# TECHNICAL MEMORANDUM NO. 1

# ASSESSMENT MODELING FOR REMOVAL OF FLOATING FREE PRODUCT

## BAY E-28
## GM POWERTRAIN
## YPSILANTI, MICHIGAN

groundwater direction

Ag90

ABB Environmental Services, Inc.

ASEA BROWN BOVERI

# TECHNICAL MEMORANDUM NO. 1

# ASSESSMENT MODELING FOR REMOVAL OF FLOATING FREE PRODUCT

BAY E-28
GM POWERTRAIN
YPSILANTI, MICHIGAN

TECHNICAL MEMORANDUM NO. 1

PROJECT: Bay E-28
Willow Run Transmission Plant
Powertrain Division of General Motors Corporation

SUBJECT: Assessment Modeling for Removal of Floating Free Product

PREPARED BY: Ron A. Lewis and Thomas Winebrenner
ABB Environmental Services, Inc.

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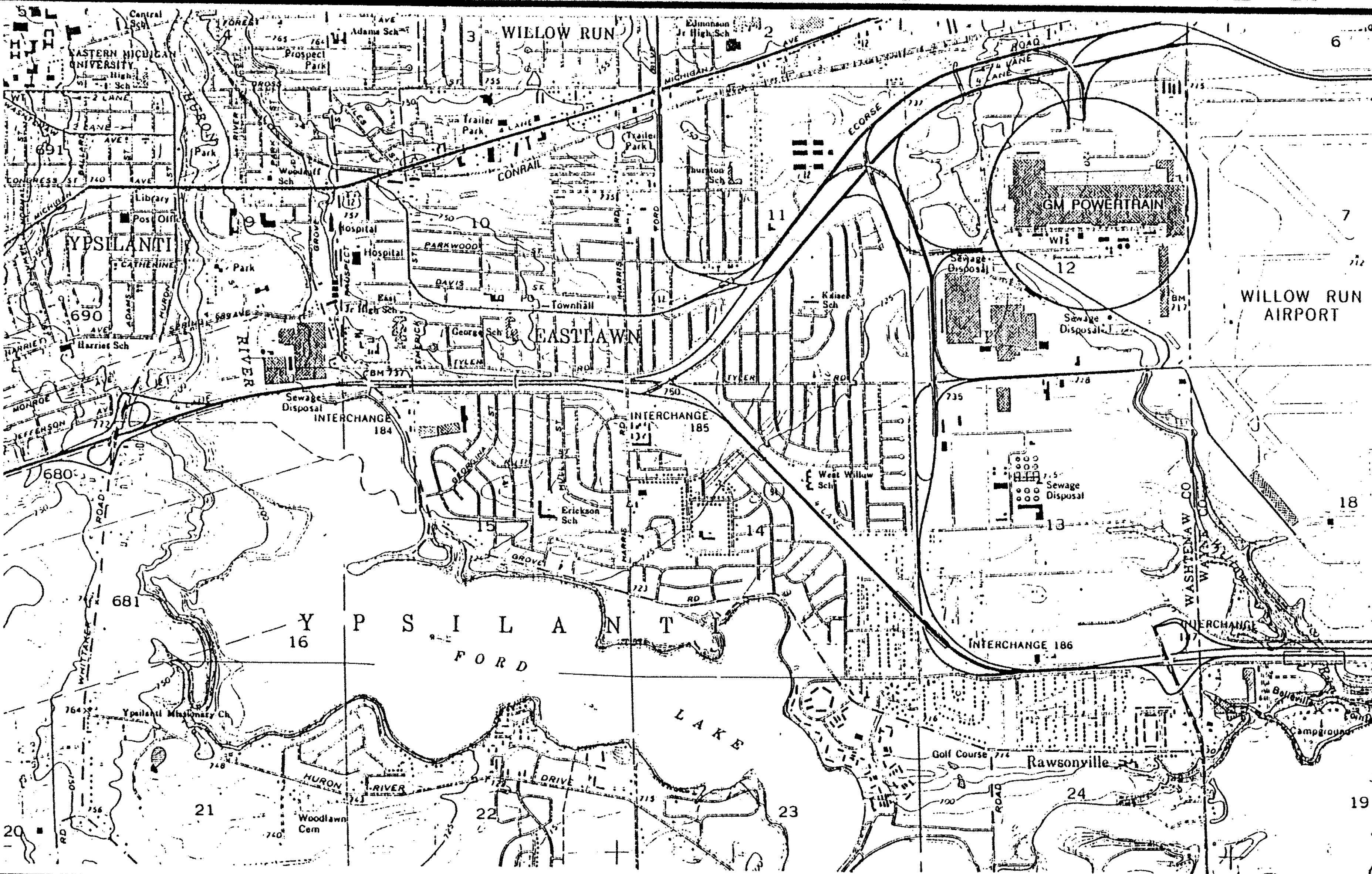
## 1.0 INTRODUCTION

Recent investigations in Bay E-28 of the Powertrain Division of General Motors Corporation (see Figure TM1-1) Ypsilanti, Michigan, plant have been performed to evaluate the presence of a lighter-than-water free product floating over the water table. The free product is believed to be a mixture of two petroleum distillates of relatively low volatility each with a specific gravity of 0.7. Apparent free product thickness has been monitored in eight monitoring wells installed in the area, with a maximum apparent thickness of nearly 5 feet measured in MW-3 (see Figure TM1-2). The area of concern measures approximately 500 by 360 feet.

