Exigency Plan
Summary Water Quality Assessment

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Executive Summary

It is possible that the inter-island tunnel could be completed before the new outfall tunnel to Massachusetts Bay. There would then be two treatment and discharge scenarios possible for South System wastewater.

- Scenario A, "NoTransfer": the inter-island tunnel does not transfer South System flows, and Nut and Deer Island treatment and outfall systems continue operation until the new outfall tunnel is completed.
- Scenario B, "Transfer": the inter-island tunnel transfers South System flows to Deer Island for treatment and discharge.

This report compares the environmental impacts of NoTransfer and Transfer based on the results of a pollutant transport and water quality computer model called TEA-ELA. Three pollutants were modeled:

- copper,
- biochemical oxygen demand, which causes dissolved oxygen depletion, and
- fecal coliform.

The analysis is based on pollutant concentrations at two sets of locations:

- in the outfalls' nearfields, immediately after initial dilution, and
- at key resource areas chosen in this study's Water Quality Assessment Program and Protocol (MWRA, 1994) to assess the effect of pollutants on aquatic life, shellfish beds, and swimming areas.

The differences between the environmental effects of Transfer and NoTransfer are fairly small. In general, the pollutants chosen for analysis meet water quality standards in either scenario. The only risk of standard violation comes from copper in the nearfield and fecal coliform in the unlikely event of a chlorination failure.

Where a valid comparison between scenarios could be made, Transfer was preferable to NoTransfer (see Table 1). However, the recommendation depends partially on the risk of chlorination failures at Deer and Nut Islands which is beyond the scope of this report. Given the caveat for chlorination failure, Transfer is the preferred scenario from an environmental perspective, but the difference is small.

Preferred Scenario

	Copper	BOD	Fecal Coliform
Nearfield	**Transfer**	not an issue	**depends on plant performance***
Resource Areas	indeterminate	Transfer	**depends on plant performance***

Table 1. For each pollutant in the nearfield and at the resource areas, the preferred scenario is indicated, or other comment is given when there is no preferred scenario. **Bold** indicates that the choice of scenario is likely to affect violation of standard.
* For fecal coliform, choosing the scenario that minimizes use of the treatment plant most likely to experience chlorination failure is likely to affect standard violation. The location of incompletely chlorinated effluent discharge is unlikely to affect standard violation.

1 Introduction

1.1 The Exigency Plan

"NoTransfer":
the inter-island tunnel does not transfer South System flows, and Nut and Deer Island treatment and outfall systems continue operation until the new outfall tunnel is completed.

"Transfer":
the inter-island tunnel transfers South System flows to Deer Island for treatment and discharge.

In 1989 the parties to the Boston Harbor case reached agreement on a long-term schedule for construction of a new treatment plant on Deer Island to treat wastewater from the entire MWRA collection system. Wastewater from the South System, now treated at Nut Island, will be conveyed from headworks at Nut Island to the new treatment plant on Deer Island through a cross-harbor tunnel, known as the "inter-island tunnel." Effluent from the treatment plant will be discharged through a new effluent outfall tunnel in Massachusetts Bay, 9.5 miles from Deer Island.

The parties recognized that facilities for bringing wastewater to Deer Island from the South System and the facilities to treat those flows (Batteries C and D of the new primary plant) might be completed before the new effluent outfall tunnel was ready for operation. In December 1993 the parties agreed to produce an "Exigency Plan" that determined whether South System flows should be treated at Deer Island if they could not be discharged through the new outfall tunnel. Two scenarios were identified as potential options.

- Scenario A, "NoTransfer": the inter-island tunnel does not transfer South System flows, and Nut and Deer Island treatment and outfall systems continue operation until the new outfall tunnel is completed.
- Scenario B, "Transfer": the inter-island tunnel transfers South System flows to Deer Island for treatment and discharge.

1.2 Water Quality Computer Model

In accordance with the Exigency Plan agreement, the parties developed a plan to study the water quality impacts of the two discharge scenarios, NoTransfer and Transfer. To evaluate water quality impacts, a transport and water quality computer model, known as TEA-ELA (Tidal Embayment Analysis - Eulerian Lagrangian Analysis), was used to predict the concentrations of representative pollutants under different discharge scenarios and effluent flow conditions. From the model's predictions of pollutant concentrations, the comparative benefits and drawbacks of the two options can be assessed.

The pollutants modeled were copper, biochemical oxygen demand (BOD), and fecal coliform bacteria. Copper and fecal coliform have a direct effect on water quality, whereas BOD affects water quality by reducing dissolved oxygen concentrations. These pollutants were chosen because they are important to water quality in the harbor and are representative of a wide range of pollutant decay rates.

The flows modeled include the average (median) flow, as well as simulations of various intensity rainstorms. Rainstorms were modeled as 12-hour pulses of high effluent flows. Pulse flows of both 600 million gallons per day (mgd) and 900 mgd were run, as was a worst-case scenario based on historical data from the spring of 1993. The optimization of outfall use was also tested ("ideal hydraulics" runs), but had a limited, local effect. Not all flow conditions were run for each pollutant. More detailed information about the computer model runs and output may be found in McGillivary and Adams, 1995.

1.3 Analysis of Model Results

1.3.1 Introduction

The most important difference between the two scenarios is which outfalls are used to discharge effluent.

This report summarizes and analyzes the information produced by the TEA-ELA model and described in "Inter-Island Tunnel Water Quality Assessment: Technical Memo #2" (McGillivary and Adams, 1995). Based on Technical Memo #2, this report recommends a preferred alternative, from a water quality perspective. The recommendation is based on an analysis of pollutant concentrations at two sets of locations:

- in the outfalls' nearfields, immediately after initial dilution and
- at key resource areas chosen in the study's Program and Protocol to assess the effect of pollutants on aquatic life, shellfish beds, and swimming areas.

Assuming that both treatment plants are operating properly, the most important difference between the two scenarios is which outfalls are used to discharge effluent. Whether or not South System flows are transferred controls which outfalls are used. The location of effluent discharge affects water quality in the nearfield and at the resource areas.

1.3.2 Nearfield

Nearfield water quality is most affected by the initial dilution at each outfall.

Nearfield water quality is most affected by the initial dilution at each outfall; that is, how well effluent is mixed with receiving water immediately after discharge. Because NoTransfer uses the combined capacity of Deer Island and Nut Island outfalls (see Figure 1), it minimizes use of the shallowest outfalls, which have poor initial dilution. The shallow outfalls (004, 005, and 104) are activated only when the MWRA total system flow is very high. In Transfer all effluent is discharged from Deer Island, so Deer Island's best, deep outfalls (001 and 002) reach capacity much faster than in NoTransfer. Therefore, Transfer activates the Deer Island shallow outfalls (004 and 005) at much lower flows than NoTransfer. However, Nut Island's best outfalls do not have as good initial dilution as Deer Island's best outfalls, so there is some advantage in not discharging from Nut Island at all, if the capacity of 001 and 002 is not exceeded.

1.3.3 Resource Areas

Water quality at the resource areas (see Figure 1) is most affected by where in the harbor effluent is discharged. NoTransfer spreads effluent more evenly throughout the harbor because it has discharge from both Deer Island in the north and from Nut Island in the south. Transfer concentrates effluent in the north because all effluent is discharged from Deer Island. However, the Deer Island outfalls discharge effluent closer to the edge of the harbor, which makes it easier for tidal currents to flush effluent from the harbor. Better flushing reduces the total amount of pollutants in the harbor.

Water quality at the resource areas is most affected by where in the harbor effluent is discharged.

The following sections weigh the advantages and disadvantages of the scenarios in regard to these nearfield and resource area water quality issues.

