APPENDIX F — ATTACHMENT 3

Analysis of Effluent Dissolved Oxygen Demand

Analysis of Effluent Dissolved Oxygen Demand

Attached are the equations and descriptions of methods used to calculate the requested oxygen depression values due to the effluent. The information contained herein supports the answers provided in Part II-B of the application.

Initial Dilution

The dissolved oxygen concentration immediately following initial dilution is calculated using the following equation:

$$DO_f = DO_a + \frac{(DO_e - IDOD - DO_a)}{S_a}$$

where:

DO_f = Final dissolved oxygen concentration of the receiving water at the plume trapping level (mg/L)

DO_a = Ambient dissolved oxygen concentration averaged from the diffuser port depth to the trapping level (mg/L) (assumed minimum of 5.848 mg/L)

DO_e = Dissolved oxygen concentration of the treatment plant effluent (mg/L) (assumed to be 0 mg/L)

IDOD = Immediate dissolved oxygen demand (mg/L) (assumed to be 5.0 mg/L)

S_a = Minimum initial dilution = 210

The dissolved oxygen water quality standard is expressed as a percent difference from ambient conditions. As a result, critical periods are expected to occur when ambient concentrations are low. However, the dissolved oxygen concentration immediately following initial dilution is calculated in this section using ambient concentrations from each quarterly receiving water sample. The above method yields a reduction of 0.052 mg/L or 0.88 percent. Field data show that reductions can be somewhat higher (up to 0.213 mg/L or 3.5 percent), but still far above levels that would violate water quality standards in Hawaii, which are based on the percent saturation (82.3 percent saturation versus a 75 percent standard).

The Amended Section 301(h) Technical Support Document (EPA, 1994) (TSD) indicates that the least favorable combination of parameter values should be used. The following values remained constant throughout the calculations. Dissolved oxygen concentration of the

effluent is assumed to be 0 mg/L, which is a conservative value, and IDOD was assumed to be 5.0 mg/L, based on primary treatment and a travel time of 100 minutes with an effluent BOD of 200 mg/L (worst-case assumption). Peak month flow rates result in a minimum initial dilution of 210:1, assuming a peak daily flow rate of 46.96 (in the year 2010) mgd and assuming receiving water density data from the month of January (actual peak flow projected to occur in March). Control sample station data used to calculate DO_a and DO_t are HB1 from Honouliuli monitoring program water column sampling. (See Table III.A.3-1 for initial dilution estimates.)

Ambient dissolved oxygen concentrations are averaged over the height of rise of the plume for each of the sampling dates. Dissolved oxygen concentrations are interpolated at the plume trapping level depth of 48.0 m below the surface (occurs in March, but there is no March profile to use and January is the worst case).

In Hawaii, water quality standards for dissolved oxygen are based on the federal regulations, which calculate percent dissolved oxygen depression using the following equation (Baumgartner, 1981):

$$DO_a\ (\%) = (DO_t + IDOD - DO_e)/(S_a \times DO_t)$$

The results using this equation show a depression of 1.86 percent. Actual field monitoring data for the Honouliuli discharge show a slightly higher percentage difference between the upcurrent reference station and the edge of the Zone of Mixing (ZOM), as summarized in Table F-1.

Table F-1. Measured Dissolved Oxygen Depression Resulting from Honouliuli discharge

Monitoring		Minimum DO, mg/L (% Saturation)		Difference, mg/L	Difference (percent depression)
Date	Depth	HB1	HM4		
17 Jan 1995	28m	5.933 (85.62)	5.708 (82.31)	0.255	3.8
3 Nov 1994	30m	5.860 (89.36)	5.709 (86.50)	0.150	2.6
15 Jul 1994	1m	6.202 (93.66)	6.016 (90.70)	0.180	3.0
14 Apr 1994	48m	6.361 (91.00)	6.250 (89.83)	0.110	1.7

The minimum dissolved oxygen value for the ZOM station was used for each comparison; often this was not at the trapping depth, but the worst case was taken for each situation.

As evidenced in Table F-1, the methods used to calculate the percent change in dissolved oxygen concentrations yield similar results for the theoretical calculation and the actual field data. This shows that the field monitoring program is accomplishing what can be predicted based on worst-case conditions.

Farfield Oxygen Demand

EPA guidelines suggest that applicants calculate farfield oxygen demand based on use of equations. There is no substitute for actual monitoring data, and since the City has a good data base, this is used to address the farfield oxygen demand. Table F-1 presents data showing oxygen values at the upcurrent reference station (HB1) and compares this with data from the downcurrent ZOM station HM4. This provides one good way to show what actual dissolved oxygen suppression is in the field. These numbers were used in earlier calculations and clearly indicate that saturation is always maintained above 82 percent under worst-case conditions throughout the entire water column.