The groundwater beneath the area is estimated to flow at a rate of about 120 feet per year, but the average aquifer thickness is only about 3 feet. A product recovery system consisting of four to six extraction wells is planned for the area. To aid in the design of the system, estimates of the effectiveness and time required for recovery of the product were developed by ABB Environmental Services, Inc. (ABB-ES) for two alternative well configurations. The first alternative includes four recovery wells (RW-1 through RW-4), and the second alternative includes two additional recovery wells (RW-5 and RW-6). Figure TM1-3 shows the approximate locations of the proposed recovery wells. ABB-ES utilized computer modeling to provide the required estimates.




SCALE

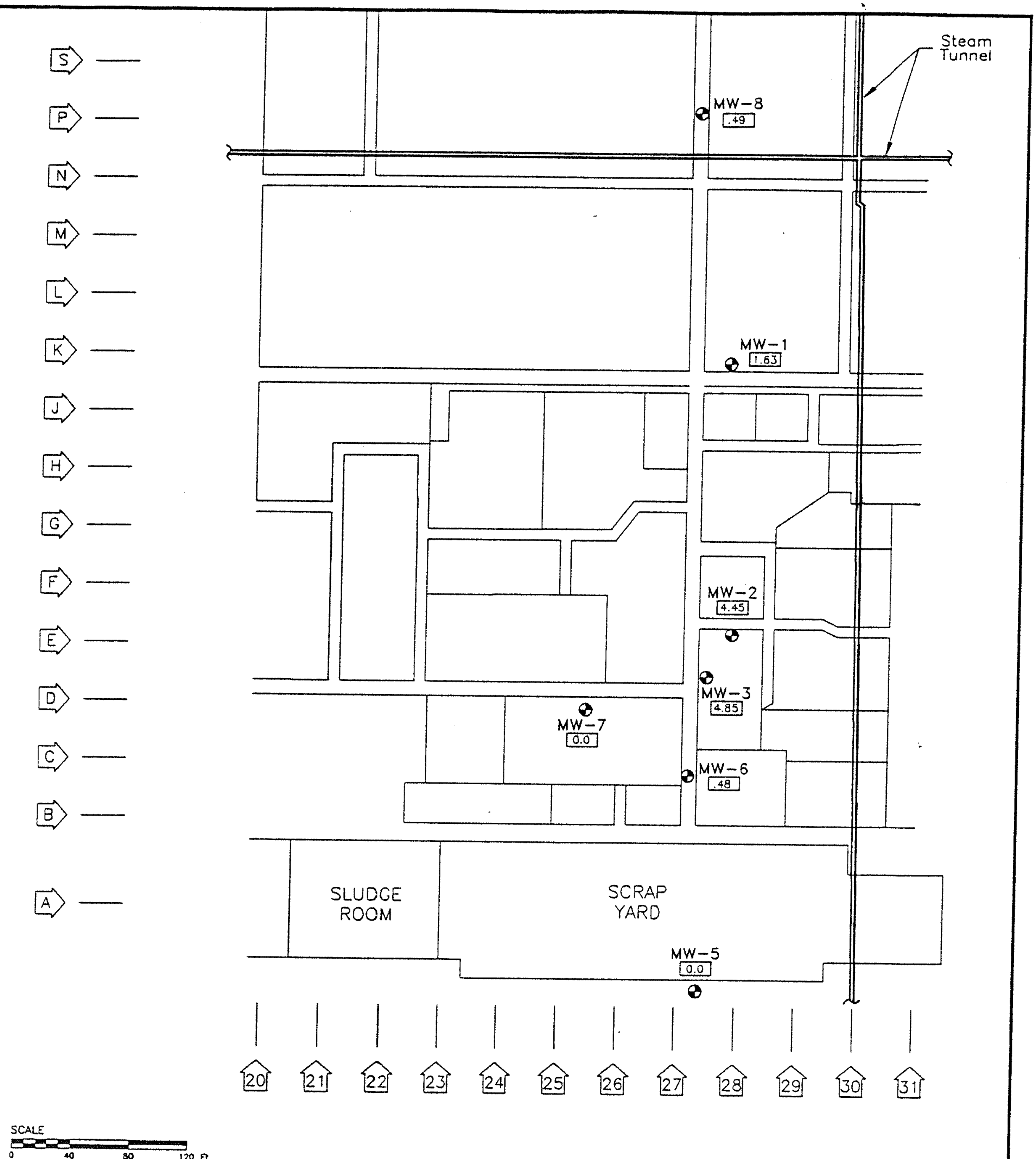
0 1000 2000 3000 FEET

TAKEN FROM THE YPSILANTI EAST, MICHIGAN, USGS, 7.5 SERIES TOPOGRAPHIC QUADRANGLE.

QUADRANGLE LOCATION

# FIGURE TM1-1
## SITE LOCATION MAP
## GM POWERTRAIN PLANT
## YPSILANTI, MICHIGAN

ABB ENVIRONMENTAL SERVICES, INC.