Outfall and Resource Area Locations

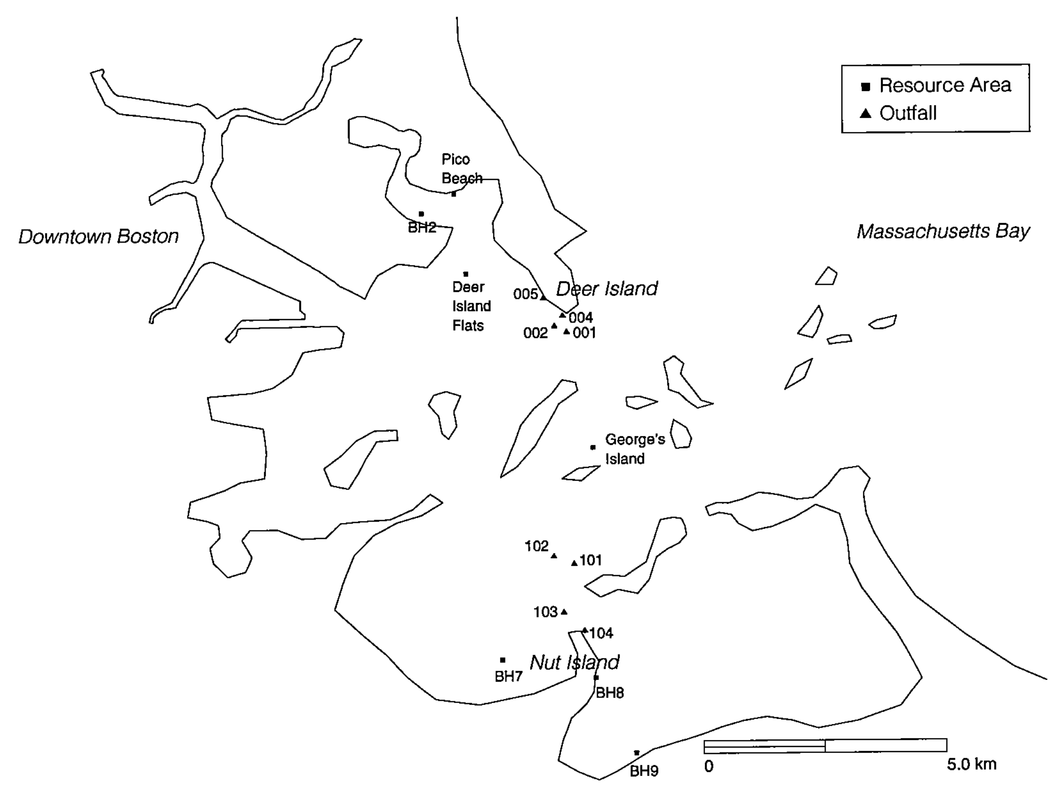

Figure 1. Deer and Nut Island outfalls and the resource areas at which modeled pollutant concentrations were compared (McGillivary and Adams, 1995, Figures 1a and 2).

2 Nearfield

2.1 Introduction

Initial dilution of effluent by receiving water reduces pollutant concentrations, thereby mitigating the environmental effects of effluent. The effect of initial dilution on effluent concentration is localized and quickly lessens with distance from the outfall. Consequently, initial dilution is most important to water quality in the immediate vicinity of an outfall, known as the "nearfield."

Initial dilution is most important to water quality in the immediate vicinity of an outfall, known as the "nearfield."

Initial dilution is a more important concern for pollutants that have an immediate effect on water quality (e.g. copper, fecal coliform) than pollutants that have a delayed effect on water quality (e.g. BOD).

2.2 General Analysis

Analysis Format. The amount of initial dilution that MWRA effluent receives depends on which outfalls are used. The outfalls that operate daily (001, 002, 101, 102, and 103) have better initial dilutions than the outfalls that operate only during periods of high flow (004, 005, and 104) (see Table 2). Of the outfalls used for low and medium flows, Deer Island's have better initial dilution than Nut Island's. However, Nut Island's high flow outfalls have better initial dilution than Deer Island's.

These differences in initial dilutions tend to favor Transfer in some cases and NoTransfer in other cases. These cases are divided accord-

Outfall Initial Dilution and Activation Flow

	Deer Island				Nut Island			
	001	002	004	005	101	102	103	104
Low Tide								
initial dilution	20	18	2	2	12	8	6	5
activation flow (mgd)	0	0	760	1130	0	0	140	240
Mean Tide								
initial dilution	67	59	2	2	22	17	6	5
activation flow (mgd)	0	0	640	970	0	0	110	210
High Tide*								
activation flow (mgd)	0	0	520	810	0	0	90	180

Table 2. Higher flows cause activation of outfalls with lower (worse) initial dilution. Activation flow refers to flow through the treatment plant, not system flow.
*High tide initial dilutions were not modeled. Because initial dilution is strongly dependent on current, high tide initial dilutions are similar to low tide initial dilutions. (McGillivary and Adams, 1995, Table 1B and Figures 6 and 7).

As effluent flow increases, outfalls with worse initial dilution must be activated.

Definition of Effluent Flow Ranges (mgd) and Their Frequencies (1992 / 1993)

	"Low/Medium" Flow (004 not activated)		"High" Flow (004 activated in Transfer)		"Highest" Flow (004 activated in both)	
	range	frequency	range	frequency	range	frequency
low tide	0 - 770	99% / 98%	770 - 1155	1% / 2%	>1155	0% / 0%
mean tide	0 - 640	98% / 95%	640 - 960	2% / 5%	>960	0% / 0%
high tide	0 - 510	94% / 88%	510 - 765	5% / 11%	>765	1% / 2%

Table 3. Higher flows cause activation of outfalls with lower (worse) initial dilution. (McGillivary and Adams, 1995, Table 1B and Figures 6 and 7).

ing to whether 004 is activated in neither scenario ("Low/Medium Flow"), only in Transfer ("High Flow"), or in both scenarios ("Highest Flow").

To determine which scenario is better and by how much, the following analysis of initial dilution is based on three parameters:

- Whether flow activates 004 in neither scenario, in Transfer only, or in both scenarios[1]. These flow ranges are referred to as "Low/Medium," "High," and "Highest", respectively (see Table 3).
- How frequently each flow range occurs[2] (see Table 3).
- How much the initial dilution differs between scenarios for each set of flows (Figures 2, 3, and 4).

The focus of the analysis will be on minimum initial dilution because it creates the highest pollutant concentrations, but dilutions for other portions of the flow will also be considered.

Low/Medium Flow: Transfer is better because it avoids the relatively poor initial dilution at the Nut Island outfalls.

Low/Medium Flow: 004 activated in neither scenario. For low and medium flows, the outfalls used in Transfer have better initial dilution than the outfalls used in NoTransfer (see Figure 2). If the combined North and South Systems flow does not exceed the capacity of 001 and 002, Transfer is better because it avoids the relatively poor initial dilution at the Nut Island outfalls (101, 102, and sometimes 103 are used).

At mean tide, the worst initial dilution in Transfer is 3 to 9 times

Activated Outfalls at Low/Medium Flow

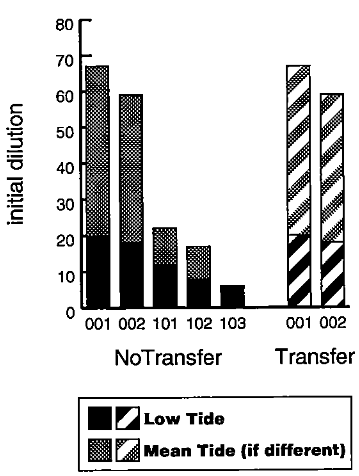

Figure 2. Low/medium flows: activated out- falls and their initial dilutions.

1. McGillivary and Adams (1995, Figure 6) described the flow through Deer Island at which 004 is activated, depending on the tide: 770 mgd at low tide, 640 mgd at medium tide, and 510 mgd at high tide. Based on their assumption that Deer Island's outfalls handle twice as much flow as Nut Island's, 004 would be activated in NoTransfer when the combined flow exceeded 1.5 times the aforementioned 004 capacities.

2. The frequency of each flow condition is determined by comparing the range of flows with frequencies given in McGillivary and Adams, 1994, Tables 5a and 5b.

better than in NoTransfer, depending on whether 103 is activated (103 is activated above 110 mgd at mean tide). The difference between scenarios is greatest at high tide because 103 is almost always activated then. At low tide when dilutions are worst, the minimum initial dilution in Transfer is 2 to 3 times better than in NoTransfer (McGillivary and Adams, 1995, Table 1b).

High Flow:
NoTransfer has better initial dilutions because it sends flow through the Nut Island outfalls instead of through 004, which has very poor initial dilution.

High Flow: 004 is activated in Transfer, but not in NoTransfer. If the combined flow requires 004 in Transfer, but not in NoTransfer, then NoTransfer has better initial dilutions (see Figure 3). NoTransfer sends flow through the Nut Island outfalls instead of through 004, which has very poor initial dilution. The worst initial dilution in NoTransfer is 2.5 times better than in Transfer. NoTransfer also reduces the flow through 001 and 002, the outfalls with the best initial dilutions, which lessens its advantage over Transfer.

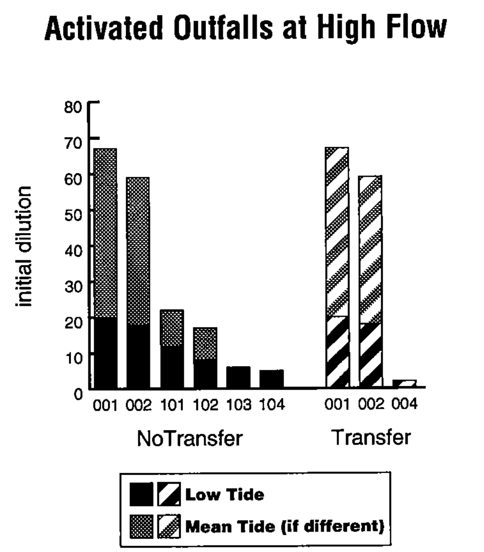

Figure 3. High Flows: activated outfalls and their initial dilutions.

