A COMPUTER PROGRAM TO PREDICT SCALING TENDENCY OF OIL-FIELD WELL WATER COMPOSITE

by

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ABSTRACT

A simple computer program based on LOTUS 1-2-3 Release 2.3 or 2.4 has been prepared for scaling tendency prediction of oilfield well water composite. Up to four individual well waters can compose the composite. Scaling material considered are calcium carbonate, calcium sulfate, and barium sulfate.

The prediction of scaling tendency is accomplished by comparing the concentration of each salt compound with its respective solubility; and the scaling is only likely to occur, when the concentration exceeds the solubility.

The actual concentration of a salt compound at the existing water condition is calculated from water analysis result data. The required solubility value of the same compound is taken from the published empirical data correlation, that is a function of temperature (25 to 95 °C) and ionic strength (0 to 7).

I. INTRODUCTION

Oilfield well water generally contains ion species such as Na^+, K^+, Ca^{++}, Ba^{++}, Mg^{++}, Cl^-, CO_3^-, HCO_3^- and SO_4^-, in varying concentrations. Certain cation and anion may combine to form salt of low solubility. If the salt concentration exceeds its solubility, then to avoid oversaturation, solid salt particles are separated. Solid precipitate can cause many troubles. For example, solid precipitate can accumulate on internal surface of the water flowline and progressive building of scale will occur. We will define that a well water indicates "scaling tendency" by a particular salt compound, if its concentration in the solution exceeds its solubility.If a huge amount of water is needed and it can not be supplied by one well, then mixing waters coming from two or more wells would be the solution. Although the individual water shows no scaling tendency, it is not guaranteed that the water mixture (composite) has the same tendency. It is just because by mixing the waters, the cation and anion relevant for insoluble salt formation are available at the same time, where otherwise not the case before mixing. Since scaling tendency is related to ion concentration, it is obvious that changing the mixing ratio of the composite could eventually avoid scaling.

This paper describes a simple computer program based on Lotus 1-2-3 Release 2.3 or 2.4, prepared for predicting scaling tendency of oilfield well water composite. The program covers only the insolubility behaviors of calcium carbonate, calcium sulfate, and barium sulfate. The fact that the solubility of a salt depends not only on the temperature, but also is influenced by the concentration of ion species contained in the water, is also considered by the program.

The input data for the program is the water analysis result of a given set of up to four individual waters and their volume ratios constituting the water composite. The program will then calculate the scaling tendency of each individual water as well as the composite. By varying the volume ratios, the program can be used to find out whether certain volume ratio values indicate that the water composite "no scaling tendency".

II. DEFINITIONS AND METHODS

A. *General*

1. Well water analysis

The input data for the scaling tendency prediction is the report of well water analysis. Such report contains usually water temperature, pH, density and concentrations of ions such as Na^+, K^+, Ca^{++}, Ba^{++}, Mg^{++}, Cl^-, CO_3^{--}, HCO_3^- and SO_4^-. Concentration is normally expressed in "mg/liter". Since water is electrically neutral, then the sum of all positive ions (cations) should be equal to the sum of all negative ions (anions). This condition can be verified by the so called "ionic balance" formulated as:

$$\text{Ionic Balance (\%)} = \left(1 - \frac{\sum_{i=1}^{i=m} C_i . Z_i - \sum_{j=1}^{j=n} C_J . Z_j}{\frac{1}{2} \cdot \left(\sum_{i=1}^{i=m} C_i . Z_i + \sum_{j=1}^{j=n} C_j . z_j \right)} \right) . 100 \,. \quad \text{(Eq.1)}$$

where:

C_i : concentration of cation i in "mole/liter"
Z_i : charge (valenz) of cation i
m : all the names of cation i
C_j : concentration of anion j in "mole/liter"
Z_j : charge (valenz) of anion j
n : all the names of anion j.

The value of ionic balance should ideally be 100%. Good water analysis usually shows deviation by not more than ±2%.

2. Salt solubility

"Solubility" is defined as the limiting amount of solute that can be dissolved in a volume of solvent under a given set of conditions. Solubility and concentration have the same unit such as "g/liter" or "mole/liter". We can say that solubility is the maximum concentration of the solute under a given set of condition. The set of conditions is temperature and electrolyte concentration. At this maximum concentration the solution is saturated with the solute. In undersaturated or not saturated solution, the solute concentration is lower than the solubility. If the solute concentration is higher than the solubility, then the solution is oversaturated. Oversaturated solution is unstable, soon or later it turns to a saturated solution by giving up its excessive concentration as solid precipitate.

In distilled water at 25 °C, the solubility values of the following salts are: 2.3 mg/l (9.85×10^{-6} mole/l) for barium sulfate, 53.0 mg/l (5.30×10^{-4} mole/l) for calcium carbonate, and 2080.0 mg/l (1.53×10^{-2} mole/l) for calcium sulfate (gypsum). The solubility of a given salt is influenced not only by temperature, but also by the presence of all ion species contained in the solution.

The basic principle to predict scaling tendency of water caused by a low soluble salt is to calculate its concentration from the existing actual ion concentrations (as reported by the water analysis), and compare the result with the salt solubility. If the calculated salt concentration is greater than the solubility, then the solution is oversaturated and therefore scale formation is likely to occur.

The *calculated salt concentration* in a particular well water can be determined from the actual ion concentrations reported in the water analysis result. The *solubility* of the same salt is obtainable from empirical data correlation which can be found in some publications.

3. Calculation of salt concentration

We take $BaSO_4$ salt as an example, with its solubility equilibrium

$$(BaSO_4)\text{solid} \Leftrightarrow (BaSO_4)\text{dissolved} \Leftrightarrow Ba^{++} + SO_4^{-} \quad \ldots\ldots\ldots \quad \text{(Eq.2)}.$$

The actual ion concentrations ($C_{Ba^{++}:act}$ and $C_{SO_4^{-}:act}$) expressed in "mole/liter", are taken from the water analysis result. The *calculated salt concentration* ($C_{Salt;calc}$) is determined as follows:

- If $C_{Ba^{++}:act} < C_{SO_4^{-};act}$, then
  $$C_{Salt;calc} = C_{Ba^{++};act} \qquad \text{(Eq. 3a)}$$
- If $C_{Ba^{++};act} = C_{SO_4^{-};act}$, then
  $$C_{Salt;calc} = C_{Ba^{++};act} = C_{SO_4^{-};act} \qquad \text{(Eq. 3b)}$$
- If $C_{Ba^{++};act} > C_{SO_4^{-};act}$, then
  $$C_{Salt;calc} = C_{SO_4^{-};act} \qquad \text{(Eq. 3c)}$$

4. Calculation of salt solubility

We take $BaSO_4$ salt as an example, with its solubility equilibrium reaction as above in Eq. 2. In a saturated solution, the product of concentrations (in "mole/liter") of ions involved in the formation of the precipitate ($BaSO_4$), each is raised to its stochiometric coefficient (in this case each is 1) and is equal to the *solubility product* value K_{sp}, which is taken from an empirical correlation:

$$C_{Ba^{++}} \cdot C_{SO_4^{-}} = K_{sp}$$

K_{sp} of a salt is a function of temperature and "ionic strength" defined below.