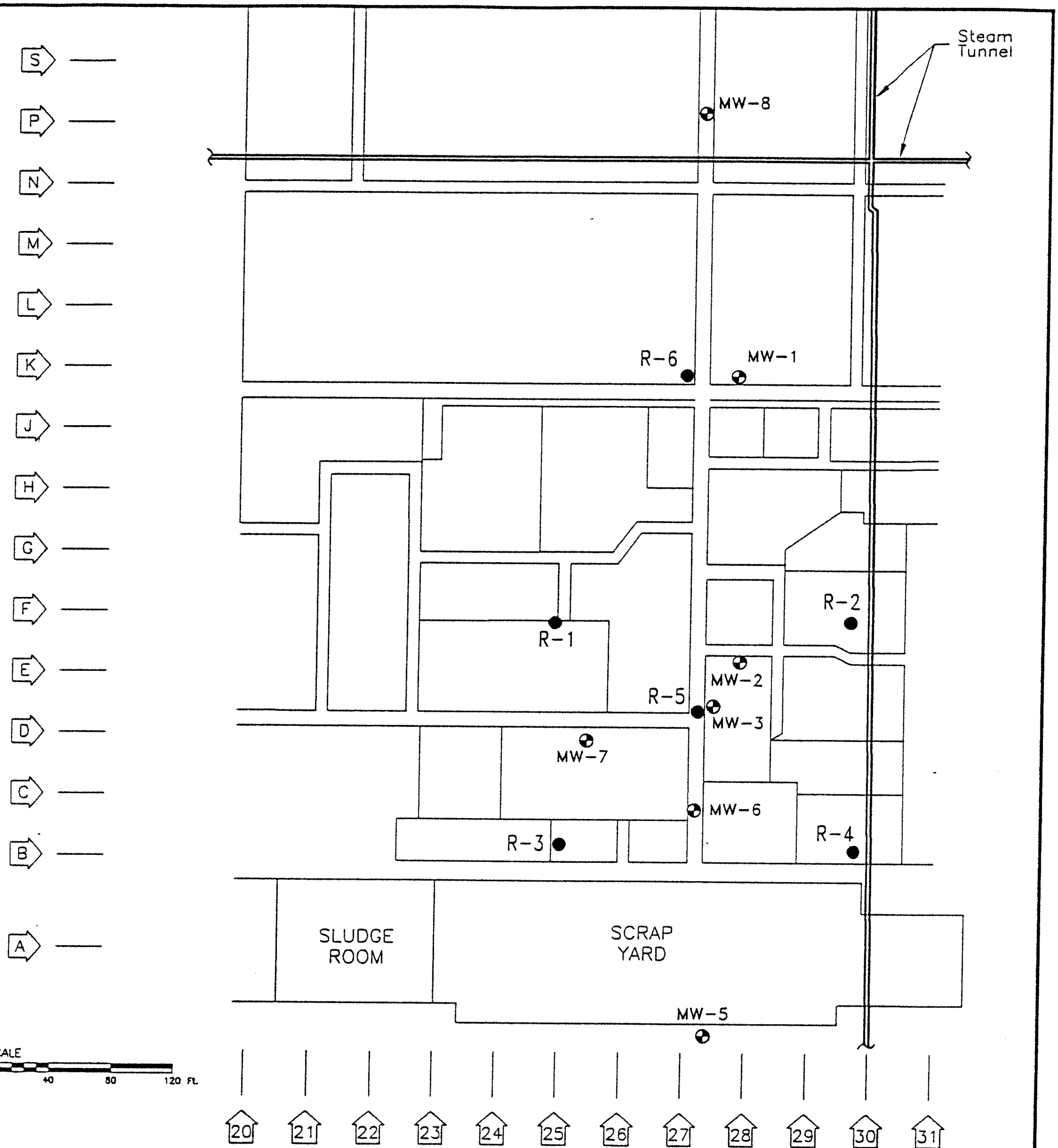

LEGEND

MW-5 Monitoring well location

.48 Apparent product thickness measurement in feet

FIGURE TM1-2
APPARENT PRODUCT THICKNESS
MEASUREMENTS BAY E-28
AUGUST 6, 1990
POWERTRAIN DIVISION
GENERAL MOTORS CORPORATION

ABB ENVIRONMENTAL SERVICES, INC.




LEGEND

MW-5 Existing monitoring well location

Proposed recovery well location

NOTE: R-1 through R-4 used for four well array
R-1 through R-6 used for six well array

FIGURE TM1-3
PROPOSED RECOVERY WELL LOCATIONS
BAY E-28
POWERTRAIN DIVISION
GENERAL MOTORS CORPORATION

A9204031/5883-14/AC068

ABB ENVIRONMENTAL SERVICES, INC.

## 2.0 MODEL DESCRIPTION

Because soil properties vary considerably under natural conditions, and small variations in soil or liquid properties can significantly alter the flow of the non-aqueous phase (i.e., free product), two-phase flow systems (i.e., water and free product) are very difficult to analyze. The theory of two-phase flow, and its' practical application to the estimation of free-product volumes and remediation of free-product by pumping, is in its infancy. The few models available should be applied only with the realization that there may be a great deal of uncertainty in the results. Nonetheless, this area of research and application is receiving a great deal of attention, and the development of quantitative models for two-phase flow is on-going.

One of the more active research and application groups has developed some models which have been incorporated into a short course sponsored by the National Water Well Association. Two of these models, SPILLVOL and ARMOS (Environmental Systems and Technology, Inc., 1990), were used to evaluate the spill volume and potential product recovery in Bay E-28. SPILLVOL requires the user to enter estimates of soil and free product properties together with an estimate of the uncertainty associated with each variable. The program then calculates an estimate of the spill volume along with the variance of the estimate. It also identified the parameters that contribute most to the variance of the estimate which can be used to assess the sensitivity of the resulting volume estimate to variations in average soil and fluid properties. ARMOS contains the same type of volume estimator, but it does not analyze the uncertainty of the results. However, it would be reasonable to expect that the same uncertainty is present in the estimation of product volume using ARMOS as in the estimate calculated using SPILLVOL.