Highest Flow:
NoTransfer has less flow through 004 and 005 than Transfer and thus better initial dilutions.

Highest Flow: 004 is activated in both scenarios. At extremely high flows, 004 is used in both NoTransfer and Transfer, making the scenarios' lowest initial dilutions the same. However, NoTransfer has less flow through 004 than Transfer, making NoTransfer superior for extreme flows (see Figure 4). NoTransfer also has less flow through 001 and 002, which reduces its advantage over Transfer.

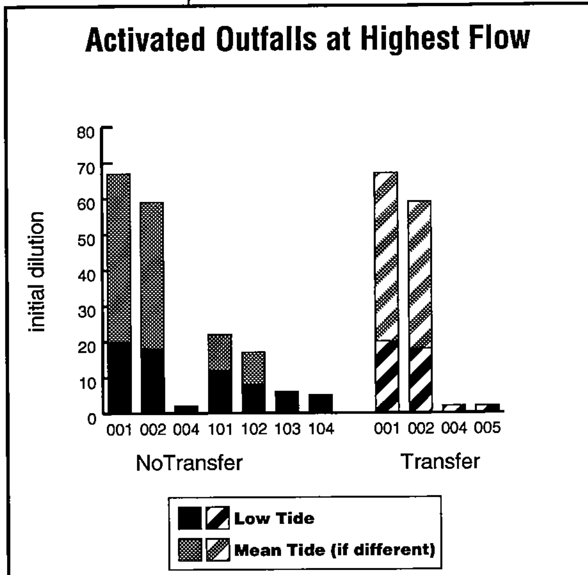

Figure 4. Highest flow: activated outfalls and their initial dilutions (at mean tide).

Conclusions. The differences between lowest initial dilutions in each case appear to be relatively comparable, with Transfer's advantage perhaps a little more important than NoTransfer's (see Figure 5). Transfer has up to 9 times better minimum initial dilution at Low/Medium flows. NoTransfer has up to 2.5 times better minimum initial dilution for the High and Highest flows.

Transfer has better initial dilution than NoTransfer most of the time.

The final step is to compare the frequency with which each case occurs (see Table 3). Here the difference between NoTransfer and Transfer is dramatic. Even in a year with high peak flows, like 1993, Low/Medium flows are almost twenty times more likely than High and Highest flows combined. That is to say, Transfer has better initial dilution than NoTransfer most of the time.

It is true that High and Highest flows have the lowest minimum dilutions and thus a greater chance of violating standards than the Low/Medium flows. But, as the following pollutant-specific analysis shows, violation of standards in the nearfield is not closely related to flowrate for the pollutants modeled.

Minimum Initial Dilution at Activated Outfalls

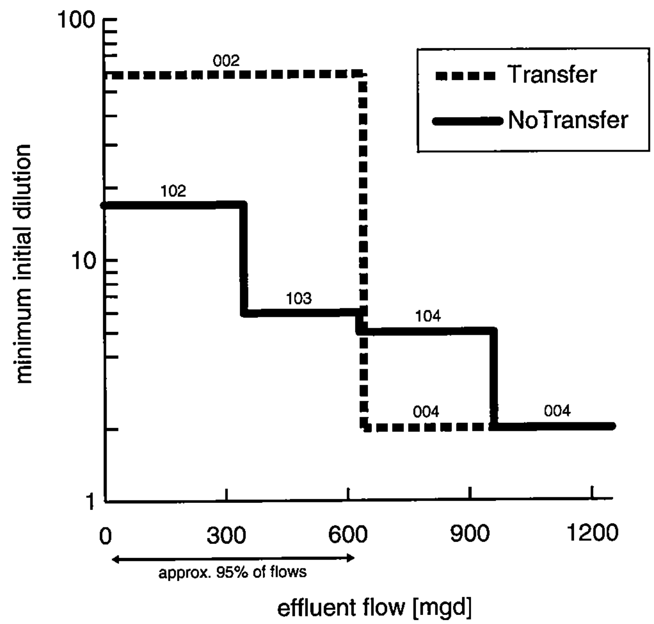

Figure 5. The activated outfall with the lowest initial dilution at a given effluent flow is identified above its dilution. As effluent flow increases, outfalls with lower (worse) initial dilutions must be activated. In Transfer, initial dilution is generally high because the Nut Island outfalls (medium initial dilution) are not used. However, 004 (little initial dilution) is activated in Transfer at lower total system flow (more frequently) than in NoTransfer because all effluent is discharged through Deer Island in Transfer. Activations and dilutions are for mean tide.[3]

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3. When comparing dilution values it is the ratio of dilutions that is important. This is because a dilution figure describes how many times smaller, and not how much smaller, the post-dilution concentration is than the pre-dilution concentration. Only if one knows the actual pollutant concentration in effluent is the absolute difference a useful measure. In Figure 5, a log scale is used for dilution so that a given vertical distance represents a certain number of times better dilution rather than a certain amount better dilution.

2.3 Pollutant-Specific Analysis

2.3.1 Copper

Transfer has significantly less nearfield violation of the copper standard than NoTransfer.

However, these differences exist only in the immediate vicinities of the outfalls, and the violations are small in areal extent.

Introduction. Because copper concentrations in MWRA effluent are above the receiving water quality standard, effluent generally requires significant initial dilution to meet the acute toxicity standard of 2.9 µg/L. If the initial dilution is insufficient, there is potential for copper toxicity near the outfall.

For system flow up to the median flow of 340 mgd, copper is assumed to discharge at constant concentration of 57 µg/L , the flow-weighted Nut and Deer Island effluent mean for FY 1993 (Bigornia-Vitale and Sullivan, 1994). Above 340 mgd system flow, copper is assumed to discharge at constant load equal to the load at 340 mgd and 56.85 µg/L, except for flow through the 109 bypass. Nut Island flow above 240 mgd goes through the 109 treatment bypass and is distributed between outfalls 101, 102, and 103 (but not 104) in proportion to each outfall's total discharge. Copper concentration of flow through 109 is assumed to be equal to 102 µg/L, the flow-weighted Nut and Deer Island effluent mean for FY 93.

Using these copper loads, the initial dilutions at each outfall, and the background buildup copper concentration of 0.3 µg/L as observed in President Roads (Shea and Kelly, Figure 3-1), maximum copper concentrations at the edge of the zone of initial dilution can be calculated. This allows for a comparison of the specific effects of NoTransfer and Transfer on compliance with the copper standard.

Comparison with standard. Of the outfalls that operate on a regular basis, Nut Islands' cause nearfield copper violations more frequently than Deer Islands' (see Figure 6). Discharge from the Nut

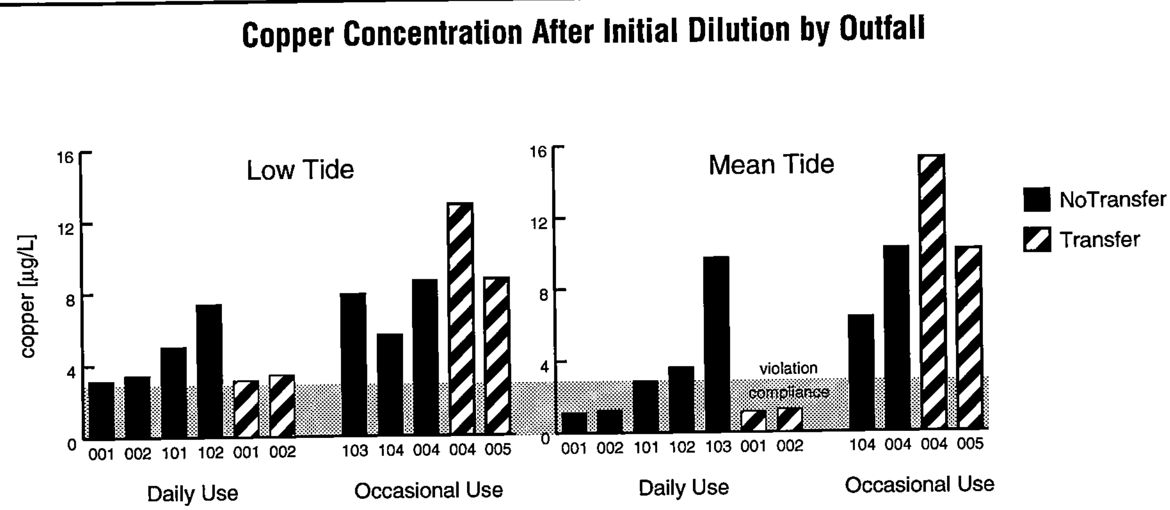

Figure 6. Maximum copper concentrations after initial dilution for outfalls used daily and occasionally in each scenario.