Under the assumption that the water is saturated with $BaSO_4$, we calculate the cation and anion concentrations:

- $$C_{Ba^{++};calc} = \frac{K_{sp}}{C_{SO_4^{-};act}}. \qquad \text{(Eq. 4a)}$$
- $$C_{SO_4^{-};calc} = \frac{K_{sp}}{C_{Ba^{++};act}} \qquad \text{(Eq. 4b)}$$

The determination of the *salt solubility* (of $BaSO_4$) is accomplished under the principle that must be equal to the concentration of the suppressed ion ($C_{Ba^{++};calc}$ or $C_{SO_4^{-};calc}$, whichever is lower), as follows:

- If $C_{Ba^{++};calc} < C_{SO_4^{-};calc}$, then *the salt solubilty* $= C_{Ba^{++};calc}$. (Eq.5a)
- If $C_{Ba^{++};calc} = C_{SO_4^{-};calc}$, then *the salt solubility* $= C_{Ba^{++};calc} = C_{SO_4^{-};calc}$ (Eq. 5b)
- If $C_{Ba^{++};calc} > C_{SO_4^{-};calc}$, then *the salt solubility* $= C_{SO_4^{-};calc}$ (Eq. 5c).

5. Calculation of water scaling tendency

The calculation of water scaling tendency by a particular salt is based on the result of comparison between *calculated salt concentration* (Eq. 3a-3c) and *salt solubility* (Eq. 5a-5c) mentioned above. The following is the three possibilities:

(1) If the *calculated salt concentration* is greater than the *salt solubility*, then the solution is oversaturated; we predict that scale formation is likely to occur.

(2) If the *calculated salt concentration* is less than the *salt solubility*, then the solution is undersaturated; we predict that there will be surely no scaling.

(3) If the *calculated salt concentration* is equal to the *salt solubility*, then the solution is at saturation point; we can predict that there will be no scaling, but it is critical.

B. *Empirical Calculation Method of Calcium Carbonate Solubility*

The empirical equation for scaling tendency calculation is the Langelier saturation index extended by Stiff and Davis, to be valid for oilfield brines:

$$SI = \mathrm{pH} - \mathrm{pHs} \qquad \text{(Eq. 6)}$$

$$pHs = \mathrm{K} + \mathrm{pCa} + \mathrm{pAlK} \qquad \text{(Eq. 7)}$$

and the combination of both equations gives.

$$SI = \mathrm{pH} - K\,\mathrm{pCa} - \mathrm{pAlK} \qquad \text{(Eq. 8).}$$

where:

SI : Scaling Index. If *SI* is negative, the water is under saturated with $CaCO_3$ and scale formation is unlikely. If *SI* is positive, scale is likely to form.

pH : Actual pH of the water.

pHs : pH at which system would be saturated with $CaCO_3$.

K : "$CaCO_3$ Solubility Constant", a constant that is a function of salinity, composition and water temperature. K values are obtained from a graphical correlation with *ionic strength* and the temperature of the water.

μ : ionic strength, is defined by

$$\mu = \frac{1}{2}\,(C_1 . Z_1^2 + C_2 . Z_2^2 ... + ... C_n . Z_n^2)$$

Ci : Concentration of the ion i in "moles/1000 grams" of water.

Zi : Valence of the ion i.

$$pCa = \log\left[\frac{1}{mole\ Ca^{++}/liter}\right]$$

$$pA1K = \log\left[\frac{1}{equivalents\ Total Alkalinity/liter}\right]$$

where:

$$\text{Total Alkalinity} = C_{CO_3^{=}} + C_{HCO_3^{-}}$$

In order to be able to calculate calcium carbonate solubility in accordance to this method the following water analysis result data must be available: the *pH* and temperature of the water and the ion concentrations of Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, CO_3^{--}, HCO_3^- and $SO4^{--}$.

The plotted empirical values of $CaCO_3$ Solubility Constant K as a function of ionic strength at different temperatures, are given in Figure 1. The summary of the calculation is:

(1) If *SI* is negative, the water is not saturated with $CaCO_3$ and scale formation is unlikely.

(2) If *SI* is positive, the water is supersaturated with $CaCO_3$ and scale formation is indicated.

(3) If *SI* is zero, the water is at saturation point.

C. *Empirical Calculation Method of Calcium Sulfate (Gypsum) Solubility*

Here we use the method of Skillman, McDonald and Stiff, which can be applied to predict gypsum solubility in oilfield brines for temperatures up to 80 °C. The method is based on thermodynamic solubility measurements and has a theoretical basis:

$$S = 1000\,[(X^2 + 4K)^{0.5} - X] \qquad \text{(Eq. 9).}$$

where:

S : Calculated solubility of gypsum ("meq/liter")

K : "Solubility Product Constant", a constant which is a function of water composition and temperature. Values of K are obtained from a graphical correlation with ionic strength as in case of *SI* calculation for calcium carbonate. The graphical correlation is presented in Figure 2.

X : Excess common ion concentration, expressed in "M" or "moles/liter". This is simply the difference between the calcium concentration and the sulfate concentration. The same water analysis result data are required for this calculation as for the *SI* calculation for calcium carbonate.

The calculated gypsum solubility ("meq/liter") is compared with the actual concentration of Ca^{++} and SO_{4--} ions present in the water (expressed in "meq/liter"). The summary of the calculation is:

(1) If *S* is less than the smaller of the two concentrations (Ca^{++} or SO_4^{--}), the formation of gypsum scale is likely.

(2) If S is greater than either the Ca^{++} or the SO_4^{--} ion concentrations, the water is not saturated with gypsum and scaling is unlikely.

(3) If the actual concentration of S is equal Ca^{++} or the SO_4^{--} ion concentrations, then the $CaSO_4$ solution is at saturation point.

D. *Empirical Calculation Method of Barium Sulfate Solubility*

To predict the solubility of barium sulfate of water we can use graphical correlation of "$BaSO_4$ Solubility" expressed in "mg/liter", as a function of ionic strength by different temperatures as shown in Figure 3. These data are calculated based on data of Templeton[1]. The summary of the calculation is:

(1) If the actual concentration of $BaSO_4$ is less than its solubility, the $BaSO_4$ solution is undersaturated and the formation of $BaSO_4$ scale is unlikely.

(2) If the actual concentration of $BaSO_4$ is greater than its solubility, the $BaSO_4$ solution is oversaturated and the formation of $BaSO_4$ scale is indicated.

(3) If the actual concentration of $BaSO_4$ is equal to its solubility, the $BaSO_4$ solution is at saturation point.