Farfield Oxygen Demand

The following equation is used to estimate farfield dissolved oxygen demand:

$$DO(t) = DO_a + \frac{DO_f - DO_a}{D_S} - \frac{L_{fc}}{D_S} 1 - \exp(-k_c t) - \frac{L_{fn}}{D_S} 1 - \exp(k_n t)$$

where:

$DO(t)$ = Dissolved oxygen concentration in a submerged wastefield as a function of travel time t, (mg/L)

DO_a = Affected ambient dissolved oxygen concentration immediately updrift of diffuser (mg/L)

k_c = CBOD decay rate coefficient

k_n = NBOD decay rate coefficient

L_{fc} = Ultimate CBOD concentration at completion of initial dilution (mg/L)

L_{fn} = Ultimate NBOD concentration above ambient at the completion of initial dilution (mg/L)

D_s = Dilution attained subsequent to initial dilution as a function of travel time.

The following assumptions are made in using the above equation to estimate the farfield dissolved oxygen depletion:

- Oxygen depletion is a function of distance from the discharge and is caused by carbonaceous oxygen demand. Because the discharge is into open coastal waters, the effects of nitrogenous oxygen demand are negligible.
- The wastewater plume does not surface during the critical case.

- The discharge is to an open coastal area, so the lateral diffusion coefficient increases as the 4/3 power of the wastefield width.

- The wastefield entrains ambient water as a function of travel time. Lateral diffusion is the predominant mechanism of entrainment.

Ambient dissolved oxygen concentrations averaged over the plume height of rise are calculated in the previous section. The critical ambient concentrations are calculated to occur in January when minimum DO_a is 5.848 mg/L and DO_f is measured to be 5.796 mg/L in January. In order to calculate k_c, the ambient temperature must be determined. This is estimated by averaging recorded temperatures over the height of rise of the plume. The decay rates are then corrected for temperature. In January, k_c is estimated to be 0.160/day.

L_{fc} is defined as the following:

$$L_{fc} = 1.46 \times BOD_f$$

where:

BOD_f = Final BOD_5 concentration (mg/L)

BOD_f can be calculated using the following equation:

$$BOD_f = BOD_a + (BOD_e - BOD_a)/S_a$$

where:

BOD_a = Ambient BOD_5 concentration in the receiving water (mg/L)

BOD_e = Maximum monthly average BOD_5 concentration (mg/L)

S_a = Initial dilution at the average flow rate

BOD_5 monitoring of the receiving water was not required, so this value (BOD_a) is assumed to be 0 mg/L. EPA indicates that the maximum monthly average effluent BOD_5 concentration should be used with the initial dilution at the average flow rate. The projected peak month BOD_e concentration for 2000 is 238 mg/L and S_a is 210. BOD_f is 1.13 mg/L and consequently L_{fc} is assumed to be 1.66 mg/L for this calculation.

Sediment Oxygen Demand and Resuspension

The dissolved oxygen depletion due to a steady sediment oxygen demand can be predicted by the following equation:

$$\Delta DO = \frac{\bar{S}_B X_M}{86{,}400\ UHD} = \frac{a\ \bar{S}\ k_d\ X_M}{86{,}400\ UHD}$$

where:

ΔDO = Oxygen depletion, mg/L

$\bar{S}_B$ = Average benthic oxygen demand over the deposition area, g $O_2/m^2/day$

X_M = Length of deposition are (generally measured in longshore direction, m

H = average depth of water column influenced by sediment oxygen demand, measured above bottom, m

U = minimum sustained current speed over deposition area, m/sec

k_d = sediment decay rate constant, 0.01/day

a = oxygen:sediment stoichiometric ratio, 1.07 mg O_2/mg sediment

$\bar{S}$ = average concentration of deposited organic sediments over the deposition area, g/m^2

D = Dilution caused by horizontal entrainment of ambient water as it passes over the deposition area (always ≥).

For the purposes of this approximation, the following values are used. The stoichiometric ratio a is 1.07. $\bar{S}$ is estimated at $25 g/m^2$ based on flows from 2020 MER and January 1995 model results for steady state organics accumulation for the total area of deposition and total mass remaining. The sediment decay rate constant k_d is 0.01/day. X_M measures approximately 3,000 m, and U is .03 m/sec. A depth for H is calculated using the following equation:

$$H = 0.08 \left(\frac{e_z x_M}{U} \right)^{1/2}$$

When e_z is assumed to be 1 cm^2/sec, then H is 2.53m. D is determined from Table B-5 of the TSD.

Using the above values, the maximum DO_{ss} is calculated to be .122 mg/L occurring at t = 2 hours. This represents a 2.1 percent reduction in the dissolved oxygen concentration at the bottom resulting from sediment steady-state oxygen demand.