Copper Concentration After Initial Dilution by Flowrate

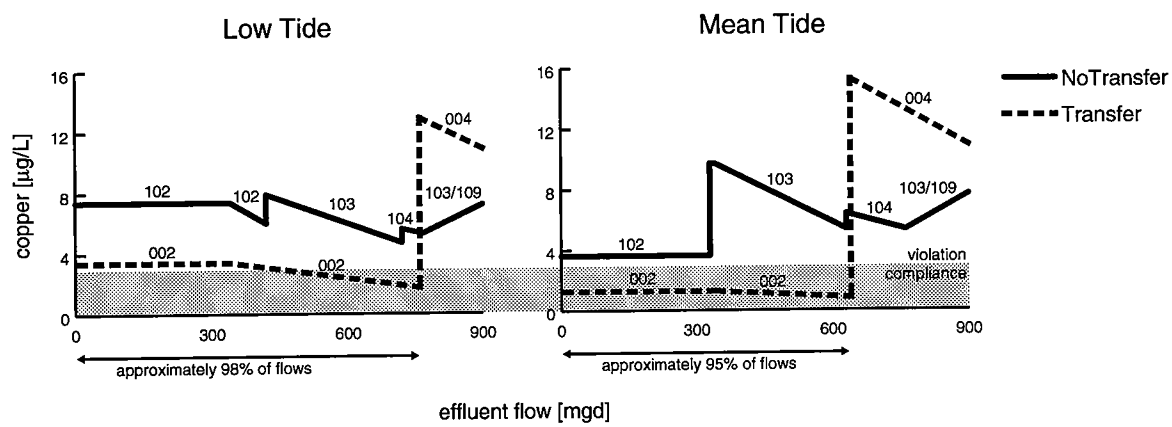

Figure 7. The activated outfall with the highest copper concentration after initial dilution at a given flow is identified above the concentration. As total system effluent flow increases, outfalls with lower initial dilution must be activated, but copper concentration decreases. Assumes constant copper concentration in effluent for flows less than 340 mgd. 103/109: outfall 103 with some effluent from the 109 treatment bypass.

Island outfalls that operate daily (103 above mean tide and 101 and 102 continuously) brings nearfield copper concentrations to between 1 and 3.5 times the standard at median flow, depending on the tide. By contrast, the outfalls that discharge regularly from Deer Island provide nearfield copper concentrations at median flow of one-third of the standard to just over the standard, depending on the tide. Thus, for Low/Medium flows, Transfer has less nearfield violation of the copper standard because it does not use the Nut Island outfalls.

As system flow increases above median flow, copper concentrations in effluent decrease. However, the benefit to water quality is counteracted when outfalls with worse initial dilutions must be activated. At its activation flow, outfall 104 provides nearfield copper concentrations that are two to three times the standard. When flow through Nut Island exceeds 240 mgd, the use of the 109 treatment bypass increases copper concentrations in the nearfields of outfalls 101, 102, and 103. The receiving water concentration near outfall 103 can exceed the concentration near outfall 104.

For high flows in NoTransfer, 004 and 005 provide nearfield copper concentrations that are 2 to 4 times the standard at their respective activation flows. However, 004 is rarely required, and 005 is almost never activated. In Transfer, 004 and 005 must be activated at lower system flow when the effluent concentration is higher. The resulting copper concentrations are 3 to 6 times the standard at the activation flows. Thus, for flows that require the use of 004 in Transfer, but not in NoTransfer ("High Flow" in Table 3), there is significantly less nearfield violation of the copper in NoTransfer than in Transfer. As Table 3 shows, "High Flow" conditions occur very infrequently.

Conclusions. Figure 7 shows that in the nearfield at low and mean tide, Transfer has less violation of the copper standard and generally lower maximum copper concentrations than NoTransfer. High tide conditions would most likely show similar results, but were not modeled.

However, these differences exist only in the immediate vicinities of the outfalls, and in most cases the violations are small in areal extent. For most flows, at least some of the Nut Island discharge violates the copper standard after initial dilution, while Deer Island discharge rarely has any standard violations. When Transfer discharge does violate the standard (i.e. when 004 is used), the copper concentrations are generally 2 to 3 times higher than in NoTransfer.

2.3.2 Biochemical Oxygen Demand

The water quality effects of BOD are less dependent on initial dilution and more dependent on subsequent dilution by currents and dispersion. Because it takes hours to days for BOD to reduce dissolved oxygen concentrations, initial dilution has relatively little effect on dissolved oxygen depletion caused by effluent BOD load. BOD is better discussed in terms of concentrations at resource areas (see Section 3.3.2).

Initial dilution has relatively little effect on dissolved oxygen depletion caused by BOD from effluent.

2.3.3 Fecal Coliform

The effect of initial dilution is not particularly important for reducing the effect of fecal coliform, if disinfection operates properly. Fecal coliform concentrations in effluent are already in compliance with swimming and boating standards, and shellfishing is prohibited near the outfalls.

Initial dilution is not particularly important for reducing the effect of fecal coliform, if disinfection operates properly.

In the case that disinfection is not complete, however, initial dilution could play an important role. A chlorination failure would lead to complete violation of all fecal coliform standards in the nearfield, regardless of which outfalls were used. Therefore water quality is much more affected by which plant is most likely to cause a chlorination failure than by where unchlorinated effluent is discharged. Determining the risk of chlorination failure at each plant is an operations issue and beyond the scope of this report. Incomplete disinfection is discussed further in the Resource Areas section.

3 Resource Areas

3.1 Introduction

Pollutant concentrations at the resource areas provide information about how differences between NoTransfer and Transfer would affect the uses of Boston Harbor. Boston Harbor is a habitat for aquatic life, and it supports shellfishing, swimming, and boating for humans. The resource areas are primarily swimming and shellfishing areas, but they also indicate how the harbor's ecosystem would be affected by the scenarios. The resource areas are far enough away from the outfalls for the concentrations of pollutants from effluent to approach harborwide averages. Because the resource areas are relatively representative of the harbor as a whole, environmental effects at these areas are especially important in assessing the overall environmental advantages and disadvantages of the two scenarios.

Pollutant concentrations at the resource areas provide information about how differences between NoTransfer and Transfer would affect the uses of Boston Harbor.

A variety of effluent flow conditions were used in modeling the effects of copper, biochemical oxygen demand (BOD), and fecal coliform at resource areas. Average (median) flow of 340 mgd was modeled for all three pollutants. Twelve-hour effluent pulses of 600 and 900 mgd were run for copper and fecal coliform to model the effect of peak system flow. Peak flows were not modeled for BOD because BOD loading is not significantly affected by high system flow. A "wet spring" was also modeled for fecal coliform as a 2 month period of high flows. NoTransfer discharges 2/3 of effluent through Deer Island outfalls and 1/3 through Nut Island outfalls. Transfer discharge all effluent through Deer Island outfalls. More detailed description of the model runs can be found in McGillivary and Adams, 1995.

3.2 General Analysis

Introduction. Copper and BOD showed variations of the same pattern of environmental effect: as would be expected, NoTransfer benefits the northern resource areas because some effluent is kept in the south; Transfer benefits the southern resource areas because all effluent is discharged in the north. Fecal coliform behaved differently and is discussed later.

The next level of analysis is based on two measures of environmental effect:

- net difference in pollutant concentrations between the two scenarios and
- maximum pollutant concentrations.

Transfer has lower pollutant concentrations at resource areas than NoTransfer

Net difference in pollutant concentrations. Clearly, it is important to reduce overall pollutant concentrations in the harbor. Since each scenario raises concentrations in some areas and lowers them in others, the best way to evaluate harbor-wide effects is to look at the net change in pollutant concentrations at northern and southern resource areas.

In general, Transfer has lower pollutant concentrations at the resource areas than NoTransfer, possibly indicating that the harbor-wide average concentration of effluent pollutants is lower in Transfer than in NoTransfer. Transfer benefits the southern resource areas more than NoTransfer benefits the northern resource areas. In addition, at the Georges Island resource area in the central harbor, Transfer had lower pollutant concentrations than NoTransfer for all copper and BOD runs; Transfer and NoTransfer were similar at Georges Island for fecal coliform.

Transfer maximizes discharge through the Deer Island outfalls, which are near the mouth of the President Roads channel. By contrast, NoTransfer discharges a large portion of effluent from the Nut Island outfalls, which are near the head of the Nantasket Roads channel. Because the Deer Island outfalls have better initial dilution and are closer to the edge of the harbor, their discharges are flushed from the harbor more effectively than Nut Island discharges. More effective flushing in the north explains why transferring flows to the north would reduce pollutant concentrations in the south more than it increases them in the north.

NoTransfer is preferable to Transfer for minimizing the maximum pollutant concentrations at resource areas.