## 3.0 ESTIMATION OF SPILL VOLUME

Estimation of the total spill volumes using SPILLVOL was performed first. The input data were primarily the observed apparent product thicknesses in the existing monitoring wells (see Table TM1-1), soil grain-size distributions, the fluid properties, and assumed values for the residual saturation (i.e., the volume of immobile product in the soil above and below the water table). During the field investigation in Bay E-28, two soil samples were collected for analysis of grain-size distribution. One was a fairly clean sand, while the other contained a much greater proportion of fines. These soil conditions were taken as representing extremes in the soil conditions, and separate computer runs were made using the two different grain-size distributions as the major input differences. The other input parameters were entered as best estimates with the same uncertainty for both runs. A specific gravity of 0.7 was provided by Powertrain for the free product, but other fluid properties were assumed to be similar to kerosene for which suggested parameters were provided in the model documentation.

SPILLVOL computed an estimate of 6,910 cubic feet (about 52,000 gallons) with a residual volume fraction of 0.67 for the cleaner sands, and an estimate of 10,900 cubic feet (about 81,500 gallons) with a residual fraction of 0.45 for the finer-grained soils. The uncertainty (total error) associated with each estimate was larger than the estimated volume (i.e., the spill volumes could be twice as large) with most of the error due to the uncertainty in the soil properties, especially the value for irreducible saturation. Copies of input files and outputs from these runs are contained in Appendix A.

**TABLE 1**
**APPARENT PRODUCT THICKNESS MEASUREMENTS IN EXISTING WELLS**
**GM POWERTRAIN**
**Bay E-28**
**Ypsilanti, Michigan**

| LOCATION | DATE | APPARENT PRODUCT THICKNESS | MEASUREMENTS TAKEN BY |
|---|---|---|---|
| MW-1 | 9/20/89 | 1.74 | GTI |
| | 8/6/90 | 1.63 | OB&G |
| | 8/7/90 | 1.62 | OB&G |
| | 12/17/91 | 1.72 | ABB-ES |
| | 1/10/92 | 2.23 | ABB-ES |
| MW-2 | 9/20/89 | 3.83 | GTI |
| | 8/6/90 | 4.45 | OB&G |
| | 8/7/90 | 3.91 | OB&G |
| | 12/17/91 | Found welded closed | ABB-ES |
| MW-3 | 9/20/89 | 3.64 | GTI |
| | 8/6/90 | 4.85 | OB&G |
| | 8/7/90 | 4.31 | OB&G |
| | 12/17/91 | 1.18 | ABB-ES |
| | 1/10/92 | 1.34 | ABB-ES |
| MW-4 | 8/6/90 | 0 | OB&G |
| | 8/7/90 | 0 | OB&G |
| | 12/17/91 | Found cemented over | ABB-ES |
| MW-5 | 8/6/90 | 0 | OB&G |
| | 8/7/90 | 0 | OB&G |
| | 1/10/92 | 0 | ABB-ES |
| MW-6 | 8/6/90 | .48 | OB&G |
| | 8/7/90 | .25 | OB&G |
| | 12/17/91 | .63 | ABB-ES |
| | 1/10/92 | .74 | ABB-ES |
| MW-7 | 8/6/90 | 0 | OB&G |
| | 8/7/90 | 0 | OB&G |
| | 12/17/91 | Found cemented over | ABB-ES |
| MW-8 | 8/6/90 | .49 | OB&G |
| | 8/7/90 | .37 | OB&G |
| | 12/17/91 | Well not usable | ABB-ES |

**NOTES:**
All measurements in feet.
GTI = Groundwater Technology Inc.
OB&G = O'Brien & Gere
ABB-ES = ABB Environmental

## 4.0 ESTIMATION OF CLEAN-UP RATES

The ARMOS model was used to simulate recovery of the free product for three scenarios: (1) a four-well extraction system with low values for residual saturation; (2) a four-well system with high values for residual saturation; and (3) a six-well system with low values for residual saturation. The low residual saturation values would represent a more favorable situation for recovery. Figure TM1-3 shows the assumed recovery well arrays. A number of dummy observation wells were also inserted around the inferred perimeter of the spill volume extent as a means to tighten up the spill volume estimates and reduce some uncertainty in the initial and time-dependent boundary conditions.

The initial spill volume in all runs was estimated by the program at about 8,000 cubic feet or about 60,000 gallons. The program was run for a simulated time of 500 days to compare the rates of removal and relative efficiencies of the four- and six-well recovery systems. Although product removal would not be completed in this time frame, each simulation took about three hours of run time, and the value of simulating longer recovery periods was considered minimal, given the uncertainties in the analysis.

For a 500-day simulation period, the results of the modeling yielded estimated recovery rates of 1.8 gallons per day (gpd) for four wells assuming the higher residual saturation values. Under lower residual saturation values, this rate was improved to 2.4 gpd. Well R-2 was by far the most productive, providing about two-thirds of the product recovery. With six wells, the recovery rate was increased to 4.8 gpd. Well R-5 was the most productive under this scenario, accounting for over half of the recovery rate. Wells R-5 and R-2 together provided about 80 percent of the total recovery rate for the six-well system. Although recovery rates would be expected to decrease over time, these average rates over the first 500 days of operation suggest recovery periods in excess of 35 years even for the more productive well array and favorable soil conditions.

The output files for ARMOS are very long with closure tracking and other diagnostics as well as time step output at prescribed intervals. The pertinent information has been extracted and discussed above. However, copies of the input data files are provided in Appendix B, and the input and output files for each ARMOS run are available on computer diskettes.