Dissolved oxygen depression resulting from sediment resuspension can be estimated using the following equation:

$$\Delta DO = \frac{\overline{S}_r}{DH} \left[1 - \exp\left(\frac{-k_r t}{24}\right) \right]$$

where:

ΔDO = Oxygen depletion, mg/L

$\bar{S}_r$ = Average concentration (in g/m^2) of resuspended organic sediment (based on 90-day accumulation)

H = Depth of water volume containing resuspended materials, m

k_r = Decay rate of resuspended sediments, 0.1/day

t = Elapsed time following resuspension, h (t varies from 0 to 24 h)

D = Dilution as defined previously (generally set equal to 1)

$\bar{S}_r$ can be approximated as the average concentration over the width of the deposition zone (EPA, 1982). This value is assumed to be $25 g/m^2$ based on 90-day accumulation and averaged by total mass over all model cells with accumulation (see Figure III.A.5.4). H is a function of travel time and is calculated using the following equation:

$$H = \frac{1.6}{100} \left(3{,}600\ t\ \varepsilon'_z\right)^{1/2}$$

It is assumed that ε'_z is 5 cm^2/sec, k_r is 0.01/day. The travel time t is varied in 3-hour increments from 0 to 24. The farfield dilution is assumed to increase as a function of the 4/3 law for open waters. The results are presented in Table F-2. The maximum dissolved oxygen depression due to sediment resuspension is .083 mg/L and it occurs at t = 3 hours. Using the lowest ambient bottom dissolved oxygen concentration (5.848 mg/L), the minimum concentration resulting from sediment resuspension is 5.765 mg/L. This represents 1.4 percent in ambient dissolved oxygen concentrations.

Table F-2. Oxygen Depletion Resulting From Sediment Resuspension

Time (hrs.)	Delta DO (mg/L)
0	0.0
3	0.083
6	0.059
9	0.048
12	0.042
15	0.037
18	0.034
21	0.031
24	0.029

APPENDIX F- Attachment 3
Supporting Model and Documentation for Analysis of Dissolved Oxygen SuppressionCalculations

Visual Basic Program HONODO1

Written by Alex Steele of K. P. Lindstrom, Inc.

```
Sub Command1_Click ()
  ' Nearfield DO demand following Initial Dilution

  Debug.Print ""
  Debug.Print " Nearfield DO demand following Initial Dilution"
  Debug.Print ""

  ' Equation from TTRTD, 1994
  ' DOf = DOa + (DOe - IDOD - DOa) / Sa

    ' Where...
    ' DOf = final DO conc.
    ' DOa = ambient DO upcurrent of diffuser between
    '     diffuser depth and trapping depth
    ' DOe = DO of eff.
    ' IDOD = imediate DO demand (typically 0 - 10 -
    '      TTRTD, 1994)
    ' Sa = Initial Dilution

    ' Using for Honolulu...
    DOa = 5.848
    DOe = 0
    IDOD = 5: 'see table B-3, TTRTD, 1994 -
          'used Effl BOD=200 mg/L,travel time=100 min
    Sa = 210: 'ID in 2010

  Debug.Print "Ambient DO (DOa) ="; Format$(DOa, "####.000"); " mg/L"
    ' calc #1
    DOf = DOa + (DOe - IDOD - DOa) / Sa
  Debug.Print "Final DO (DOf) ="; Format$(DOf, "####.000"); " mg/L"
    ' calc #2
    DOred = DOa - DOf
  Debug.Print "Reduction in ambient DO ="; Format$(DOred, "####.000"); " mg/L"
    ' calc #3
    DOpred = ((DOa - DOf) / DOa) * 100
  Debug.Print "% reduction in ambient DO ="; Format$(DOpred, "####.000"); " %"

  ' no indication of entrainment reduction in DO
  ' use real data to check for compliance with % DO
  ' saturation - >75%

End Sub
```

Sub Command1 Click - RUN - output equals...

