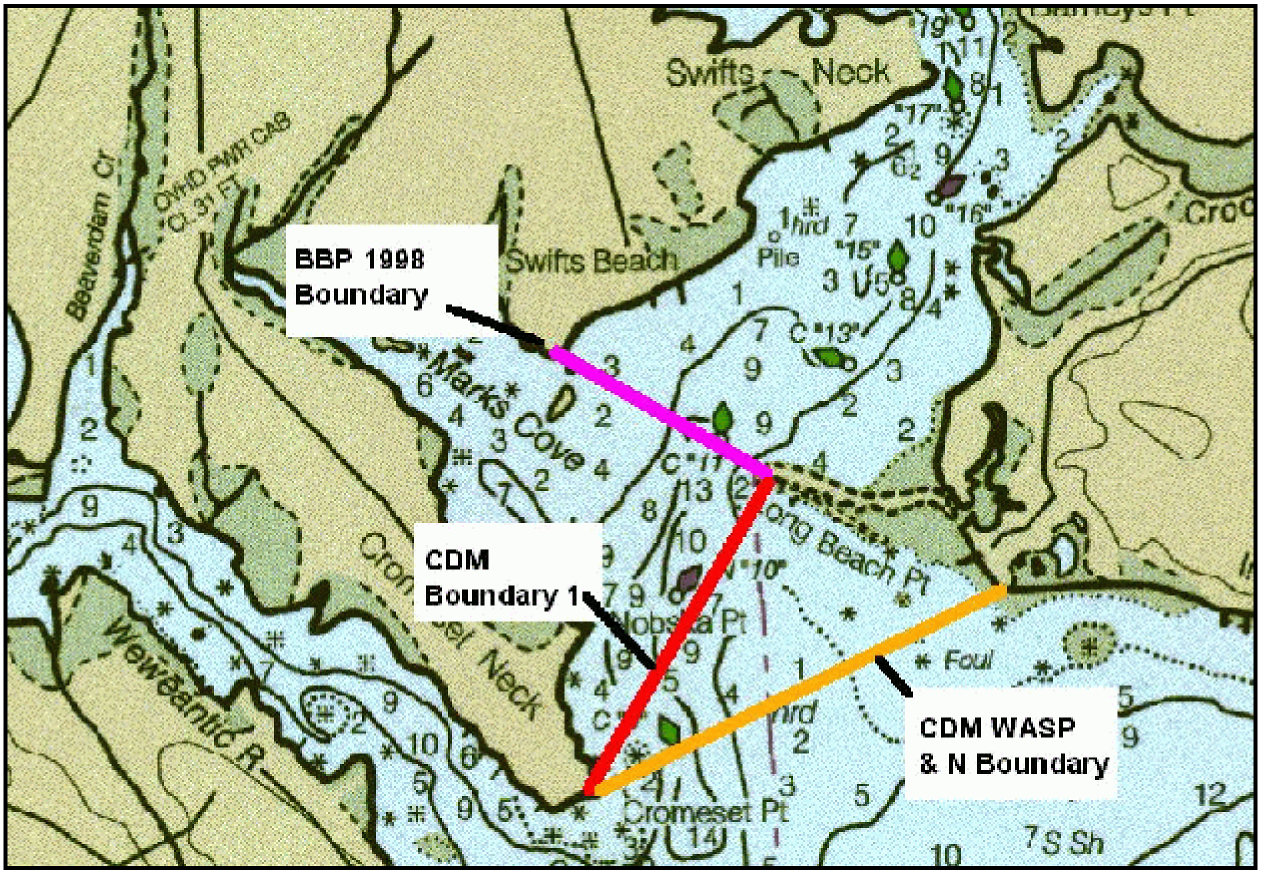
Another factor that was not considered was the fact that there is a lag time between groundwater discharges from new development, and discharges to the surface waters. This lag time for some parts of the watershed may be 10 to 20 years. This lag could also account for part of the lower than expected loadings in the stream, and should be accounted for.