## 5.0 CONCLUSIONS/RECOMMENDATIONS

The modeling suggests that product recovery rates will be extremely slow, even with six recovery wells as opposed to four wells. In general, the proposed recovery well locations appear to be appropriate. Incremental improvements in the total recovery rate may be possible by "fine tuning" well locations, but the level of uncertainty in the modeling analysis makes the effort of questionable value. Positioning the primary wells closer to the R-5 and R-2 locations seems advisable, as these provide the bulk of the estimated recovery. Based on their relatively small contribution, the value of the more peripheral recovery wells is questionable.

Uncertainty in the evaluation could be reduced by more soil sample grain-size analysis and by experimentally determining residual saturation values for the soil/product.

The water pumping rate needed to contain the free product may not be critical as the free product zone doesn't appear to change much with time. Reduction of the water table at recovery well locations was assumed to be 1 foot. The limited thickness of the aquifer at Bay E-28 may not provide opportunities to lower the water table level much more than the 1 foot assumed for recovery wells in the model. Further, the more the water table is drawn down, the greater will be the losses to residual saturation (i.e., immobile product in the soil above and below the water table).

# APPENDIX TM1-A

# SPILL VOLUME INPUT AND OUTPUT DATA FILES

```
*************************************************
*                S P I L L V O L                *
*   A program to estimate the volume of an oil  *
*  spill and its uncertainty from measurements  *
*  of oil thickness in observation wells        *
*                                               *
*       COPYRIGHT  1990  Version 3.0            *
* Environmental Systems and Technologies, Inc.  *
* P.O. Box 10457, Blacksburg,VA 24062-0457 USA  *
*                                               *
*************************************************
```

```
*************************************************
*                    RUN2                       *
*                    test3                      *
*************************************************
```

Particle Size Distribution Data

| | | |
|---|---|---|
| % fines (clay/silt) | => | 4.20 |
| % fine sand | => | 85.80 |
| % medium sand | => | 7.00 |
| % coarse sand | => | 1.20 |
| % fine gravel | => | 1.80 |

| | | | | |
|---|---|---|---|---|
| VG alpha (1/ft) = | .993 | Error (%) | = | 51.640 |
| S_m = | .548 | Error (%) | = | 80.350 |
| VG n = | 2.421 | Error (%) | = | 20.990 |
| Porosity = | .360 | Error (%) | = | 5.000 |
| Sog = | .060 | Error (%) | = | 25.000 |
| Sor = | .250 | Error (%) | = | 25.000 |
| Correlation between alpha and n (%) | | | = | -61.671 |

| | | | | |
|---|---|---|---|---|
| Oil-wtr density ratio = | .700 | Error (%) | = | 5.000 |
| Air-oil scaling factor = | 3.200 | Error (%) | = | 5.000 |
| Oil-wtr scaling factor = | 1.454 | Error (%) | = | 5.000 |

Observation Well Data (in feet)

| | | | Current | | | Historical | |
|---|---|---|---|---|---|---|---|
| Well | X | Y | Do | Dw | Ho | Do_min | Dw_max |
| 1 | 290.00 | 360.00 | 6.55 | 8.78 | 2.23 | 6.55 | 8.78 |
| 2 | 310.00 | 220.00 | 7.11 | 11.02 | 3.91 | 7.11 | 11.02 |
| 3 | 272.00 | 140.00 | 6.72 | 8.06 | 1.34 | 6.72 | 8.06 |
| 4 | 560.00 | 142.00 | 8.04 | 8.04 | .00 | 8.04 | 8.04 |
| 5 | 255.00 | -40.00 | 9.81 | 9.81 | .00 | 9.81 | 9.81 |
| 6 | 257.00 | 65.00 | 7.36 | 8.10 | .74 | 7.36 | 8.10 |
| 7 | 91.00 | 108.00 | 8.15 | 8.15 | .00 | 8.15 | 8.15 |
| 8 | 159.00 | 541.00 | 6.82 | 7.12 | .30 | 6.82 | 7.12 |
| 9 | .00 | 300.00 | 7.00 | 7.00 | .00 | 7.00 | 7.00 |
| 10 | 200.00 | 600.00 | 7.00 | 7.00 | .00 | 7.00 | 7.00 |

---- Summary of calculations ----

```
Estimated Free Oil Volume (ft^3) ====>  .691E+04
Total Error in Estimation(ft^3) =====>  .150E+05

Residual Volume Fraction  ===========>     .67
Error in Residual Volume Fraction ===>    1.22
```

-- Analysis of Variance for Free Volume --

```
Percent Variance Due to:

 Interpolation uncertainty =======>    1.3  %

 Fluid property uncertainty
    oil density                         .4  %
    air-oil scaling factor              .0  %
    oil-water scaling factor            .1  %
 Total due to fluid properties ===>     .5  %

 Soil property uncertainty
    porosity                            .1  %
    irreducible saturation            20.0  %
    VG alpha                           9.0  %
    VG n                              69.2  %
 Total due to soil properties ====>   98.2  %
```