Maximum pollutant concentration. Although the net difference in pollutant concentrations is an important consideration, it may not be the best indicator of environmental effect. A few pollutant peaks mixed in with otherwise low concentrations can be worse than higher but less variable overall concentrations if the peaks exceed a threshold of environmental effect (see Figure 8). Because the highest pollutant concentrations can have disproportionate environmental effects, it can be important to minimize the maximum pollutant concentrations, even if it means raising overall concentrations.

NoTransfer is preferable to Transfer for minimizing the maximum pollutant concentrations at resource areas. The maximum pollutant concentration was always lower in NoTransfer than in Transfer. Under existing conditions (equivalent to the NoTransfer scenario), pollutant concentrations are already higher at northern resource areas than southern resource areas. It is no surprise that transferring discharge from the south to the north will only widen the gap between north and south concentrations.

Minimizing the Maximum Concentration

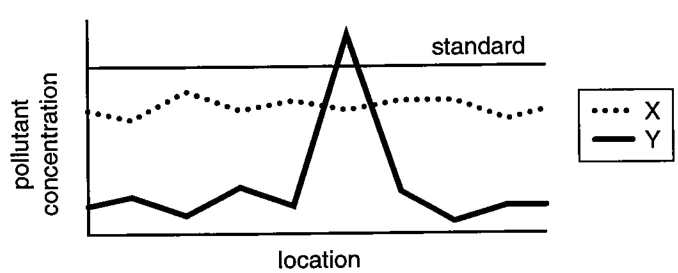

Figure 8. In this hypothetical case, although Y has a lower average concentration than X, Y has a higher maximum concentration than X. Y may have greater environmental impact than X because Y violates the standard.

Conclusions. We are faced with the question of choosing between minimizing the maximum concentration and minimizing the average concentration. NoTransfer spreads pollutant concentrations more evenly throughout the harbor than Transfer. However, Transfer does not increase pollutant concentrations in the north very much, and it significantly reduces them in the south.

A more detailed, pollutant-specific analysis provides additional insight into the nature of this trade-off. Most importantly, it must be determined how much these changes in pollutant concentrations affect the uses of the harbor, for both humans and aquatic life. For instance, if the concentrations of all pollutants at all resource areas are well below water quality standards in all cases, then the actual differences are not very important. If, however, one scenario causes many standard violations while the other does not, then the differences are very important.

3.3 Pollutant-Specific Analysis

3.3.1 Copper

Any differences between the two scenarios in resource area copper concentrations are not particularly important because there are no standard violations.

Accuracy. McGillivary and Adams (1995) estimate that actual copper concentrations from MWRA treatment plant effluent are within 50% of the model's predicted values. The model results closely match the contribution of MWRA effluent to Boston Harbor copper concentrations. The model predictions of concentrations at northern resource areas are about the same as the concentration measured in the nearfield of the Deer Island outfalls: approximately 0.9 μg/L predicted vs. 0.8 μg/L measured (MWRA, 1988).

The model may slightly overestimate the effluent contribution. Measured values near the outfalls (0.8 μg/L) should be slightly higher than modeled values farther from the outfalls (0.9 μg/L) for two reasons. First, there should be some dilution achieved between the outfalls' nearfields and the resource areas. Second, the model does not consider copper from sources other than MWRA effluent, which is probably of minor importance. The background concentration in President Roads has been measured at 0.3 μg/L (Shea and Kelly, Figure 3-1). The portion of this background from sources other than MWRA treatment plants is probably small: MWRA effluent makes up 84% of copper discharged into Boston Harbor (Alber and Chan, Figure 3.2-1). An undetermined portion of the Boston Harbor copper background comes from sources outside of the harbor.

Relevance of results. For copper, any differences between the two scenarios are not particularly important because there are no standard violations. The concentrations at the resource areas of copper from MWRA effluent are at most one-half of the standard. The standard is 2.9 μg/L and the background concentration is 0.3 μg/L (see above). To be conservative, it is assumed that the MWRA effluent contribution predicted by the model is in addition to this background. Therefore, MWRA effluent can contribute 2.6 µg/L of copper without harbor waters violating the copper standard. 2.6 µg/L is therefore referred to as the "effective standard." Concentrations at the resource areas never exceeded 1.4 µg/L in any of the runs. The maximum concentration during the mean flow runs was 1.0 µg/L.

Copper at Resource Areas

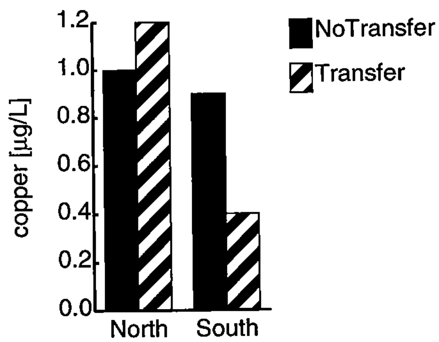

Figure 9. Comparison of copper concentrations at resource areas for each scenario. Data shown are from the resource area in each region with the greatest difference between the two scenarios. Transfer benefits southern resource areas more than NoTransfer benefits northern resource areas. Median effluent flow shown; pulses of higher flows showed similar results.

The maximum difference at a resource area between the two scenarios ranges from 0.2 µg/L to 0.6 µg/L. Considering that the effective standard is 2.6 µg/L, the differences between the two scenarios could have a small effect on water quality.

As with the General Analysis above, the comparison for copper is based on determining how well each scenario

- maximizes the net benefit and
- minimizes the maximum concentration.

Net difference in pollutant concentrations. Transfer provides better overall copper concentrations at the resource areas than NoTransfer. The maximum benefit of NoTransfer in the north areas is 0.2 µg/L for all but the extreme 900 mgd flow run (see Figure 9). Benefits of this magnitude are probably not significant. In the south, the maximum benefit of Transfer was 0.5 or 0.6 µg/L in all runs, cutting concentrations from around 1.0 µg/L to around 0.5 µg/L (see Figure 9). Transfer's halving of MWRA effluent's contribution to copper concentrations could have a small effect on water quality and aquatic life in Quincy and Hingham Bays.

Maximum pollutant concentration. NoTransfer minimizes the maximum copper concentration, but probably not enough to have a significant effect on water quality. The difference in maximums for all but 900 mgd flow is 1.2 µg/L vs. 1.0 µg/L.

Conclusions. It is unlikely that choosing one scenario or the other will have a major effect on copper concentrations. The benefit to the south of Transfer may slightly outweigh the benefit to the north of NoTransfer, but this is not entirely clear.

3.3.2 Biochemical Oxygen Demand

Transfer is a better option than NoTransfer for minimizing the effect of BOD on Boston Harbor dissolved oxygen concentrations.

Introduction. Because it takes hours to days for BOD to deplete dissolved oxygen concentrations, tidal circulation can disperse BOD to low enough concentrations that it does not affect water quality. In Boston Harbor, where tides run 9 feet, tidal flushing plays a major role in mitigating the effect of BOD. Because the model shows better flushing for Deer Island effluent than Nut Island effluent, Transfer is a better option than NoTransfer for minimizing the effect of BOD on Boston Harbor dissolved oxygen concentrations.

NoTransfer BOD effluent concentrations for 340 mgd are 134.9 mg/L for Deer Island and 97.2 mg/L for Nut Island, as determined by Metcalf & Eddy (Metcalf & Eddy, 1994). Because BOD effluent concentration is strongly dependent on influent quality, the Transfer BOD effluent concentration is equal to the flow-weighted average of Deer and Nut Island effluent concentrations.

Relevance of Results. It is hard to tell exactly how much better Transfer is than NoTransfer because there are limited field data to compare with model results and because the model does not take into account background photosynthesis and respiration of aquatic plants. During the day, dissolved oxygen concentrations in Boston Harbor are usually near saturation for most daytime hours. However, dissolved oxygen concentrations are lowest at night due to respiration of aquatic plants. The limited data available indicate that there is significant depletion at night (Alber et al., 1993). Although dissolved oxygen concentrations are generally better in the south than in the north, even the south may suffer from dissolved oxygen depletion during the night.

Quantitatively, summertime dissolved oxygen saturation is 8.0 mg/L in the summer, and the standard is 5.0 mg/L, except in parts of Hingham and Quincy Bays where the standard is 6.0 mg/L. With the available data it is impossible to determine exactly how close dissolved oxygen concentrations go to the standard in different parts of the harbor and the degree to which different BOD sources are responsible for dissolved oxygen depletion. Without those data it is difficult to determine whether the model overestimates or underestimates dissolved oxygen depletion. Therefore, it cannot be determined whether one scenario causes more standard violation than the other scenario.

For the purpose of this analysis it is assumed that MWRA effluent has a significant effect on dissolved oxygen concentrations, as described by the model results, but is not the only factor controlling dissolved oxygen. The model predicts dissolved oxygen depletion of between 0.3 and 0.8 mg/L at the resource areas. These values should be compared with 8.0 mg/L of dissolved oxygen at saturation and with 3.0 mg/L of dissolved oxygen between saturation and the standard (2.0 mg/L in the parts of Hingham and Quincy Bays where the standard is 6.0 mg/L).