E. *Calculation of Water Composite Properties*

All equations to predict scaling tendency in the individual water samples are surely applicable to the water composites. The required input for the predictive calculation can be obtained from the properties of the individual water samples and their amounts composing the water composite as formulated in the following equations:

Composite Volume: $V_{comp} = \sum V_i$ (Eq. 10a)

Composite Density: $D_{comp} = \dfrac{\sum V_i . D_i}{\sum V_i}$ (Eq. 10b)

Composite Temperature

$$T_{comp} = \frac{\sum V_i . D_i . T_i}{\sum V_i . D_i} \qquad \text{(Eq. 10c)}$$

Composite pH:

$$pH_{comp} = -\log\left(\frac{\sum V_i . 10^{-pH_i}}{\sum V_i}\right) \qquad \text{(Eq. 10d)}$$

Composite Composition :

$$C_{comp,j} = \frac{\sum V_i . C_{i,j}}{\sum V_i} \qquad \text{(Eq. 10e)}$$

Composite Ionic Strength:

$$\mu_{comp} = \frac{\sum C_{comp,j} . Z_j^2}{2} \qquad \text{(Eq. 10f)}$$

where :

subscript "i" refers to the individual water samples
subscript "comp" refers to composite, subscript "j" refers to ion names.

Z_j : charge (valenz) of ion j.
$C_{i,j}$: concentration of ion j in water sample i
V_i : volume of water sample i
D_i : density water sample i
T_i : temperature water sample i
pH_i : pH in water sample i
μ_i : ionic strength in water sample i

F. *Solubility Calculation Used in the Prepared Program*

Empirical K values as functions of ionic strength and temperature are plotted as diagrams in Figure 1, 2, and 3 for calcium carbonate, calcium sulfate, and barium sulfate respectively. By the use of these empirical correlations on the individual water analysis result data, the solubility of calcium carbonate, calcium sulfate, and barium sulfate, can be calculated. The same correlations can be applied for water composite, whereby the relevant properties of which are calculated using Eq. 10a to 10f.

The K value for a given temperature and ionic strength is obtained by linear interpolation among four nearest empirical K values around the presumed K value.

III. COMPUTER PROGRAM

A. *"WScale1" Program*

This program named "WScale1" is a program based on Lotus 1-2-3 Release 2.3 or 2.4 that can be used to predict scaling tendency of oilfield well water composite caused by calcium carbonate, calcium sulfate (gypsum), or barium sulfate concentration, that exceeds its respective solubility; up to four individual water samples can compose the water composite. The input data are the results of the well water analysis of the individual samples and the volume ratios of these individual samples composing the desired composite.

To initiate calculation of scaling tendencies, select and press command "CALCULATE;". After finishing this calculation process, the calculated prediction can be obtained and printed.

B. *How to Activate "WScale1" Program*

When not already the case, first activates Lotus 1-2-3 Release 2.3 or 2.4 as usual. Change drive and directory to the drive and the directory where the "WScale1.wk1" is located. Assumed the drive is "A:" and the directory is "\WScaleT", then the command is accomplished by pressing the following keys:

[/] [f] [d] [A] [:] [Enter]
[/] [f] [d] [\] [w] [s] [c] [a] [l] [e] [t] [Enter]

Now we are ready to retrieve "WScale1.wk1" file by pressing the following keys:

[/] [f] [r] [w] [s] [c] [a] [l] [e] [1] [Enter]

We get the worksheet display of "WScale1.wk1" similar to Figure 4.

C. *Command Menu*

"WScale1.wk1" has a menu of commands as shown in Table 1. The menu has several sub-menus, and can be displayed or hidden. If the menu is in displayed status, it can be hidden by selecting "Quit;" command (using Left-Arrow or Right-Arrow keys) and then pressing key [Enter], or by pressing key [Esc] once or several times. The menu must be in hidden state whenever we want to input data. If the menu is hidden, it can be brought to display by pressing the macro keys [Alt]+[M] (i.e. keeping key [Alt] pressed and press key [M]). To operate a command in the menu can be done by selecting the desired command (using Left-Arrow or Right-Arrow keys) and then pressing key [Enter]. The same result can also be gained by using short-cut key, i.e. as usual by pressing a key of the first character of the desired command in the menu.

D. *Data Input*

The input data are the results of well water analysis of the individual samples, and the volume ratios of these samples composing the desired composite. The program can accept up to four individual water samples.

The main concern of the user of this program is really only the worksheet part with the cell range B1..L51. Input and/or result data for the individual water samples (Water#1, Water#2, Water#3, and Water#4) are found in column F, H, J, and L, respectively. Result data for the water composite are listed in column D. Input data are introduced to the unprotected cells as described in Table 2.

It is to be noted that the input data for "Water Volume Ratio" are introduced only in cell H9, J9, and L9 (for Water#2, Water#3, and Water#4); the value for Water#1 is automatically calculated..

E. *How to Use the Program*

If the required data are already introduced into the right cells, then to initiate the calculation process select the menu command "CALCULATE;"; after a while you will see the result that is similar to Figure 4 (bottom). Scaling formations in the individual water samples or their composite, either by calcium carbonate, by calcium sulfate, or by barium sulfate, are indicated by "YES" or "NO".

To save the worksheet, select menu command "SAVE;". The worksheet will be saved in the disk as WK1-file with the name found in the cell D3 (see Figure 4, top).

To get a hardcopy of the result using the available printer, select the menu command "PRINT;" and then "Scale_T;". If the suitable printer driver is not activated yet, it can be done by selecting the menu command "PRINT;" and then "Printer;", select the appropriate driver, and finally press [Enter]. We can also get a hardcopy of the three solubility diagrams (Figure 1, 2, and 3) by using menu command "PRINT;" and then "Ca_SP;".

F. *Examples*

Four cases as the examples of the calculation are shown in Figure 5, 6, 7, and 8. All cases use the same four water samples, but with different water volume ratios.

Scaling tendencies in each of the four individual water samples are summarized in Table 3. Water#1 (LP224) and Water#2 (HVB) suggest the calcium carbonate scaling tendencies, while Water#3 (HGB) and Water#4 (HYW) indicate no scaling tendency at all.

Table 4 is a summary of four composite cases, where by the scaling tendency can be avoided by the variation of the water volume ratio.

In Case-1, the composite with 15.00% Water#1 and 15.00% Water#2, shows the calcium carbonate and barium sulfate scaling tendencies. If this volume ratio is changed to be 18.00% Water#1 and 12.00% Water#2 as in Case-2, no scaling occurs. In Case-3 where Water#1 is excluded (= 0%) and Water#2 is increased to 30%, barium sulfate scaling is indicated. And on the contrary, we find no scaling at all in the composite if Water#2 is excluded (= 0%) and the volume of Water#3 is increased to 30%.

REFERENCES

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2. **Stiff, H.A. and Davis, L.E., 1952, "A Method for Predicting the Tendency of Oil Field Waters to Deposit Calcium Carbonate"**, *Transactions AIME,* **Vol.195.**

3. **Skillman, H.L., McDonald, J.P.Jr., and Stiff, H.A.Jr.**, 1969, **"A Simple, Accurate, Fast Method for Calculating Calcium Sulfate Solubility in Oil Field Brine"**, *API Presentation*, **Texas.**

4. **Patton, C.C.**, 1977, **"Oilfield Water Systems"**, *Campbell Petroleum Series*.