-- Analysis of Variance for Residual Volume Fraction --

```
Percent Variance Due to:

 Interpolation uncertainty =======>     .0  %

 Fluid property uncertainty
    oil density                         .0  %
    air-oil scaling factor              .0  %
    oil-water scaling factor            .1  %
 Total due to fluid properties ===>     .1  %

 Soil property uncertainty
    porosity                            .0  %
    irreducible saturation            49.8  %
    VG alpha                           1.5  %
    VG n                              47.8  %
    Sog                                 .1  %
    Sor                                 .7  %
 Total due to soil properties ====>   99.9  %
```

run 2
~~test2~~

run 2. SNF

```
1
  0.9929  51.64
  0.5476  80.35
  2.4205  20.99
  0.3600   5.00
  0.7000   5.00
  3.2000   5.00
  1.4545   5.00
-61.67086
 .06            25
 .25            25
```

```
*********************************************
*                S P I L L V O L            *
*   A program to estimate the volume of an oil *
*  spill and its uncertainty from measurements *
*  of oil thickness in observation wells      *
*                                             *
*      COPYRIGHT  1990  Version 3.0           *
* Environmental Systems and Technologies, Inc. *
* P.O. Box 10457, Blacksburg,VA 24062-0457 USA *
*                                             *
*********************************************
```

```
*********************************************
*               RUN 3                       *
*********************************************
```

Particle Size Distribution Data

```
% fines (clay/silt) => 43.00
% fine sand         => 51.00
% medium sand       =>  4.50
% coarse sand       =>  1.00
% fine gravel       =>   .50
VG alpha (1/ft) =      1.305      Error (%) =      51.660
S_m             =       .700      Error (%) =      53.190
VG n            =      1.990      Error (%) =      15.370
Porosity        =       .360      Error (%) =      10.000
Sog             =       .100      Error (%) =      20.000
Sor             =       .200      Error (%) =      20.000
Correlation between alpha and n (%)         =     -71.512

Oil-wtr density ratio  =      .700     Error (%) =      5.000
Air-oil scaling factor =     3.200     Error (%) =      5.000
Oil-wtr scaling factor =     1.454     Error (%) =      5.000
```

Observation Well Data (in feet)

| Well | X | Y | Current Do | Current Dw | Current Ho | Historical Do_min | Historical Dw_max |
|---|---|---|---|---|---|---|---|
| 1 | 290.00 | 360.00 | 6.55 | 8.78 | 2.23 | 6.55 | 8.78 |
| 2 | 310.00 | 220.00 | 7.11 | 11.02 | 3.91 | 7.11 | 11.02 |
| 3 | 272.00 | 140.00 | 6.72 | 8.06 | 1.34 | 6.72 | 8.06 |
| 4 | 560.00 | 142.00 | 8.04 | 8.04 | .00 | 8.04 | 8.04 |
| 5 | 255.00 | -40.00 | 9.81 | 9.81 | .00 | 9.81 | 9.81 |
| 6 | 257.00 | 65.00 | 7.36 | 8.10 | .74 | 7.36 | 8.10 |
| 7 | 91.00 | 108.00 | 8.15 | 8.15 | .00 | 8.15 | 8.15 |
| 8 | 159.00 | 541.00 | 6.82 | 7.12 | .30 | 6.82 | 7.12 |
| 9 | .00 | 300.00 | 7.00 | 7.00 | .00 | 7.00 | 7.00 |
| 10 | 200.00 | 600.00 | 7.00 | 7.00 | .00 | 7.00 | 7.00 |

---- Summary of calculations ----

```
Estimated Free Oil Volume (ft^3) ====>  .109E+05
Total Error in Estimation(ft^3) =====>  .138E+05

Residual Volume Fraction  ===========>    .45
Error in Residual Volume Fraction ===>    .70
```

-- Analysis of Variance for Free Volume --

```
Percent Variance Due to:

 Interpolation uncertainty =======>      .6  %

 Fluid property uncertainty
    oil density                          .1  %
    air-oil scaling factor               .0  %
    oil-water scaling factor             .0  %
 Total due to fluid properties ===>      .1  %

 Soil property uncertainty
    porosity                             .6  %
    irreducible saturation             96.6  %
    VG alpha                             .0  %
    VG n                                2.0  %
 Total due to soil properties ====>    99.3  %
```

-- Analysis of Variance for Residual Volume Fraction --

```
Percent Variance Due to:

 Interpolation uncertainty =======>     2.6  %

 Fluid property uncertainty
    oil density                         1.2  %
    air-oil scaling factor               .0  %
    oil-water scaling factor             .0  %
 Total due to fluid properties ===>     1.2  %

 Soil property uncertainty
    porosity                             .0  %
    irreducible saturation             94.1  %
    VG alpha                             .0  %
    VG n                                1.3  %
    Sog                                  .5  %
    Sor                                  .4  %
 Total due to soil properties ====>    96.2  %
```

run 3 ~~test3~~

run 3. SNF

```
1
 1.3052  51.66
 0.7002  53.19
 1.9903  15.37
 0.3600  10.00
 0.7000   5.00
 3.2000   5.00
 1.4545   5.00
-71.51231
 .1           20
 .2           20
```

RUN2.WEL = RUN3.WEL

10

| | | | | | | |
|---|---|---|---|---|---|---|
| 290.00 | 360.00 | 6.550 | 8.780 | 6.550 | 8.780 | 1 |
| 310.00 | 220.00 | 7.110 | 11.020 | 7.110 | 11.020 | 2 |
| 272.00 | 140.00 | 6.720 | 8.060 | 6.720 | 8.060 | 3 |
| 560.00 | 142.00 | 8.040 | 8.040 | 8.040 | 8.040 | 4 |
| 255.00 | -40.00 | 9.810 | 9.810 | 9.810 | 9.810 | 5 |
| 257.00 | 65.00 | 7.360 | 8.100 | 7.360 | 8.100 | 6 |
| 91.00 | 108.00 | 8.150 | 8.150 | 8.150 | 8.150 | 7 |
| 159.00 | 541.00 | 6.820 | 7.120 | 6.820 | 7.120 | 8 |
| 0.00 | 300.00 | 7.000 | 7.000 | 7.000 | 7.000 | 9 |
| 200.00 | 600.00 | 7.000 | 7.000 | 7.000 | 7.000 | 10 |