Nearfield DO demand following Initial Dilution

Ambient DO (DOa) =5.848 mg/L
Final DO (DOf) =5.796 mg/L
Reduction in ambient DO =.052 mg/L
% reduction in ambient DO =.883 %

```
Sub Command2_Click ()
   ' Farfield DO demand following Initial Dilution

   Debug.Print ""
   Debug.Print " Farfield DO demand following Initial Dilution"
   Debug.Print ""

   ' This discussion is organized as follows;
' I.  find final BOD after initial dilution
'     find ultimate BOD
' II. find decay constants for Carbonaceous and
'     Nitrogenous BOD demand
' III. Find the Centerline dilution using 4/3 law
'     (compare 4/3 law to other dilution methods)
' IV.  Combine above to get Far field DO demand

' I.
   ' Equation from TTRTD, 1994
   ' BODf = BODa + (BODe - BODa) / Sa

      ' Where...
      ' BODf = final BOD5 conc. (mg/L)
      ' BODa = ambient BOD5 upcurrent of diffuser between
      '     diffuser depth and trapping depth
      ' BODe = BOD5 of eff.
      ' Sa = Initial Dilution

      ' Using for Honolululi...
      BODa = 0
      BODe = 238: 'see table B-3, TTRTD, 1994 -
            'used Effl BOD=200 mg/L,travel time=100 min
            'used worst case for honoululi effluent
      Sa = 210: '2010 ID

      ' First check whether
      ' DOstd <= DOf - BODfu
      ' Where...
      ' DOstd=DO standard
      ' DOf = DO conc after initial dilution
      ' BODfu = Ultimate BOD at completion of
      ' Initial dilution (=BODf * 1.46)

      Debug.Print "Ambient Ocean BOD assumed to equal = 0.000 mg/L"
      Debug.Print "Effluent BOD = "; Format$(BODe, "####.000"); "mg/L"
      ' get BODf
      BODf = BODa + (BODe - BODa) / Sa
      Debug.Print "BOD final after initial dilution = "; Format$(BODf, "####.000"); "mg/L"
      ' convert BOD5 to Ultimate BOD (BODl)
      BODl = BODf * 1.46
      Debug.Print "Ultimate BOD (* 1.46) = "; Format$(BODl, "####.000"); "mg/L"
```

```
' II.
    ' BOD has two forms;
    ' 1. Carbonaceous - CBOD
    ' use temperature correction below
    ' Kt=0.23*1.047^(T-20)/day

    ' Where...
    ' Kt = BOD decay rate at temp T (deg C)

    t = 20: 'default
    KtCarb = .23 * 1.047 ^ (t - 20)
    Debug.Print "at "; t; "deg C The Carbonaceous BOD decay constant = "; Format$(KtCarb, "####.000")

    t = 24.5: 'Honouliuli
    KtCarb = .23 * 1.047 ^ (t - 20)
    Debug.Print "at "; t; "deg C The Carbonaceous BOD decay constant = "; Format$(KtCarb, "####.000")

    ' 2. Nitrogenous - NBOD
    ' NBOD1=4.57 (TKN)
    ' NBOD5=NBOD1/2.54

    ' Where...
    ' TKN = total Kjeldahl nitrogen
    ' NBOD1 = ultimate NBOD
    ' NBOD5 = 5 day NBOD

    ' Kt=0.10*1.047^(T-20)/day

    ' Where Kt = BOD decay rate at temp T (deg C)
    ' 0.10 = decay rate at 20 deg C

    t = 20: 'default
    KtNitr = .1 * 1.047 ^ (t - 20)
    Debug.Print "at "; t; "deg C The Nitrogenous BOD decay constant = "; Format$(KtNitr, "####.000")

    t = 24.5: 'Honouliuli
    KtNitr = .1 * 1.047 ^ (t - 20)
    Debug.Print "at "; t; "deg C The Nitrogenous BOD decay constant = "; Format$(KtNitr, "####.000")


' III.
    ' To determine additional dilution use 4/3 law
    ' for lateral diffusion coefficient
    '   E = E0*(L/b)^(4/3)

    ' Where...
    ' E = Lateral diffusion coefficient ft^2/sec
    ' E0 = Diffusion coeff when L=b
    ' L = Width of sewage field at any distance from
    '     ZID in feet
    ' b = Initial width of sewage field (approx as
    '     longest dimension of the ZID), in feet

    ' E0 can be approximated as
    ' E0 = .001 * b ^ (4 / 3)
```

```
  ' based on the 4/3 law the centerline dilution
  ' Ds=1/erf*( (1.5/(1+(8*E0*t)/(b^2))^3-1)^.5

  ' Where...
  ' t = travel time, sec
  ' erf = the error function

  ' The TTRTD also recommends for coastal areas
  ' D=1/erf((1.5/(1+(12*E0*t)/(B^2))^2-1)^.5