5. **Christian, G.D.**, 1980, *Analytical Chemistry*, **3rd Edition, John Wiley & Sons (1980).**☐

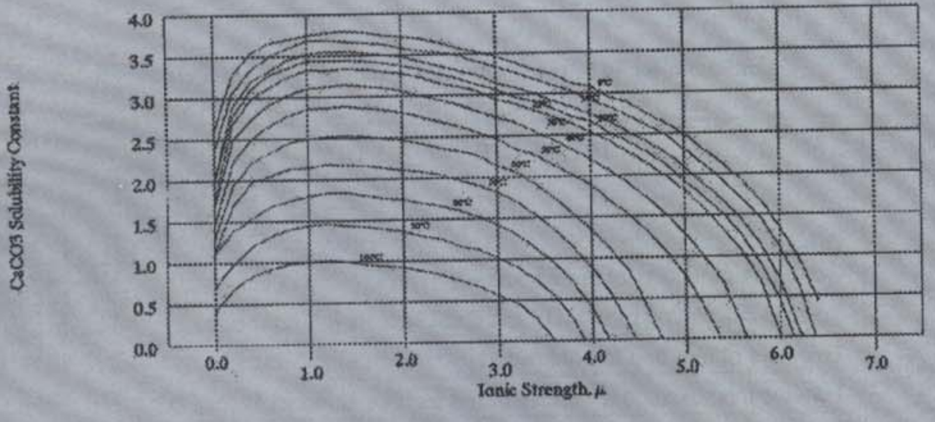


Figure 1
$CaCO_3$ solubility constant vs ionic strength

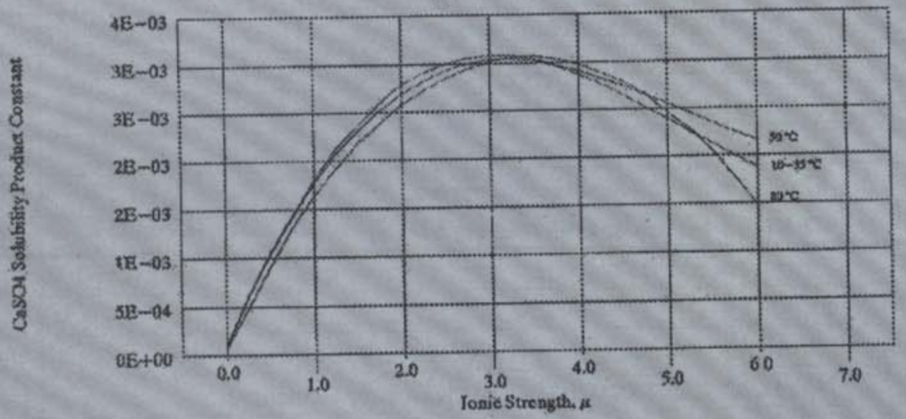


Figure 2
$CaSO_4$ solubility product vs ionic strength

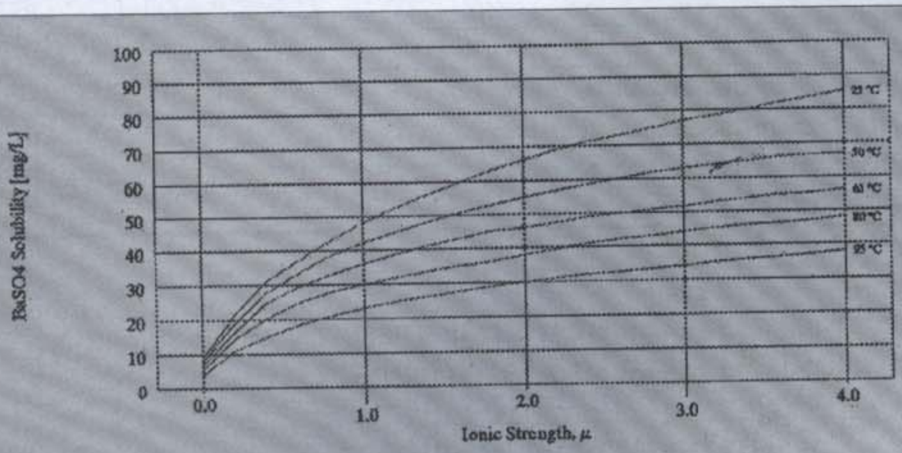


Figure 3
$BaSO_4$ solubility product vs ionic strength

Table 1
Command menu in the program worksheet "WScale.wk1"

COMMAND	DESCRIPTION	NOTE
Main Menu		
MENU		
GoTo,	Go to different parts of the worksheet	To Sub-Menu 1
Calculate;	To start calculation of $CaCO_3$ and $CaSO_4$ scaling tendencies.	
Print;	To select printer and to print report	To Sub-Menu 2
Save;	To save this worksheet with file name as "FileName.wk1" (cell D3).	
QUIT	To quit this session and turn MENU off.	
Sub-Menu 1		
LOCA:		
Home;	Go to HOME and to cell D3 (FileName).	
WaterVol;	Go to WATER VOLUME.	
Ions;	Go to CATIONS and ANIONS.	
ScaleTendency;	Go to results of SCALING TENDENCY calculation.	
Gr_Label;	Go to place to make solubility graph LABELING.	
Zoom;	Display of full-screen view of a graphic ..	To Sub-Menu 3
Quit;	QUIT this session and return to Main Menu.	
Sub-Menu 2		
PRINTING:		
View;	Preview a print range of the REPORT or DIAGRAM ...	To Sub-Menu 4
Scale_T;	Print CALCULATION RESULT of the Scaling Tendency.	
Ca_SP;	Print Solubility Graphs of $CaCO_3$, $CaSO_4$, and $BaSO_4$.	
Printer;	To select printer ...	
Quit;	QUIT this session and return to Main Menu.	
Sub-Menu 3		
ZOOMGR:		
1$CaCO_3$-Graph;	Zoom $CaCO_3$ solubility graphic.	
2$CaSO_4$-Graph;	Zoom $CaSO_4$ solubility graphic.	
3$BaSO_4$-Graph;	Zoom $BaSO_4$ solubility graphic.	
Quit;	QUIT this session and return to Main Menu.	
Sub-Menu 4		
PREV0:		
RepPrev;	Preview print range of CALCULATION RESULT of Scale Tendencies.	
DiaPrev;	Preview print range of SOLUBILITY GRAPHS: $CaCO_3$, $CaSO_4$, and $BaSO_4$.	
Quit;	QUIT this session and return to Main Menu.	