Finally, it appears that concentrations and loadings in the stream were volume weighted in the report's calculation of river nitrogen flux. That is important because during high flow periods, nitrogen concentrations were sometimes quite high in the stream. This is consistent with observations elsewhere that overland runoff of nitrogen occurs during heavy rains, and DIN in estuaries tend to be much higher during wet periods. However, loadings were only estimated for the period of March to October. Stream flows and DIN concentrations tend to be much higher in winter, and there is also less biological uptake in freshwater wetlands during this period. If the stream flows of the period November to February were accounted for, annual stream loading would be much closer to annual loadings projected from land use. The implications of choosing the lower flow stream period for evaluating upper watershed attenuation should be discussed.

Application of results to Nitrogen Loading standards

For the purposes of setting nitrogen loading limits, there must be agreement as to the boundary of the estuary, its area, volume, and flushing rate. Unfortunately, the delineation of the estuary boundary in Figure 1-1, the WASP model, the BBP 1998 report, and earlier flushing analyses all differ somewhat. The BBP questions CDM's proposed new boundary from Cromset Point to Long Beach Point as shown in Figure 1-1 of their report because the boundary does not agree with the estuary boundary as defined in their WASP model or land use a loading model in their report. It also differs from the BBP 1998 proposed boundary.

Roughly, the CDM estuary boundary in Fig. 1-1 of the CDM report corresponds to WASP model segments 2-21, and the BBP 1998 boundary corresponds to WASP segments 3-21. The position of the estuary boundary is important, because it defines the watershed boundary and watershed nitrogen loading estimates. What is more important, both flushing times, and acceptable loading limits can be



greatly affected by boundary position. For example, the further outward into Buzzards Bay that the estuary is defined, the longer the whole system residence time, reducing proposed allowable nitrogen inputs. On the other hand, including the deeper areas at the mouth increases bay volume used in the nitrogen limit calculations, which in turn increases proposed allowable nitrogen limits.

There may also be a discrepancy on the estuary areas. The WASP model does not include upper Broad Marsh River and Upper Crooked River, and estuary area is reported to be 394 ha. Based on digitizing the entire area from a USGS quad maps, the total area of the estuary is 407 ha, which matches the omitted area of 13.8 hectares in the upper Broad Marsh River and upper Crooked River in segment 4. The depth of these areas was assumed to be 0.3 meters at half tide, with a volume equal to 41,000 cu m.

In reports issued in September 1999 and January 2000, the Buzzards Bay Project proposed more stringent nitrogen loading strategies for all Buzzards Bay embayments and recommended that regulatory agencies and municipalities adopt these more stringent standards for planning growth and upgrading wastewater treatment plants. The proposed “BBP-SB” standard corresponds to “eutrophic” water quality, “BBP-SA” standard corresponds to “fair” water quality, and the “BBP-ORW” limit corresponds to “Good to Excellent” in the Eutrophic Index scoring scheme, with no specific standard for “Excellent.” There is concern and debate among regulators that the proposed Buzzards Bay Project standards may be too lenient for water quality designations under the clean water act and for application to TMDLs. For an estuary, like the Wareham River, the new proposed BBP-SA standard is 150 mg per cubic meter during the Vollenweider term adjusted residence time of water in the estuary, and .50 mg per cubic meter during the Vollenweider term adjusted residence time of water in the estuary for the BBP-ORW.

Below we show how the proposed standards apply to the estuary using the different assumed flushing times and estuary boundaries with their resulting differing bay volumes. To show the sensitivity of the analysis to salinity in the last segment, we also include loading limits if salinities in the reference segment were underestimated by 0.2 ppt. All bay volumes include the Broad Marsh River and Crooked River margin areas not included in the WASP Model. It is worth noting that when whole system freshwater replacement times are used for the three potential definitions of the estuary, and when the half tide volume appropriate to that definition of the estuary, the resulting recommended limits under the three definitions do not vary greatly (i.e., 71,100, 77,200, and 78,500). Use of the upper 1/3 of the estuary flushing time, and applying it to the whole system WASP 1-21 definition of the estuary results in a much more lenient limit, nearly twice existing nitrogen loadings.