  ' or most conservatively - assume diff coef const
  ' Ds=1/erf*( (b^2/(16*E0*t))^.5

  ' Test above 3 possibilities to see what happens...
  ' Note can check/confirm calculations with data
  ' in TTRTD, 1994 Table B-5 pg. B-41...

  t = 9000: '2.5 hours
  ' difuser length =1750' +
  ' 1/2 water depth at each end
  b = 2000: 'based on 1750 + 60 * 3.28
  E0 = .001 * b ^ (4 / 3)

  Ds43 = 1 / (1.5 / ((1 + ((8 * E0 * t) / (b ^ 2))) ^ 3 - 1)) ^ .5
  Debug.Print "Given t="; t; "secs, b="; b; "feet, Then Ds43="; Format$(Ds43, "####.000")
  Dcoast = 1 / (1.5 / ((1 + ((12 * E0 * t) / (b ^ 2))) ^ 2 - 1)) ^ .5
  Debug.Print "Given t="; t; "secs, b="; b; "feet, Then Dcoast="; Format$(Dcoast, "####.000")
  Dcons = 1 / ((b ^ 2) / (16 * E0 * t)) ^ .5
  Debug.Print "Given t="; t; "secs, b="; b; "feet, Then Dcons="; Format$(Dcons, "####.000")

' Use above to plot Dilution versus time
' for t=0 to 300000 seconds
  picture1.Scale (-34000, 300)-(340000, -30)
  picture1.Line (0, 0)-(300000, 0)
  picture1.Line (0, 0)-(0, 250)
' hour and day tick marks
  For t = 0 To 300000 Step 3600
    picture1.Line (t, 0)-(t, -3), RGB(0, 0, 0)
  Next t
  daystep = 3600 * 24#
  For t = 0 To 300000 Step daystep
    picture1.Line (t, 0)-(t, -6), RGB(0, 0, 0)
  Next t

For t = 5000 To 300000 Step 5000
  Ds43 = 1 / (1.5 / ((1 + ((8 * E0 * t) / (b ^ 2))) ^ 3 - 1)) ^ .5
  If t = 5000 Then picture1.PSet (t, Ds43), RGB(255, 0, 0)
  If t > 5000 Then picture1.Line -(t, Ds43), RGB(255, 0, 0)
Next t
For t = 5000 To 300000 Step 5000
  Dcoast = 1 / (1.5 / ((1 + ((12 * E0 * t) / (b ^ 2))) ^ 2 - 1)) ^ .5
  If t = 5000 Then picture1.PSet (t, Dcoast), RGB(255, 0, 0)
  If t > 5000 Then picture1.Line -(t, Dcoast), RGB(0, 255, 0)
Next t
For t = 5000 To 300000 Step 5000
  Dcons = 1 / ((b ^ 2) / (16 * E0 * t)) ^ .5
```

```
  If t = 5000 Then picture1.PSet (t, Dcons), RGB(255, 0, 0)
  If t > 5000 Then picture1.Line -(t, Dcons), RGB(0, 0, 255)
 Next t


'IV.
    ' from TTRTD, 1994 (originally from Brooks, 1960)
    ' DOfar(t)=DOa+((DOf-DOa)/Ds) - (Lfc/Ds)*1-exp(-kc*t)-(Lfn/Ds)*1-exp(kn*t)

    ' Where...
    ' DOfar(t)=DO in submerged wastefield as function of time t
    ' DOa = ambient DO
    ' DOf = DO after initial dilution
    ' kc = CBOD decay rate constant (KtCarb)
    ' kn = NBOD decay rate constant (KtNitr)
    ' Lfc = Ultimate CBOD conc above ambient after initial
    '     dilution
    ' Lfn = Ultimate NBOD conc above ambient at completion
    '     of initial dilution
    ' Ds = Dilution attained after initial dilution
    '     as function of travel time

    ' Using for Honolululi...
    DOa = 5.848
    DOe = 0
    IDOD = 5: 'see table B-3, TTRTD, 1994 -
          'used Effl BOD=200 mg/L,travel time=100 min
    Sa = 210: '2010 ID
    ' calc #1
    DOf = DOa + (DOe - IDOD - DOa) / Sa
    Lfc = BODl
    t = 24.5: 'Honouliuli temperature (deg C)
    KtNitr = .1 * 1.047 ^ (t - 20)
    KtCarb = .23 * 1.047 ^ (t - 20)
    b = 2000: '1750 + 60 * 3.28
    E0 = .001 * b ^ (4 / 3)

 Close 2
 Open "dodemand.dat" For Output As #2
 Print #2, "Farfield DO demand following Initial Dilution"
 Print #2, " Time   Subsequent   DO"
 Print #2, " hours  Dilution   mg/L"
 For t = 0 To 72
   ' using Ds43 equation for Ds -
   tsec = t * 3600: ' convert t to seconds
   If tsec = 0 Then tsec = 1:
   Ds = 1 / (1.5 / ((1 + ((8 * E0 * tsec) / (b ^ 2))) ^ 3 - 1)) ^ .5
   Carbred = (Lfc / Ds) * (1 - Exp(1) ^ (-KtCarb / 24 * t))
   Nitrred = (Lfn / Ds) * (1 - Exp(1) ^ (-KtNitr / 24 * t))
   'Debug.Print "Carbred ="; Carbred; " Nitrred ="; Nitrred
   DOfar = DOa + ((DOf - DOa) / Ds) - Carbred - Nitrred
   Debug.Print "At t="; t; "hours, Ds="; Format$(Ds, "####.000"); "  DOfar="; Format$(DOfar, "####.000")
   Print #2, "   "; t; ",   "; Format(Ds, "####.000"); ",  "; Format(DOfar, "####.000")

 Next t
```