Table 2
Input data for "WScale.WK1"

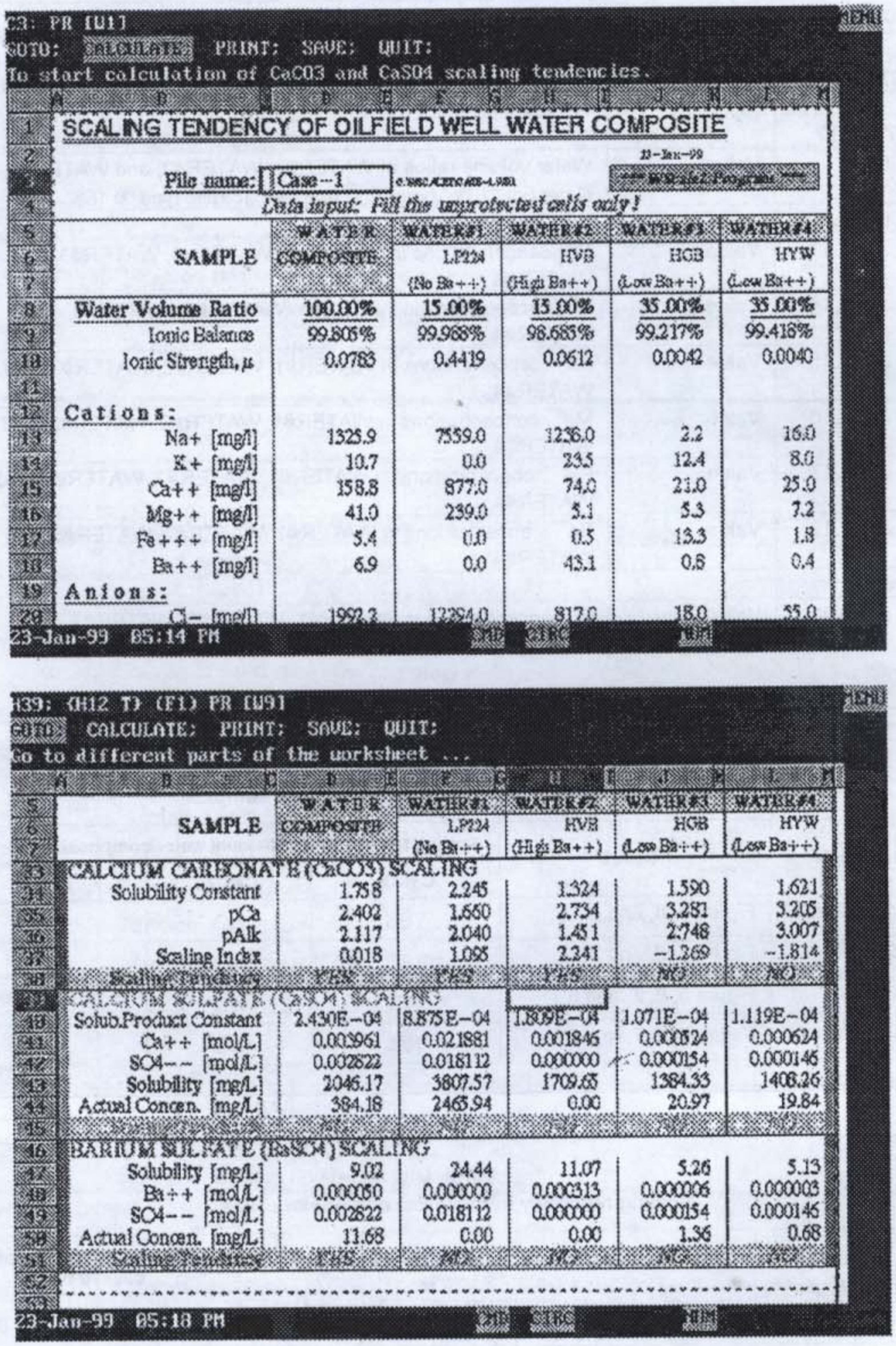
CELL	FORMAT	DESCRIPTION
D3	Label	The Name of the worksheet file.
F6..F7, H6..H7, J6..J7, L6..L7	Label	Water sample IDs for WATER#1, WATER#2, WATER#3, and WATER#4.
H8, J8, L8	Value	Water volume ratios of WATER#2, WATER#3, and WATER#4. Note: For "10%" type "0.1" and for "15.6%" type "0.156".
Cations		
H13, J13, L13	Value	Na$^+$ concentrations in WATER#1, WATER#2, WATER#3, and WATER#4.
H14, J14, L14	Value	K$^+$ concentrations in WATER#1, WATER#2, WATER#3, and WATER#4.
H15, J15, L15	Value	Ca^{++} concentrations in WATER#1, WATER#2, WATER#3, and WATER#4.
H16, J16, L16	Value	Mg^{++} concentrations in WATER#1, WATER#2, WATER#3, and WATER#4.
H17, J17, L17	Value	Fe^{+++} concentrations in WATER#1, WATER#2, WATER#3, and WATER#4.
H18, J18, L18	Value	Ba^{++} concentrations in WATER#1, WATER#2, WATER#3, and WATER#4.
Anions:		
H20, J20, L20	Value	Cl$^-$ concentrations in WATER#1, WATER#2, WATER#3, and WATER#4.

Table 3
Scaling tendency in the four individual water samples

Water sample	Report	Scaling tendency of individual water composite caused by		
		$CaCO_3$	$CaSO_4$	$BaSO_4$
Water#1: LP224	Figure 5, 6, and 8	YES	NO	NO
Water#2: HVB	Figure 5, 6, and 7	YES	NO	NO
Water#3: HGB	Figure 5, 6, 7, and 8	NO	NO	NO
Water#4: HYW	Figure 5, 6, 7, and 8	NO	NO	NO

Table 4
Scaling tendency in the water composite cases

Case	Report	Volume ratio in the water composite				Scaling tendency of water composite caused by		
		Water#1 LP224	Water#2 HVB	Water#3 HGB	Water#4 HYW	$CaCO_3$	$CaSO_4$	$BaSO_4$
Case-1	Figure 5	15.00%	15.00%	35.00%	35.00%	Yes	No	Yes
Case-2	Figure 6	18.00%	12.00%	35.00%	35.00%	No	No	No
Case-3	Figure 7	00.00%	30.00%	35.00%	35.00%	No	No	Yes
Case-4	Figure 8	30.00%	00.00%	35.00%	35.00%	No	No	No



```
C3: PR [U1]
GOTO: CALCULATE: PRINT: SAVE: QUIT:
To start calculation of CaCO3 and CaSO4 scaling tendencies.
```

SCALING TENDENCY OF OILFIELD WELL WATER COMPOSITE

23-Jan-99

File name: Case-1

Data input: Fill the unprotected cells only!