Dissolved Oxygen Depletion at Resource Areas

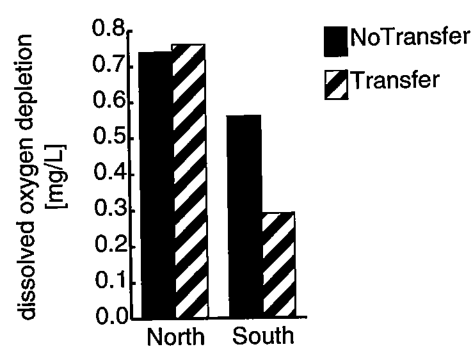

Figure 10. Comparison of dissolved oxygen depletion at resource areas for each scenario. Data shown are from the resource area in each region with the greatest difference between the two scenarios. Transfer benefits southern resource areas more than NoTransfer benefits northern resource areas. (Median effluent flow.)

Geographic Analysis. In the north, dissolved oxygen depletion was essentially the same for both scenarios (see Figure 10). The maximum dissolved oxygen depletion at a northern resource area was 0.74 mg/L for NoTransfer and 0.76

Harborwide Dissolved Oxygen Depletion

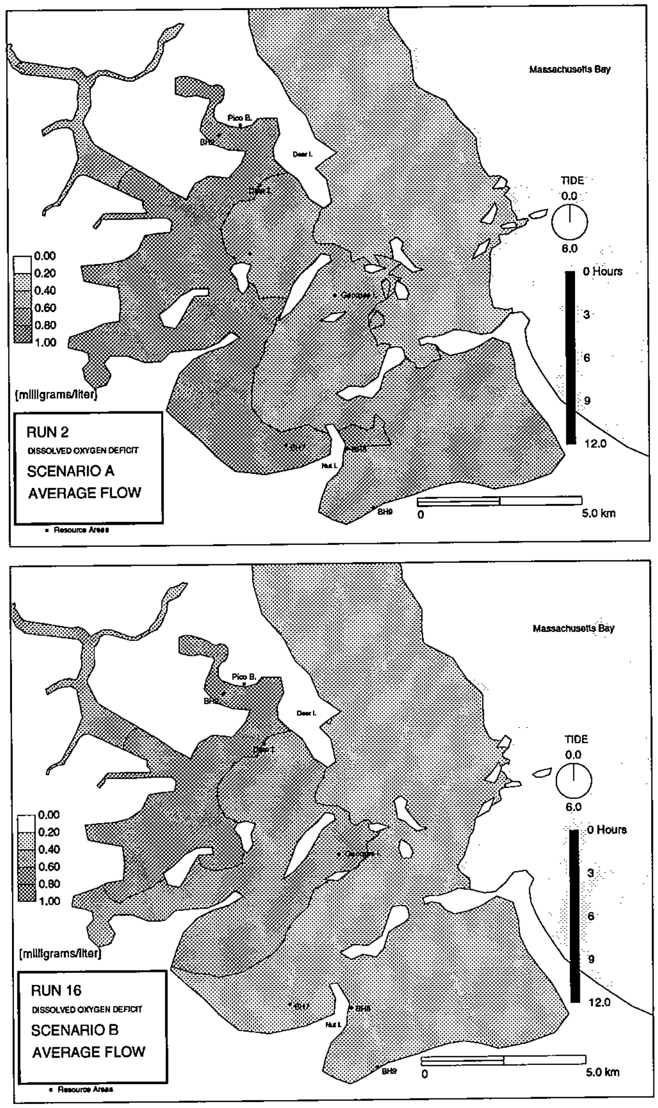

Figure 11. Dissolved oxygen depletion in Boston Harbor. NoTransfer (Scenario A, top) has greater dissolved oxygen depletion than Transfer (Scenario B, bottom) throughout most of the harbor (high tide shown) (McGillivary and Adams, 1995).

mg/L for Transfer. This was also the greatest difference in maximum dissolved oxygen depletion between the two scenarios at any northern resource area. A difference of this magnitude is not significant.

In the south, the difference between the two scenarios was much larger (see Figure 10). Dissolved oxygen depletion for Transfer was approximately 50% of NoTransfer levels. The maximum difference between the two scenarios was approximately 0.3 mg/L. Relative to the saturation value of 8.0 mg/L, 0.3 mg/L is not large. However, relative to the 2.0 mg/L difference between saturation and the standard in parts of the southern harbor, 0.3 mg/L could be relevant. A difference of this magnitude could have a small effect on the health of marine animals.

Differences between the two scenarios cover a much larger geographical extent for dissolved oxygen depletion than for fecal coliform and copper (except for the special case of chlorination failure). The advantage of Transfer extends beyond the south harbor and into the central harbor (see Figure 11). Furthermore, significant differences between the two scenarios are present in the mean case and are thus relevant to all flows and not just extreme cases.

Conclusions. The benefits of Transfer are geographically wide-ranging and are not limited to periods of extreme flow. The unanswered question is whether there is any environmental impact from low dissolved oxygen concentrations in the south that could be alleviated by the benefits of Transfer. Unfortunately, the available data are insufficient to answer this question.

3.3.3 Fecal Coliform with Chlorination

Introduction. Of the three pollutants modeled, fecal coliform has the highest decay rate. Because of chlorination, fecal coliform in effluent is below the swimming standard (in the model it is assumed to be 200 counts/100 mL, the maximum daily average allowed by the MWRA's discharge permits and equal to the swimming standard). The combination of a high decay rate and a low discharge concentration makes fecal coliform concentrations at the resource areas essentially insignificant to the safety of shellfishing and swimming. However, an occasional very high concentration caused by incomplete chlorination could be very significant. Therefore, chlorination failure runs are considered separately from the other fecal coliform runs.

The combination of a high decay rate and a low discharge concentration makes fecal coliform concentrations at the resource areas essentially insignificant to the safety of shellfishing and swimming.

Analysis. Measurements of fecal coliform concentrations near the resource areas show that counts are usually less than 10 counts/100 mL and sometimes approach 0 counts/100 mL (unpublished MWRA data). The model predicts that chlorinated effluent contributes 0.5 - 3.5 counts/100 mL. These predictions seem reasonable, considering that there are many sources of fecal coliform besides effluent.

The maximum fecal coliform concentration at a resource area in any of the runs with chlorination is 3.5 counts/100 mL. This concentration is not significant in comparison to the swimming standard of 200 counts/100 mL or the restricted shellfishing standard of 88 counts/100 mL.

Fecal coliform concentrations at resource areas showed a different pattern from copper and dissolved oxygen depletion, clearly favoring NoTransfer. NoTransfer had lower maximum concentrations and lower overall concentrations than Transfer (see Figure 12). Transfer was limited in how much it could benefit the south because concentrations were so low to start with.

Conclusions. With proper chlorination, the fecal coliform analysis favors NoTransfer, but the advantages of NoTransfer were generally insignificant relative to water quality standards.

Fecal Coliform at Resource Areas

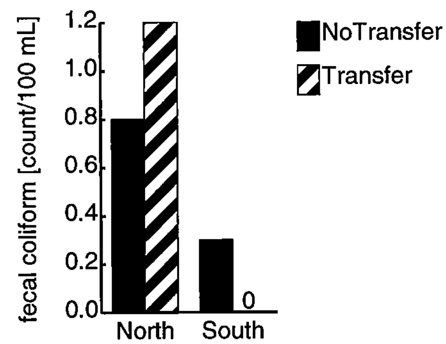

Figure 12. Fecal coliform was the only modeled pollutant for which NoTransfer benefitted the northern resource areas more than Transfer benefitted the southern resource areas. Median effluent flow shown; pulses of higher flows showed similar results.

3.3.4 Fecal Coliform with Chlorination Failure

If it could be determined that one plant was more likely to experience a chlorination failure, the scenario that minimized use of this plant would be favored significantly.

Introduction. The chlorination failure runs showed very large standard violations, but it is difficult to make a fair comparison between the effects of the two scenarios. Both the risk and effect of chlorination failure in each scenario must be considered. The model predicts the effect of a failure. The difficulty is how to weigh the higher risk of failure due to operation of an additional treatment plant in NoTransfer against the higher volume of effluent that would be affected by a chlorination failure in Transfer. As the following analysis shows, the location of unchlorinated effluent discharge is a much less important consideration than the risk of chlorination failure at each plant.

Risk of Failure. Whether there is a failure is much more important than which plant fails. Any chlorination failure, even a Nut Island failure during average flow, causes very significant standard violations. Four orders of magnitude separate the maximum fecal coliform concentrations of failure and no failure. Less than one order of magnitude separates the maximum fecal coliform concentrations of a NoTransfer failure at Nut Island (113 mgd of unchlorinated effluent) from a Transfer failure at Deer Island (340 mgd of unchlorinated effluent). Therefore, the key question is which scenario is most likely to cause a failure.