Close 2

End Sub

Sub Command2_Click - RUN - output equals...

Farfield DO demand following Initial Dilution

' Compute Ultimate BOD of diluted effluent following initial dilution

Ambient Ocean BOD assumed to equal = 0.000 mg/L
Effluent BOD = 238.000mg/L
BOD final after initial dilution = 1.133mg/L
Ultimate BOD (* 1.46) = 1.655mg/L

' test sensitivity of decay coefficient to changes in T

at 20 deg C The Carbonaceous BOD decay constant = .230
at 24.5 deg C The Carbonaceous BOD decay constant = .283
at 20 deg C The Nitrogenous BOD decay constant = .100
at 24.5 deg C The Nitrogenous BOD decay constant = .123

'compare three alternatives for farfield dilution

Given t= 9000 secs, b= 2000 feet, Then Ds43=1.175
Given t= 9000 secs, b= 2000 feet, Then Dcoast=1.103
Given t= 9000 secs, b= 2000 feet, Then Dcons=.952

'Use 4/3 law centerline dilution get Dofar for 1 to 72 hours post initial dilution

Given t= 1 hours, Ds=.658 Then DOfar=5.740
Given t= 2 hours, Ds=1.010 Then DOfar=5.759
Given t= 3 hours, Ds=1.337 Then DOfar=5.766
Given t= 4 hours, Ds=1.661 Then DOfar=5.771
Given t= 5 hours, Ds=1.989 Then DOfar=5.774
Given t= 6 hours, Ds=2.325 Then DOfar=5.777
Given t= 7 hours, Ds=2.670 Then DOfar=5.780
Given t= 8 hours, Ds=3.026 Then DOfar=5.782
Given t= 9 hours, Ds=3.391 Then DOfar=5.784
Given t= 10 hours, Ds=3.767 Then DOfar=5.785
Given t= 11 hours, Ds=4.154 Then DOfar=5.787
Given t= 12 hours, Ds=4.551 Then DOfar=5.789
Given t= 13 hours, Ds=4.959 Then DOfar=5.790
Given t= 14 hours, Ds=5.377 Then DOfar=5.792
Given t= 15 hours, Ds=5.804 Then DOfar=5.793
Given t= 16 hours, Ds=6.242 Then DOfar=5.794
Given t= 17 hours, Ds=6.690 Then DOfar=5.795
Given t= 18 hours, Ds=7.147 Then DOfar=5.797
Given t= 19 hours, Ds=7.614 Then DOfar=5.798
Given t= 20 hours, Ds=8.090 Then DOfar=5.799
Given t= 21 hours, Ds=8.575 Then DOfar=5.800
Given t= 22 hours, Ds=9.069 Then DOfar=5.801
Given t= 23 hours, Ds=9.571 Then DOfar=5.802
Given t= 24 hours, Ds=10.083 Then DOfar=5.802