SAMPLE	WATER COMPOSITE	WATER#1 LP224 (No Ba++)	WATER#2 HVB (High Ba++)	WATER#3 HGB (Low Ba++)	WATER#4 HYW (Low Ba++)
Water Volume Ratio	100.00%	15.00%	15.00%	35.00%	35.00%
Ionic Balance	99.806%	99.968%	98.685%	99.217%	99.416%
Ionic Strength, μ	0.0783	0.4419	0.0612	0.0042	0.0040
Cations:					
Na+ [mg/l]	1325.9	7559.0	1236.0	2.2	16.0
K+ [mg/l]	10.7	0.0	23.5	12.4	8.0
Ca++ [mg/l]	158.8	877.0	74.0	21.0	25.0
Mg++ [mg/l]	41.0	239.0	5.1	5.3	7.2
Fe+++ [mg/l]	5.4	0.0	0.5	13.3	1.8
Ba++ [mg/l]	6.9	0.0	43.1	0.6	0.4
Anions:					
Cl− [mg/l]	1992.3	12294.0	817.0	18.0	55.0

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23-Jan-99  05:14 PM
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H39: {H12 T} (F1) PR [U9]
GOTO: CALCULATE: PRINT: SAVE: QUIT:
Go to different parts of the worksheet ...
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SAMPLE	WATER COMPOSITE	WATER#1 LP224 (No Ba++)	WATER#2 HVB (High Ba++)	WATER#3 HGB (Low Ba++)	WATER#4 HYW (Low Ba++)
CALCIUM CARBONATE (CaCO3) SCALING					
Solubility Constant	1.758	2.245	1.324	1.590	1.621
pCa	2.402	1.660	2.734	3.281	3.205
pAlk	2.117	2.040	1.451	2.748	3.007
Scaling Index	0.018	1.095	2.241	−1.269	−1.814
Scaling Tendency	YES	YES	YES	NO	NO
CALCIUM SULFATE (CaSO4) SCALING					
Solub.Product Constant	2.430E−04	8.875E−04	1.809E−04	1.071E−04	1.119E−04
Ca++ [mol/L]	0.003961	0.021881	0.001846	0.000524	0.000624
SO4−− [mol/L]	0.002822	0.018112	0.000000	0.000154	0.000146
Solubility [mg/L]	2046.17	3807.57	1709.65	1384.33	1408.26
Actual Concen. [mg/L]	384.18	2465.94	0.00	20.97	19.84
[illegible]	NO	NO	NO	NO	NO
BARIUM SULFATE (BaSO4) SCALING					
Solubility [mg/L]	9.02	24.44	11.07	5.26	5.13
Ba++ [mol/L]	0.000050	0.000000	0.000313	0.000006	0.000003
SO4−− [mol/L]	0.002822	0.018112	0.000000	0.000154	0.000146
Actual Concen. [mg/L]	11.68	0.00	0.00	1.36	0.68
Scaling Tendency	YES	NO	NO	NO	NO