If it could be determined that one plant was more likely to experience a chlorination failure, the scenario that minimized use of this plant would be favored significantly. Without chlorination failures, there are no water quality standard violations at resource areas for any of the modeled pollutants.

Effects of Failure. Even though we cannot compare the risk of chlorination failure at each treatment plant, it is important to understand the impacts of different chlorination failures. Twelve hour, total chlorination failures were modeled for 340 mgd, 600 mgd, and 900 mgd of effluent. Fecal coliform concentration was assumed to be 5×10^6 counts/100 mL. Each failure assumed that all flow was unchlorinated, so that the fecal coliform load in each scenario would be equal for a given system flow (fecal coliform load is proportional to flow). Thus, in NoTransfer it was assumed that both Deer and Nut Island treatment plants failed simultaneously. While such a condition is very unlikely, it does allow comparison of pollutant transport provided by the two discharge scenarios.

The modeled runs also allow for comparing the effects of a chlorination failure at a single treatment plant in each scenario. The combination of tidal flushing and bacteria die-off keeps most of the effects of a Deer Island failure from southern resource areas. The same is true for Nut Island and northern resource areas. Thus, one can compare the effects of Transfer and NoTransfer failures at Deer Island, even though the model runs for NoTransfer also include failure at Nut Island.

The following analysis considers two measures of impact:

- maximum fecal coliform concentration and
- duration of standard violation.

Increasing the flow of unchlorinated effluent changed the magnitudes of the values, but did not significantly change the relative values.

Maximum concentration. Maximum fecal coliform concentration is a good measure of the degree of environmental effect, but counts that are hundreds of times the standard require special comparisons. There is not a large difference between concentrations of 100,000 counts/100 mL and 200,000 counts/100 mL. In either case, every use of the harbor that depends on bacterial pollution is severely impacted. On the other hand, there probably is a significant difference between concentrations of 10,000 counts/100 mL and 100,000 counts/100 mL; the likelihood of contracting disease increases significantly. Differences in the maximum fecal coliform concentrations are important, but only when the differences are very large.

All chlorination failures had very high violations of the fecal coliform swimming standard (200 counts/100 mL). The highest concentrations were in the north, in the Transfer scenario (see Figure 13). In NoTransfer, less untreated effluent is discharged from Deer Island and consequently fecal coliform concentrations in the north are proportionally lower, but still in major viola-

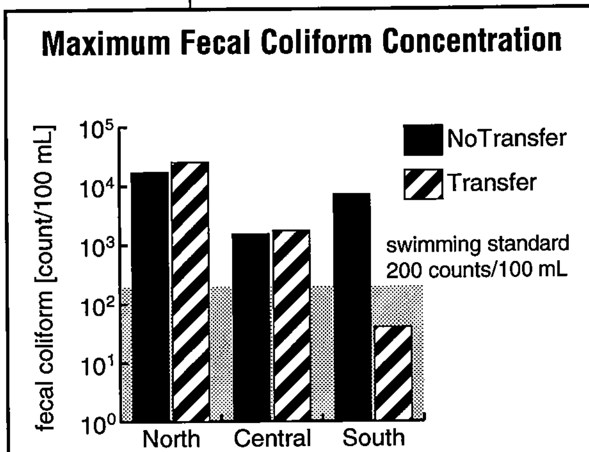

Figure 13. Maximum fecal coliform concentrations at north, central, and south resource areas resulting from a 12 hour pulse of unchlorinated effluent at 340 mgd. Note logarithmic scale.

tion of standards. At Georges Island, roughly halfway between Deer and Nut Island discharge locations, the maximum concentrations for the two scenarios were very similar, both much higher than the standard. The Georges Island data indicate that high fecal coliform concentrations would reach the harbor's center in either discharge scenario. Fecal coliform contamination was significant in the south when discharged from Nut Island. Unchlorinated effluent discharged from Deer Island is noticeable at the southern resource areas, but did not violate the swimming standard, even in the 900 mgd run.

Duration of standard violation. The fecal coliform chlorination failure runs are the only runs of any of the pollutants that clearly violate water quality standards at a resource area[4]. Because there are standard violations, the length of time that the standard is violated is an important measure of environmental effect. Length of violation indicates how long a use of the harbor is affected by a pollutant. In this analysis, fecal coliform concentrations are compared against the swimming standard as a measure of how long uses are affected.

Duration of Standard Violation

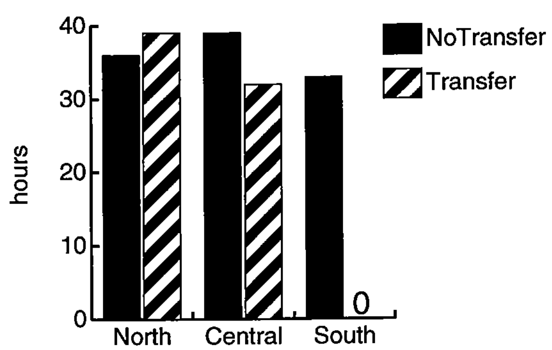

Figure 14. Maximum duration of swimming standard violation (200 counts/100 mL) at north, central, and south resource areas resulting from a 12 hour pulse of unchlorinated effluent at 340 mgd.

All chlorination failures had significant durations of standard violations (see Figure 14). The durations of standard violations in the north for the two scenarios were very similar. At Georges Island the duration of standard violation in NoTransfer was somewhat longer than in Transfer. The difference at Georges Island may be a function of when in the tidal cycle discharge of unchlorinated effluent begins. In the south, the duration of standard violation was slightly less than the duration of the northern violations.

The difference between the two scenarios' discharge locations does not have a major effect on the degree or duration of standard violation resulting from a chlorination failure.

Conclusions. Any chlorination failure causes major standard violations for extended durations. The difference between the scenarios' discharge locations does not seem to be significant. Because NoTransfer has two treatment plants, it is very unlikely that there would be chlorination failure for all of the effluent. However, the distinction between all effluent unchlorinated and just two-thirds unchlorinated is not very large. The relative odds of chlorination failure at the two treatment plants determines whether the benefit of splitting the chlorination facilities justifies the cost of having an extra plant that could fail.

4. Copper concentrations did not violate the standard at resource areas, and it is unclear whether dissolved oxygen depletion causes standard violation.

4 Conclusions

4.1 General

The differences between the environmental effects of Transfer and NoTransfer are fairly small. In general, the pollutants chosen for analysis meet water quality standards in either scenario. The only risks of standard violation comes from copper in the nearfield and from fecal coliform in the unlikely event of a chlorination failure.

Where a valid comparison between scenarios could be made, Transfer was preferable to NoTransfer (see Table 4). However, the recommendation depends partially on the risk of chlorination failures at Deer and Nut Islands which is beyond the scope of this report. Given the caveat for chlorination failure, Transfer is the preferred scenario from an environmental perspective, but the difference is small.

Transfer is the preferred scenario from an environmental perspective, but the difference is small.

In general, the pollutants chosen for analysis meet water quality standards in either scenario.

Preferred Scenario

	Copper	BOD	Fecal Coliform
Nearfield	**Transfer**	not an issue	**depends on plant performance***
Resource Areas	indeterminate	Transfer	**depends on plant performance***

Table 4. For each pollutant in the nearfield and at the resource areas, the preferred scenario is indicated, or other comment is given when there is no preferred scenario. **Bold** indicates that the choice of scenario is likely to affect violation of standard.
* For fecal coliform, choosing the scenario that minimizes use of the treatment plant most likely to experience chlorination failure is likely to affect standard violation. The location of incompletely chlorinated effluent discharge is unlikely to affect standard violation.

4.2 Pollutant-Specific

Nearfield Copper. The risk of acute toxicity from copper is minimized by using outfalls with good initial dilution. Transfer is better than NoTransfer because the Deer Island outfalls usually have much better initial dilution than the Nut Island outfalls. Effluent from the Nut Island outfalls often does not meet the copper standard in the nearfield, though the violations are very limited in areal extent. NoTransfer has less violation of the copper standard than Transfer for very high flows, but these happen only 5% of the time in a very wet year.

The only risk of standard violation comes from copper in the nearfield and fecal coliform in the unlikely event of a chlorination failure.

Fecal Coliform with Chlorination Failure. Although there were some differences between the modeled chlorination failures, they all cause major violation of standards for extended periods of time (approximately two days). Therefore, choosing the chlorination system that is least likely to fail is much more important than choosing the outfall system that minimizes the impact of a chlorination failure. The scenario least likely to experience a chlorination failure will help minimize the risk of environmental impact. Because this report addresses the performance of outfalls and not chlorination systems, no recommendation of scenario is made based on the chlorination failure criterion.