# APPENDIX TM1-B

# INPUT DATA FILES

RUN1.DAT

4 WELLS - HIGH
RESIDUAL SAT.

```
GM estimates of clean-up  3/6/92 run1
   0     1    -1     1     1
  20    18     1    36     0     4     7
  20
   1     0.0000
   2    40.0000
   3    80.0000
   4   130.0000
   5   170.0000
   6   208.0000
   7   253.0000
   8   278.0000
   9   298.0000
  10   318.0000
  11   340.0000
  12   380.0000
  13   430.0000
  14   458.0000
  15   480.0000
  16   520.0000
  17   550.0000
  18   582.0000
  19   610.0000
  20   640.0000
   0.0000   40.0000   72.0000  110.0000  150.0000  188.0000  210.0000
 236.0000  260.0000  290.0000  312.0000  334.0000  372.0000  400.0000
 430.0000  473.0000  510.0000  540.0000
   1   89.0000
   1.3000    0.7000    1.9900    0.3600    0.3600    0.2000    0.1000
   0.7000    2.0000    2.5000    1.6700    0.0100
   1   16    0.0000    0.0000    6.0000
 372.0000  312.0000  236.0000  473.0000   72.0000  176.0000  473.0000
   0.0000    0.0000  110.0000  236.0000  372.0000  540.0000  540.0000
 540.0000  260.0000
 430.0000  298.0000  253.0000   80.0000   80.0000  208.0000  582.0000
 170.0000  340.0000  480.0000  582.0000  640.0000  640.0000  520.0000
 340.0000   80.0000
  92.3200   91.9600   91.7100   91.2000   91.2600   91.5900   92.7700
  91.3600   92.0200   92.4600   92.7700   92.9500   92.9500   92.5700
  92.0200   91.2000
   2.2300    4.0000    1.3400    0.0000    0.0000    0.7400    0.4000
   0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   0.0000    0.0000
   1    1
   0.0000    0.0300  500.0000    0.0240    5.0000    1.0300   25.0000
 800     4    10     0    0.0050    0.0050    0.0050    0.1000
   1     2     0
  20     1     0
  21     2     0
  40     1     0
  41     2     0
  60     1     0
  61     2     0
  80     1     0
  81     2     0
 100     1     0
```

RUN1.DAT (CONT.)

```
 101    2    0
 120    1    0
 121    2    0
 140    1    0
 141    2    0
 160    1    0
 161    2    0
 180    1    0
 181    2    0
 200    1    0
 201    2    0
 220    1    0
 221    2    0
 240    1    0
 241    2    0
 260    1    0
 261    2    0
 280    1    0
 281    2    0
 300    1    0
 301    2    0
 320    1    0
 321    2    0
 340    1    0
 341    2    0
 360    1    0
   0  -0.4000   -0.4000    0.0020    0.0090
  28    1    5    7    0.5000
 114    1    3    7    0.5000
 144    1    6    7    0.5000
 230    1    4    7    0.5000
   2    0.0000   92.9500
      500.0000   92.9500
   2    0.0000   90.9500
      500.0000   90.9500
   3    0.0000   92.3800
        1.0000   91.8800
        2.0000   91.3800
   3    0.0000   91.9400
        1.0000   91.4400
        2.0000   90.9400
   3    0.0000   91.8100
        1.0000   91.3100
        2.0000   90.8100
   3    0.0000   91.3500
        1.0000   90.8500
        2.0000   90.3500
   3    0.0000    1.0000
        1.0000    0.5000
        2.0000    0.0000
   0
```

RUN2.DAT

```
                                          p  3/6/92 run2 6 wells
    0     1    -1     1     1
   20    18     1    36     0     6     9
   20
    1    0.0000
    2   40.0000
    3   80.0000
    4  130.0000
    5  170.0000
    6  208.0000
    7  253.0000
    8  278.0000
    9  298.0000
   10  318.0000
   11  340.0000
   12  380.0000
   13  430.0000
   14  458.0000
   15  480.0000
   16  520.0000
   17  550.0000
   18  582.0000
   19  610.0000
   20  640.0000
    0.0000    40.0000    72.0000  110.0000  150.0000  188.0000  210.0000
  236.0000   260.0000   290.0000  312.0000  334.0000  372.0000  400.0000
  430.0000   473.0000   510.0000  540.0000
    1   89.0000
    1.3000     0.7000     1.9900    0.3600    0.3600    0.1000    0.0600
    0.7000     2.0000     2.5000    1.6700    0.0100
    1   16     0.0000     0.0000    6.0000
  372.0000   312.0000   236.0000  473.0000   72.0000  176.0000  473.0000
    0.0000     0.0000   110.0000  236.0000  372.0000  540.0000  540.0000
  540.0000   260.0000
  430.0000   298.0000   253.0000   80.0000   80.0000  208.0000  582.0000
  170.0000   340.0000   480.0000  582.0000  640.0000  640.0000  520.0000
  340.0000    80.0000
   92.3200    91.9600    91.7100   91.2000   91.2600   91.5900   92.7700
   91.3600    92.0200    92.4600   92.7700   92.9500   92.9500   92.5700
   92.0200    91.2000
    2.2300     4.0000     1.3400    0.0000    0.0000    0.7400    0.4000
    0.0000     0.0000     0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000     0.0000
    1    1
    0.0000     0.0300   500.0000    0.0240    5.0000    1.0500   50.0000
  800    4    10    0     0.0050    0.0050    0.0050    0.1000
    1    2    0
   20    1    0
   21    2    0
   40    1    0
   41    2    0
   60    1    0
   61    2    0
   80    1    0
   81    2    0
  100    1    0
  101    2    0
  120    1    0
  121    2    0
```