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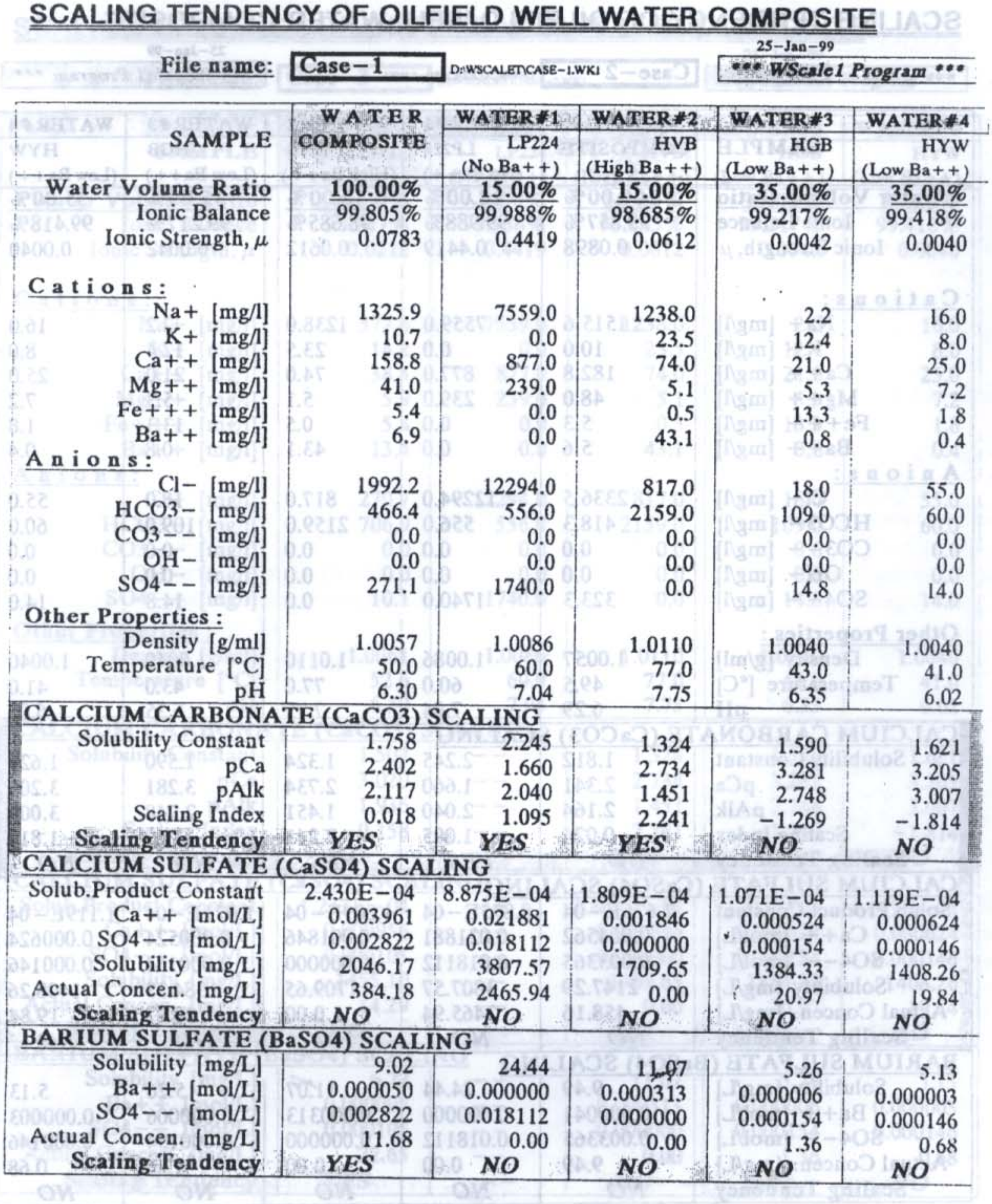
23-Jan-99  05:18 PM
```

Figure 4

Monitor display of "WScale1" program



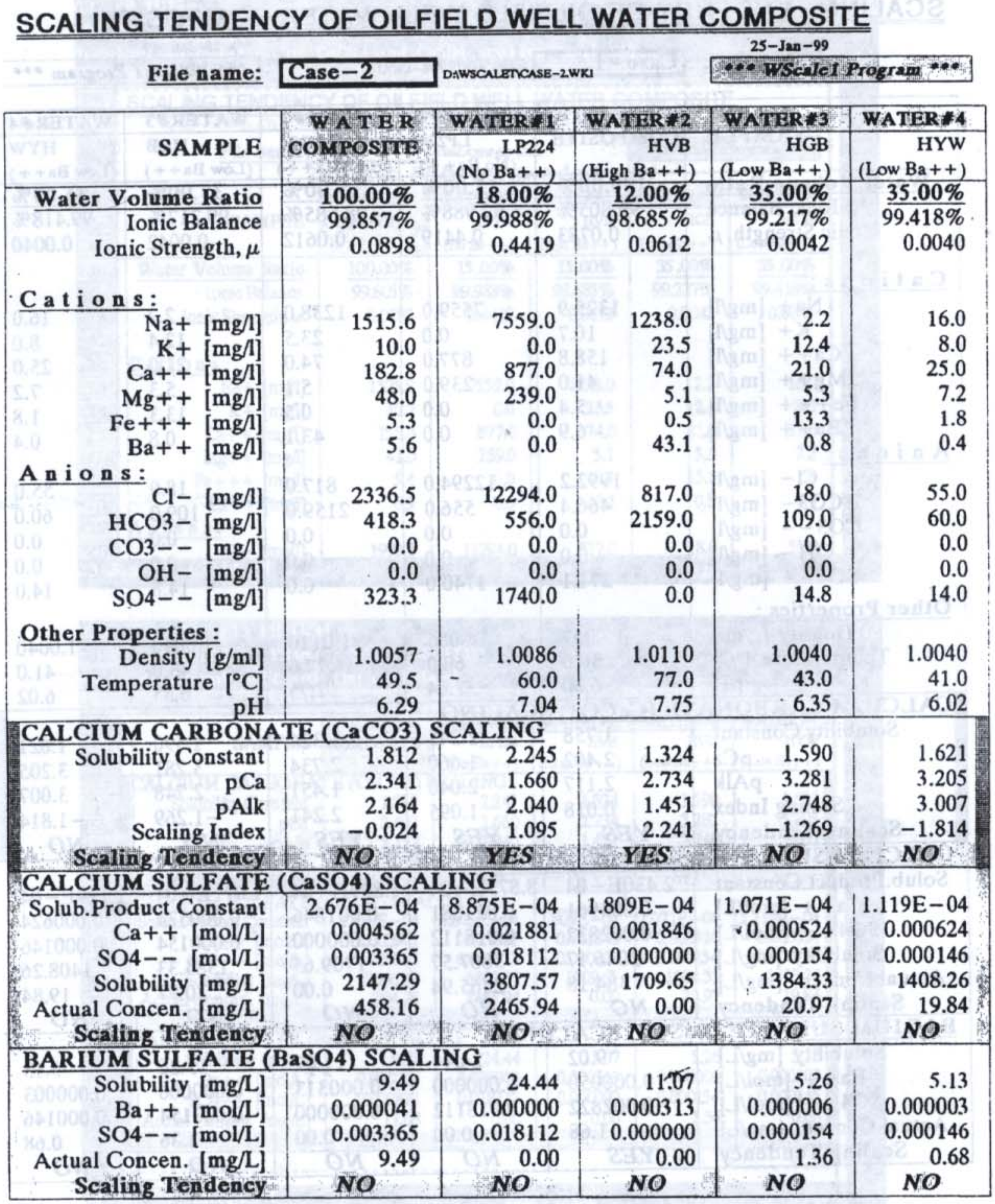
SCALING TENDENCY OF OILFIELD WELL WATER COMPOSITE

25-Jan-99

File name: Case-1 D:\WSCALE1\CASE-1.WK1 *** *WScale1 Program* ***

SAMPLE	WATER COMPOSITE	WATER#1 LP224 (No Ba++)	WATER#2 HVB (High Ba++)	WATER#3 HGB (Low Ba++)	WATER#4 HYW (Low Ba++)
Water Volume Ratio	100.00%	15.00%	15.00%	35.00%	35.00%
Ionic Balance	99.805%	99.988%	98.685%	99.217%	99.418%
Ionic Strength, μ	0.0783	0.4419	0.0612	0.0042	0.0040
Cations:					
Na+ [mg/l]	1325.9	7559.0	1238.0	2.2	16.0
K+ [mg/l]	10.7	0.0	23.5	12.4	8.0
Ca++ [mg/l]	158.8	877.0	74.0	21.0	25.0
Mg++ [mg/l]	41.0	239.0	5.1	5.3	7.2
Fe+++ [mg/l]	5.4	0.0	0.5	13.3	1.8
Ba++ [mg/l]	6.9	0.0	43.1	0.8	0.4
Anions:					
Cl− [mg/l]	1992.2	12294.0	817.0	18.0	55.0
HCO3− [mg/l]	466.4	556.0	2159.0	109.0	60.0
CO3−− [mg/l]	0.0	0.0	0.0	0.0	0.0
OH− [mg/l]	0.0	0.0	0.0	0.0	0.0
SO4−− [mg/l]	271.1	1740.0	0.0	14.8	14.0
Other Properties:					
Density [g/ml]	1.0057	1.0086	1.0110	1.0040	1.0040
Temperature [°C]	50.0	60.0	77.0	43.0	41.0
pH	6.30	7.04	7.75	6.35	6.02
CALCIUM CARBONATE (CaCO3) SCALING					
Solubility Constant	1.758	2.245	1.324	1.590	1.621
pCa	2.402	1.660	2.734	3.281	3.205
pAlk	2.117	2.040	1.451	2.748	3.007
Scaling Index	0.018	1.095	2.241	−1.269	−1.814
Scaling Tendency	***YES***	***YES***	***YES***	***NO***	***NO***
CALCIUM SULFATE (CaSO4) SCALING					
Solub.Product Constant	2.430E−04	8.875E−04	1.809E−04	1.071E−04	1.119E−04
Ca++ [mol/L]	0.003961	0.021881	0.001846	0.000524	0.000624
SO4−− [mol/L]	0.002822	0.018112	0.000000	0.000154	0.000146
Solubility [mg/L]	2046.17	3807.57	1709.65	1384.33	1408.26
Actual Concen. [mg/L]	384.18	2465.94	0.00	20.97	19.84
Scaling Tendency	***NO***	***NO***	***NO***	***NO***	***NO***
BARIUM SULFATE (BaSO4) SCALING					
Solubility [mg/L]	9.02	24.44	11.07	5.26	5.13
Ba++ [mol/L]	0.000050	0.000000	0.000313	0.000006	0.000003
SO4−− [mol/L]	0.002822	0.018112	0.000000	0.000154	0.000146
Actual Concen. [mg/L]	11.68	0.00	0.00	1.36	0.68
Scaling Tendency	***YES***	***NO***	***NO***	***NO***	***NO***