Other Modeled Pollutants. The other potential environmental effects considered are unlikely to cause standard violations. Dissolved oxygen depletion from BOD may cause violation of the dissolved oxygen standard, but the data to make that determination are not available. If there are violations, Transfer is much more likely to alleviate them than NoTransfer. Copper concentrations at the resource areas are well below the standard. The differences between the scenarios do not clearly favor either scenario, and they are unlikely to have a significant effect on water quality. With proper chlorination, fecal coliform concentrations are so much lower than the standards that any differences between the scenarios are negligible.

Pollutants Not Modeled. It should be noted that although the pollutants modeled generally meet water quality standards relevant to the Exigency Plan, MWRA effluent does have significant environmental impacts in Boston Harbor. The primary causes of concern, nutrients and sediment toxicity, have harbor-wide impacts and are not very dependent on discharge location within the harbor. Furthermore, there are no definitive numerical standards for nutrients and sediment toxicity, which makes it difficult to evaluate the effects of each scenario.

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The following people contributed to this report: E. Eric Adams, Rita Berkeley, Michael S. Connor, Carolyn DeCillo, Wendy S. Leo, Drew L. McGillivary, Andrea Rex, and Nancy Wheatley.

Figures 6 and 7

Units:

µg/L	concentration
mgd	flow

Constants:

56.85	median flow effluent concentration (µg/L)
0.3	background concentration at President Roads (µg/L)
340	median effluent flow (mgd)

Max copper concentration (µg/L) after initial dilution, at the greater of median flow and activation flow, for each outfall at low and mean tide. Because copper concnetration through 109 was only modeled for system flow up to 900 mgd, the effect of 109 on concentrations at 101, 102, and 103 is considered only up to 900 mgd.

SCENARIO A, NOTRANSFER

	LOW TIDE				MEAN TIDE			
outfall	act flow	sys flow	dilution	max [Cu]	act flow	sys flow	dilution	max [Cu]
'001	0	340	20	3.1	0	340	67	1.1
'002	0	340	18	3.4	0	340	59	1.3
'004	760	1140	2	8.6	640	960	2	10.2
'005	1130	1695	2	5.9	970	1455	2	6.8
'101	0	340	12	5.0	0	340	22	2.9
'102	0	340	8	7.4	0	340	17	3.6
'103	140	420	6	7.9	110	340	6	9.7
'104	240	720	5	5.6	210	630	5	6.4

SCENARIO B, TRANSFER

	LOW TIDE				MEAN TIDE			
outfall	act flow	sys flow	dilution	max [Cu]	act flow	sys flow	dilution	max [Cu]
'001	0	340	20	3.1	0	340	67	1.1
'002	0	340	18	3.4	0	340	59	1.3
'004	760	760	2	12.9	640	640	2	15.3
'005	1130	1130	2	8.7	970	970	2	10.1

Figure 8

Units:

μg/L concentration
mgd flow

Maximum copper concentration after initial dilution vs. flow (mean tide)

SCENARIO A, NOTRANSFER

outfall with maximum copper concentration	flow	sys flow	dilution	max [Cu]
'102	0	0	17	3.6
'102	110	330	17	3.6
'103	110	330	6	9.7
'103	113	340	6	9.7
'103	210	630	6	5.4
'104	210	630	5	6.4
'104	254	761	5	5.3
'103 with 109	254	761	6	5.3
'103 with 109	300	900	6	7.7

SCENARIO B, TRANSFER

outfall with maximum copper concentration	flow	sys flow	dilution	max [Cu]
'002	0	0	59	1.3
'002	340	340	59	1.3
'002	640	640	59	0.8
'004	640	640	2	15.3
'004	900	900	2	10.9

Maximum copper concentration after initial dilution vs. flow (low tide)

SCENARIO A, NOTRANSFER

outfall with maximum copper concentration	flow	sys flow	dilution	max [Cu]
'102	0	0	8	7.4
'102	113	340	8	7.4
'102	140	420	8	6.0
'103	140	420	6	7.9
'103	240	720	6	4.7
'104	240	720	5	5.6
'104	256	767	5	5.3
'103 with 109	256	767	6	5.3
'103 with 109	300	900	6	7.2

SCENARIO B, TRANSFER

outfall with maximum copper concentration	flow	sys flow	dilution	max [Cu]
'002	0	0	18	3.4
'002	340	340	18	3.4
'002	760	760	18	1.7
'004	760	760	2	12.9
'004	900	900	2	10.9

Figure 8 Continued

To determine the flow at which [Cu] after initial dilution is greater for 103 with 109 than for 104:

Variables:

253.8	q		flow through Nut Island
30	cthree	= (q3ut * Ci + q3t * ce) / (Q4act*Pthree)	Cu conc. of effluent from 103
7	q3ut	= (q - Qtmax)Pthree	flowrate of untreated flow through 103
98	q3t	= (Q4act*Pthree) - q3ut	flowrate of treated flow through 103
25	ce	= Ctmed * (Qmed / 3q)	Cu conc. of treated effluent
5.317	cid4	= (ce + Cb(Ifour - 1)) / Ifour	Cu conc. at 104 after initial dilution
5.320	cid3	= (cthree + Cb (Ithree - 1)) / Ithree	Cu conc. at 103 after initial dilution

Constants:

0.3	Cb	background Cu concentration in President Roads
102	Ci	influent Cu concentration to Nut Island
56.85	Ctmed	Cu concentration after treatment, at median flow
6	Ithree	initial dilution at outfall 103
5	Ifour	initial dilution at outfall 104
340	Qmed	median system flow
210	Q4act	Nut Island flow at which outfall104 activates
240	Qtmax	maximum treated flow through Nut Island
0.5	Pthree	(flow through 103) / (flow through 101, 102, and 103) (Based on McGillivary and Adams, 1994, Table 4.)

Figure 10

COPPER [μg/L]

Consider 2.6 μg/l to be standard violation, based on a background concentration of 0.3 μg/l (Shea and Kelly, Figure 3-1) and the 2.9 μg/l standard.

run	scenario	flow	hours > standard	maximum concentration at a resource area: conc.	area	maximum benefit of scenario at a resource area: high	low	benefit	area
1	A	median	0	1	Flats	0.9	0.4	0.5	8
15	B	median	0	1.2	Flats	1.2	1	0.2	Flats
4	A	600	0	1	Flats	0.9	0.4	0.5	8
18	B	600	0	1.2	Flats	1.2	1	0.2	Flats
4	A	600	0	1	Flats	0.9	0.4	0.5	8
21	B-id	600	0	1.2	Flats	1.2	1	0.2	Flats
7	A	900	0	1	8,Flats	1	0.4	0.6	8
24	B	900	0	1.4	Pico	1.4	0.9	0.5	Pico
9	A-id	900	0	1	8	1	0.4	0.6	8
26	B-id	900	0	1.2	Pico	1.2	0.9	0.3	Pico

maxes taken within first high tide after day 10 or during perturbation caused by pulse

Figure 11

DISSOLVED OXYGEN DEPLETION [mg/L]

run	scenario	flow	maximum concentration at a resource area: conc.	area	maximum benefit of scenario at a resource area: high	low	benefit	area
2do	A	median	0.74	BH2	0.56	0.29	0.27	8, 9
16do	B	median	0.76	BH2	0.76	0.74	0.02	2, Pico

Figure 13

FECAL COLIFORM WITHOUT CHLORINATION FAILURE [count/100 mL]

Use swimming standard of 200 count/100 mL

run	scenario	flow	hours > standard	maximum concentration at a resource area: conc.	area	maximum benefit of scenario at a resource area: high	low	benefit	area
3	A	median	0	0.8	Flats	0.3	0	0.3	8
17	B	median	0	1.2	Flats	1.2	0.8	0.4	Flats
6	A	600	0	1.3	Flats	0.6	0	0.6	8
20	B	600	0	2	Flats	2	1.3	0.7	Flats
6	A	600	0	1.3	Flats	0.6	0	0.6	8
23	B-id	600	0	1.9	Flats	1.9	1.3	0.6	Flats
8	A	900	0	1.9	Flats	0.9	0	0.9	8
25	B	900	0	2.8	Pico	2.8	1	1.8	Pico
10	A-id	900	0	1.4	Flats	0.9	0	0.9	8
27	B-id	900	0	2.7	Flats	2.7	1.4	1.3	Flats
12	A	storm	0	2.3	Flats	1.1	0	1.1	8
29	B	storm	0	3.5	Pico	3.5	1.2	2.3	Pico
14	A-id	storm	0	2.2	Flats	1.1	0	1.1	8
31	B-id	storm	0	3.1	Flats	2.2	1	1.2	Pico

Figures 14 and 15

FECAL COLIFORM WITH CHLORINATION FAILURE [count/100 mL]

run	scenario	flow	hours > standard: north	central	south	maximum concentration: north	central	south
rerun 1	A	340	37	39	33	17000	1500	7000
rerun 2	B	340	39	32	0	25000	1700	40

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