Given t= 25 hours, Ds=10.603 Then DOfar=5.803
Given t= 26 hours, Ds=11.132 Then DOfar=5.804
Given t= 27 hours, Ds=11.668 Then DOfar=5.805
Given t= 28 hours, Ds=12.214 Then DOfar=5.806
Given t= 29 hours, Ds=12.767 Then DOfar=5.806
Given t= 30 hours, Ds=13.328 Then DOfar=5.807
Given t= 31 hours, Ds=13.897 Then DOfar=5.808
Given t= 32 hours, Ds=14.474 Then DOfar=5.809
Given t= 33 hours, Ds=15.058 Then DOfar=5.809
Given t= 34 hours, Ds=15.650 Then DOfar=5.810
Given t= 35 hours, Ds=16.249 Then DOfar=5.810
Given t= 36 hours, Ds=16.856 Then DOfar=5.811
Given t= 37 hours, Ds=17.470 Then DOfar=5.812
Given t= 38 hours, Ds=18.092 Then DOfar=5.812
Given t= 39 hours, Ds=18.720 Then DOfar=5.813
Given t= 40 hours, Ds=19.356 Then DOfar=5.813
Given t= 41 hours, Ds=19.998 Then DOfar=5.814
Given t= 42 hours, Ds=20.648 Then DOfar=5.814
Given t= 43 hours, Ds=21.304 Then DOfar=5.815
Given t= 44 hours, Ds=21.967 Then DOfar=5.815
Given t= 45 hours, Ds=22.637 Then DOfar=5.816
Given t= 46 hours, Ds=23.313 Then DOfar=5.816
Given t= 47 hours, Ds=23.996 Then DOfar=5.817
Given t= 48 hours, Ds=24.686 Then DOfar=5.817
Given t= 49 hours, Ds=25.382 Then DOfar=5.817
Given t= 50 hours, Ds=26.084 Then DOfar=5.818
Given t= 51 hours, Ds=26.793 Then DOfar=5.818
Given t= 52 hours, Ds=27.508 Then DOfar=5.819
Given t= 53 hours, Ds=28.229 Then DOfar=5.819
Given t= 54 hours, Ds=28.956 Then DOfar=5.819
Given t= 55 hours, Ds=29.690 Then DOfar=5.820
Given t= 56 hours, Ds=30.429 Then DOfar=5.820
Given t= 57 hours, Ds=31.175 Then DOfar=5.820
Given t= 58 hours, Ds=31.927 Then DOfar=5.821
Given t= 59 hours, Ds=32.684 Then DOfar=5.821
Given t= 60 hours, Ds=33.447 Then DOfar=5.821
Given t= 61 hours, Ds=34.217 Then DOfar=5.822
Given t= 62 hours, Ds=34.992 Then DOfar=5.822
Given t= 63 hours, Ds=35.772 Then DOfar=5.822
Given t= 64 hours, Ds=36.559 Then DOfar=5.823
Given t= 65 hours, Ds=37.351 Then DOfar=5.823
Given t= 66 hours, Ds=38.149 Then DOfar=5.823
Given t= 67 hours, Ds=38.952 Then DOfar=5.823
Given t= 68 hours, Ds=39.761 Then DOfar=5.824
Given t= 69 hours, Ds=40.575 Then DOfar=5.824
Given t= 70 hours, Ds=41.395 Then DOfar=5.824
Given t= 71 hours, Ds=42.221 Then DOfar=5.825
Given t= 72 hours, Ds=43.051 Then DOfar=5.825

```
Sub Command3_Click ()
  ' Steady State Sediment DO Demand

  ' Sediment DO demand
  Debug.Print ""
  Debug.Print " Steady State Sediment DO Demand"
  Debug.Print ""

  ' Equation B-24 from TTRTD, 1994
  ' dDO = (Sb*Xm)/(86400*UHD) = (a*S*Kd*Xm)/(86400*UHD)

    ' Where...
    ' dDO = Oxygen depletion (mg/L)
    ' Sb = avg benthic oxygen demand over deposition
    '     area, g o2/m2/day
    ' Xm = length of deposition area, m
    ' H = Average depth of water column influenced
    '    by sediment demand, measured above bottom, m
    ' U =Minimum sustained current speed over bottom
    '    m/sec
    ' Kd = Sediment decay rate constant, 0.01/day
    ' a = Oxygen:sediment stoichiometric ratio,
    '    1.07 mg O2/mg sediment
    ' S = Avg conc of deposited organic sediments
    '    over the depositional area, g/m2
    ' D = Dilution caused by the horizontal entrainment
    '    of ambient water as it passes over the
    '    depositional area (always >=1)

    ' S and Xm come from suspended solids deposition
    ' analysis...
    ' TTRTD recommends averaging highest and lowest
    ' deposition values to get S.

    ' an estimate of the avg depth is eq B-26;
    ' H = 0.8*((Ez*Xm)/U)^.5

    ' Where...
    ' Ez = Vertical diffusion coeff (cm2/sec)
    ' default value of Ez is 1
    ' Ez can also be calculated by
    ' Ez = 10^-4/((1/density)*density gradient)

    ' Where...
    ' density = Ambient water density, kg/m3 (1024)
    ' density gradient = Ambient density gradient, kg/m4
    ' TTRTD recommends using the most severe stratification
    ' condition during the critical period.

    ' The dilution D should be found from
    ' TTRTD table B-5
```

```
' Using for Honolululi...
DOa = 5.848: 'used here only for comparison
Kd = .01
a = 1.07: '(From TTRTD, 1994)
S = 25: '(From Honouliuli 1995 draft)
Xm = 3000: '(conservative measure of 5g/m^2
      ' isopleth from 1983 Honouliuli application
Ez = 1: '(From Honouliuli 1995 draft)
U = .03: '(From Honouliuli 1995 draft)
D = 1: '(From Honouliuli 1995 draft, originally from TT, 1984)

Debug.Print "Lowest observed ambient DO = "; Format$(DOa, "####.000"); " mg/L"
' test calculation see TTRTD eq 8-27...
H = .8 * ((Ez * Xm * 100) / (U * 100)) ^ .5 * (1 / 100)
Debug.Print "H = "; Format$(H, "####.000"); "m"
dDO = (Sb * Xm) / (86400 * U * H * D)
Debug.Print "Eq1 delta DO due to steady state sediment demand ="; Format$(dDO, "####.000"); " mg/L"
' or
dDO = (a * S * Kd * Xm) / (86400 * U * H * D)
Debug.Print "Eq2 delta DO due to steady state sediment demand ="; Format$(dDO, "####.000"); " mg/L"
predDO = dDO / DOa * 100
Debug.Print "Percent reduction in DO ="; Format$(predDO, "####.000"); "%"

End Sub
```

Sub Command3_Click - RUN - output equals...