LOWER RESIDUAL SATURATION

RUN2.DAT (CONT)

```
 140    1    0
 141    2    0
 160    1    0
 161    2    0
 180    1    0
 181    2    0
 200    1    0
 201    2    0
 220    1    0
 221    2    0
 240    1    0
 241    2    0
 260    1    0
 261    2    0
 280    1    0
 281    2    0
 300    1    0
 301    2    0
 320    1    0
 321    2    0
 340    1    0
 341    2    0
 360    1    0
   0   -0.4000   -0.4000    0.0020    0.0090
  28    1    5    7    0.5000
 109    1    9    7    0.5000
 114    1    3    7    0.5000
 144    1    6    7    0.5000
 215    1    8    7    0.5000
 230    1    4    7    0.5000
   2    0.0000   92.9500
      500.0000   92.9500
   2    0.0000   90.9500
      500.0000   90.9500
   3    0.0000   92.3800
        1.0000   91.8800
        2.0000   91.3800
   3    0.0000   91.9400
        1.0000   91.4400
        2.0000   90.9400
   3    0.0000   91.8100
        1.0000   91.3100
        2.0000   90.8100
   3    0.0000   91.3500
        1.0000   90.8500
        2.0000   90.3500
   3    0.0000    1.0000
        1.0000    0.5000
        2.0000    0.0000
   3    0.0000   92.4500
        1.0000   91.9500
        2.0000   91.4500
   3    0.0000   91.8800
        1.0000   91.3800
        2.0000   90.8800
   0
```

RUN3.DAT

```
GM estimates of clean-up  3/7/92 run3
    0    1   -1    1    1
   20   18    1   36    0    4    7
   20
    1    0.0000
    2   40.0000
    3   80.0000
    4  130.0000
    5  170.0000
    6  208.0000
    7  253.0000
    8  278.0000
    9  298.0000
   10  318.0000
   11  340.0000
   12  380.0000
   13  430.0000
   14  458.0000
   15  480.0000
   16  520.0000
   17  550.0000
   18  582.0000
   19  610.0000
   20  640.0000
    0.0000   40.0000   72.0000  110.0000  150.0000  188.0000  210.0000
  236.0000  260.0000  290.0000  312.0000  334.0000  372.0000  400.0000
  430.0000  473.0000  510.0000  540.0000
    1   89.0000
    1.3000    0.7000    1.9900    0.3600    0.3600    0.1000    0.0600
    0.7000    2.0000    2.5000    1.6700    0.0100
    1   16    0.0000    0.0000    6.0000
  372.0000  312.0000  236.0000  473.0000   72.0000  176.0000  473.0000
    0.0000    0.0000  110.0000  236.0000  372.0000  540.0000  540.0000
  540.0000  260.0000
  430.0000  298.0000  253.0000   80.0000   80.0000  208.0000  582.0000
  170.0000  340.0000  480.0000  582.0000  640.0000  640.0000  520.0000
  340.0000   80.0000
   92.3200   91.9600   91.7100   91.2000   91.2600   91.5900   92.7700
   91.3600   92.0200   92.4600   92.7700   92.9500   92.9500   92.5700
   92.0200   91.2000
    2.2300    4.0000    1.3400    0.0000    0.0000    0.7400    0.4000
    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000    0.0000
    1    1
    0.0000    0.0300  500.0000    0.0240    5.0000    1.0500   25.0000
  800    4   10    0    0.0050    0.0050    0.0050    0.1000
    1    2    0
   20    1    0
   21    2    0
   40    1    0
   41    2    0
   60    1    0
   61    2    0
   80    1    0
   81    2    0
  100    1    0
  101    2    0
  120    1    0
  121    2    0
```

4 WELLS - LOWER RESIDUAL SATURATION

RUN3.DAT (CONT)

```
140    1    0
141    2    0
160    1    0
161    2    0
180    1    0
181    2    0
200    1    0
201    2    0
220    1    0
221    2    0
240    1    0
241    2    0
260    1    0
261    2    0
280    1    0
281    2    0
300    1    0
301    2    0
320    1    0
321    2    0
340    1    0
341    2    0
360    1    0
  0   -0.4000   -0.4000    0.0020    0.0090
 28    1    5    7    0.5000
114    1    3    7    0.5000
144    1    6    7    0.5000
230    1    4    7    0.5000
  2    0.0000   92.9500
     500.0000   92.5000
  2    0.0000   90.9500
     500.0000   90.5000
  3    0.0000   92.3800
       1.0000   91.8800
       2.0000   91.3800
  3    0.0000   91.9400
       1.0000   91.4400
       2.0000   90.9400
  3    0.0000   91.8100
       1.0000   91.3100
       2.0000   90.8100
  3    0.0000   91.3500
       1.0000   90.8500
       2.0000   90.3500
  3    0.0000    1.0000
       1.0000    0.5000
       2.0000    0.0000
  0
```