Table 2. Summary of potential nitrogen limits for the Wareham Estuary. Use of "upper 1/3 flushing" using freshwater replacement time is not recommended for application to BBP methodology.

Estuary Definition	area (ha)	½ tide[b] Vol x10^6	"flushing" (days)	"BBP-SA"= "Fair" WQ recom. limit" (kg/y)	"BBP-ORW"= "Good to Excel." recom. limit (kg/y)
Whole system, WASP 1-21	407	8.45	6.15	77,200	25,800
w/ upper 1/3 flushing, seg 4	" "	" "	*3.70*	*137,600*	*45,900*
w/ upper 1/3 flushing, seg 5	" "	" "	*3.26*	*155,300*	*51,800*
Whole System, WASP 2-21	329	6.56	5.68	71,100	23,700
same, but salinity 0.2 ppt higher	329	6.56	6.22	65,300	21,800
whole system WASP 3-21[a] whole system	264	5.35	4.13	78,500	26,200

[a] This boundary is nearly equivalent to the BBP estuary delineation of 1998. The area is somewhat larger than reported in the 1998 report because the uppermost reaches of the Agawam were not included in that analysis.

[b] mean of two dates

Conclusions and recommendations

1) Currently the Wareham River estuary is among the most eutrophic in Buzzards Bay. It therefore appears inappropriate to apply the freshwater replacement time methodology using only the "upper 1/3" of the estuary segments in their flushing model, since that approach results in a proposed allowable limit for the estuary of twice existing nitrogen inputs. As noted earlier, the upper 1/3 estuary calculation using the freshwater replacement time methodology is inconsistent with the BBP methodology where it is recognized that waters in the upper 1/3 of the estuary remain longer in the estuary than waters near the mouth. Consequently, we recommend that whole estuary system flushing times be used when if the flushing time is approximated by the freshwater replacement time methodology. In this respect, flushing times for the whole estuary system defined as WASP model segments 2-21, are most consistent with CDM's definition of the estuary in Figure 1-1 of their report. This suggests a nitrogen loading limit of 71,120 kg per year if the BBP-SA standard ("fair" water quality) is to be applied. This is higher than the 57,800 kg per year limit proposed in 1998 by the Buzzards Bay Project for a small estuary area and volume than currently defined in this report.

2) The flushing model used is highly sensitive to the salinity measured in the last segment. For example, if the salinity of the reference segment was 0.2 ppt higher (that is, less than 0.8% error), allowable loading would be 8% lower (65,350 kg per year instead of 71,120 kg per year). A margin of safety may need to be considered for this calculation because only one station was generally measured in

these reference segments, and variations in salinity between top and bottom salinities and ebb and flow tides often exceed 0.2 ppt.

3) Attenuation may have been overestimated for the upper watershed, and a sensitivity analysis should be conducted to evaluate potential underestimates of river flow or lag times between nitrogen discharges to groundwater and discharge to rivers and streams.

4) In its 1998 preliminary analysis, the Buzzards Bay Project estimated that existing nitrogen loading to Wareham River estuary was about 18% over recommended limits. The current nitrogen load by CDM using an expanded definition of the watershed and estuary boundaries is about 10% over recommended limits, using whole estuary flushing times. This finding is consistent with eutrophic conditions observed in the estuary compared to other Buzzards Bay embayments. Specifically, many of the SA water quality targets proposed for SA waters by the Buzzards Bay Project are exceeded for this estuary. The estuary far exceeds BBP-ORW targets for "good to excellent" water quality. These facts suggest that it is appropriate to undertake actions to reduce nitrogen inputs to the estuary.

Sincerely,

Joseph E. Costa, Ph.D.

cc. Dr. Brian Howes (CMAST)
Camp Dresser and McKee
Dave Janik (EOEA)
Todd Callaghan (MCZM)
Ron Lyberger, DEP
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Chuck Gricus, Wareham Planning Department
Mark Rasmussen, CBB