Steady State Sediment DO Demand

Lowest observed ambient DO = 5.848 mg/L
H = 2.530m
Eq. 1. delta DO due to steady state sediment demand =.000 mg/L
(Eq. 1. doesn't work because Sb is not provided so use Eq. 2.)
Eq. 2. delta DO due to steady state sediment demand =.122 mg/L
Percent reduction in DO =2.093%

```
Sub Command4_Click ()
  ' Oxygen Demand due to Resuspension of Sediments

  Debug.Print ""
  Debug.Print " Oxygen Demand due to Resuspension of Sediments"
  Debug.Print ""

  ' Equation from TTRTD, 1994, pg. B-42
  ' dDO = (Sb*Xm)/(86400*UHD) = (a*S*Kd*Xm)/(86400*UHD)

    ' Where...
    ' dDO = Oxygen depletion (mg/L)
    ' Sb = avg benthic oxygen demand over deposition
    '     area, g o2/m2/day
    ' Xm = length of deposition area, m
    ' H = Average depth of water column influenced
    '    by sediment demand, measured above bottom, m
    ' U = Minimum sustained current speed over bottom
    '    m/sec
    ' Kd = Sediment decay rate constant, 0.01/day
    ' a = Oxygen:sediment stoichiometric ratio,
    '    1.07 mg O2/mg sediment
    ' S = Avg conc of deposited organic sediments
    '    over the depositional area, g/m2
    ' D = Dilution caused by the horizontal entrainment
    '    of ambient water as it passes over the
    '    depositional area (always >=1)

    ' H = 1.6/100*(3,600*t*E1z)^.5

    ' Where

    ' E1z = Vertical diff coef when resuspension
    '      is occurring (5 cm2/sec)
    ' t = elapsed time following resuspension, hours

    ' For Honouliuli use
        DOa = 5.848: ' for estimating % reduction...
    E1z =5
    ' t =  0 to 72 hours
    Xm = 3000

    D = 1: 'Honouliuli value (SI value = 2.5)
    S = 25: 'Honoululi value (SI value = 8.41)
    Kd = .01: 'SI value
    U = .03: 'SI value
    a = 1.07: 'SI value

    For t = 0 To 72 Step 3
     H = 1.6 / 100 * (3600 * t * E1z) ^ .5
     Debug.Print "t="; t; "hrs, H="; Format$(H, "####.000");

     ' eq 1
     'dDO = (Sb * Xm) / (86400 * U * H * D)
```

```
'Debug.Print "eq 1. dDO ="; dDO

' eq 2
If H > 0 Then dDO = (a * S * Kd * Xm) / (86400 * U * H * D)
Debug.Print "m, dDO="; Format$(dDO, "####.000");
Debug.Print "mg/L, Estimated ambient DO reduction="; Format$(dDO / DOa * 100, "####.000"); "%"

Next t

End Sub
```

Sub Command4_Click - RUN - output equals...

Oxygen Demand due to Resuspension of Sediments

Using lowest observed ambient DO = 5.848 mg/L

t= 3 hrs, H=3.718m, dDO=.083mg/L, Estimated ambient DO reduction=1.424%
t= 6 hrs, H=5.258m, dDO=.059mg/L, Estimated ambient DO reduction=1.007%
t= 9 hrs, H=6.440m, dDO=.048mg/L, Estimated ambient DO reduction=.822%
t= 12 hrs, H=7.436m, dDO=.042mg/L, Estimated ambient DO reduction=.712%
t= 15 hrs, H=8.314m, dDO=.037mg/L, Estimated ambient DO reduction=.637%
t= 18 hrs, H=9.107m, dDO=.034mg/L, Estimated ambient DO reduction=.581%
t= 21 hrs, H=9.837m, dDO=.031mg/L, Estimated ambient DO reduction=.538%
t= 24 hrs, H=10.516m, dDO=.029mg/L, Estimated ambient DO reduction=.503%
t= 27 hrs, H=11.154m, dDO=.028mg/L, Estimated ambient DO reduction=.475%
t= 30 hrs, H=11.758m, dDO=.026mg/L, Estimated ambient DO reduction=.450%
t= 33 hrs, H=12.331m, dDO=.025mg/L, Estimated ambient DO reduction=.429%
t= 36 hrs, H=12.880m, dDO=.024mg/L, Estimated ambient DO reduction=.411%
t= 39 hrs, H=13.406m, dDO=.023mg/L, Estimated ambient DO reduction=.395%
t= 42 hrs, H=13.912m, dDO=.022mg/L, Estimated ambient DO reduction=.381%
t= 45 hrs, H=14.400m, dDO=.022mg/L, Estimated ambient DO reduction=.368%
t= 48 hrs, H=14.872m, dDO=.021mg/L, Estimated ambient DO reduction=.356%
t= 51 hrs, H=15.330m, dDO=.020mg/L, Estimated ambient DO reduction=.345%
t= 54 hrs, H=15.774m, dDO=.020mg/L, Estimated ambient DO reduction=.336%
t= 57 hrs, H=16.207m, dDO=.019mg/L, Estimated ambient DO reduction=.327%
t= 60 hrs, H=16.628m, dDO=.019mg/L, Estimated ambient DO reduction=.318%
t= 63 hrs, H=17.038m, dDO=.018mg/L, Estimated ambient DO reduction=.311%
t= 66 hrs, H=17.439m, dDO=.018mg/L, Estimated ambient DO reduction=.304%
t= 69 hrs, H=17.831m, dDO=.017mg/L, Estimated ambient DO reduction=.297%
t= 72 hrs, H=18.215m, dDO=.017mg/L, Estimated ambient DO reduction=.291%