Figure 5
Scaling tendency report for "Case-1"



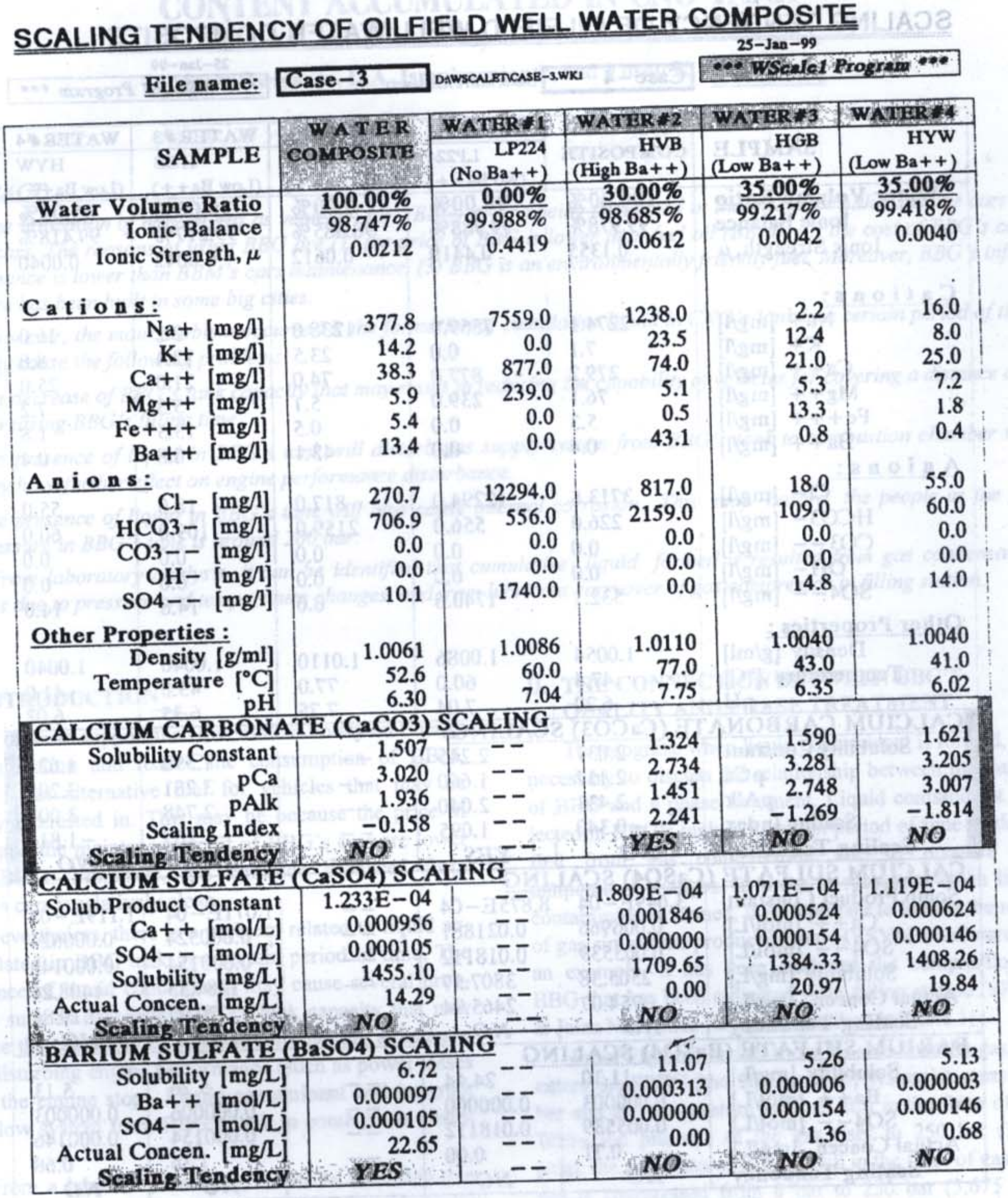
SCALING TENDENCY OF OILFIELD WELL WATER COMPOSITE

25-Jan-99

File name: Case-2 D:\WSCALE1\CASE-2.WK1 *** WScale1 Program ***

SAMPLE	WATER COMPOSITE	WATER#1 LP224 (No Ba++)	WATER#2 HVB (High Ba++)	WATER#3 HGB (Low Ba++)	WATER#4 HYW (Low Ba++)
Water Volume Ratio	100.00%	18.00%	12.00%	35.00%	35.00%
Ionic Balance	99.857%	99.988%	98.685%	99.217%	99.418%
Ionic Strength, μ	0.0898	0.4419	0.0612	0.0042	0.0040
Cations:					
Na+ [mg/l]	1515.6	7559.0	1238.0	2.2	16.0
K+ [mg/l]	10.0	0.0	23.5	12.4	8.0
Ca++ [mg/l]	182.8	877.0	74.0	21.0	25.0
Mg++ [mg/l]	48.0	239.0	5.1	5.3	7.2
Fe+++ [mg/l]	5.3	0.0	0.5	13.3	1.8
Ba++ [mg/l]	5.6	0.0	43.1	0.8	0.4
Anions:					
Cl− [mg/l]	2336.5	12294.0	817.0	18.0	55.0
HCO3− [mg/l]	418.3	556.0	2159.0	109.0	60.0
CO3−− [mg/l]	0.0	0.0	0.0	0.0	0.0
OH− [mg/l]	0.0	0.0	0.0	0.0	0.0
SO4−− [mg/l]	323.3	1740.0	0.0	14.8	14.0
Other Properties:					
Density [g/ml]	1.0057	1.0086	1.0110	1.0040	1.0040
Temperature [°C]	49.5	60.0	77.0	43.0	41.0
pH	6.29	7.04	7.75	6.35	6.02
CALCIUM CARBONATE (CaCO3) SCALING					
Solubility Constant	1.812	2.245	1.324	1.590	1.621
pCa	2.341	1.660	2.734	3.281	3.205
pAlk	2.164	2.040	1.451	2.748	3.007
Scaling Index	−0.024	1.095	2.241	−1.269	−1.814
Scaling Tendency	***NO***	***YES***	***YES***	***NO***	***NO***
CALCIUM SULFATE (CaSO4) SCALING					
Solub.Product Constant	2.676E−04	8.875E−04	1.809E−04	1.071E−04	1.119E−04
Ca++ [mol/L]	0.004562	0.021881	0.001846	0.000524	0.000624
SO4−− [mol/L]	0.003365	0.018112	0.000000	0.000154	0.000146
Solubility [mg/L]	2147.29	3807.57	1709.65	1384.33	1408.26
Actual Concen. [mg/L]	458.16	2465.94	0.00	20.97	19.84
Scaling Tendency	***NO***	***NO***	***NO***	***NO***	***NO***
BARIUM SULFATE (BaSO4) SCALING					
Solubility [mg/L]	9.49	24.44	11.07	5.26	5.13
Ba++ [mol/L]	0.000041	0.000000	0.000313	0.000006	0.000003
SO4−− [mol/L]	0.003365	0.018112	0.000000	0.000154	0.000146
Actual Concen. [mg/L]	9.49	0.00	0.00	1.36	0.68
Scaling Tendency	***NO***	***NO***	***NO***	***NO***	***NO***

Figure 6
Scaling tendency report for "Case-2"



SCALING TENDENCY OF OILFIELD WELL WATER COMPOSITE

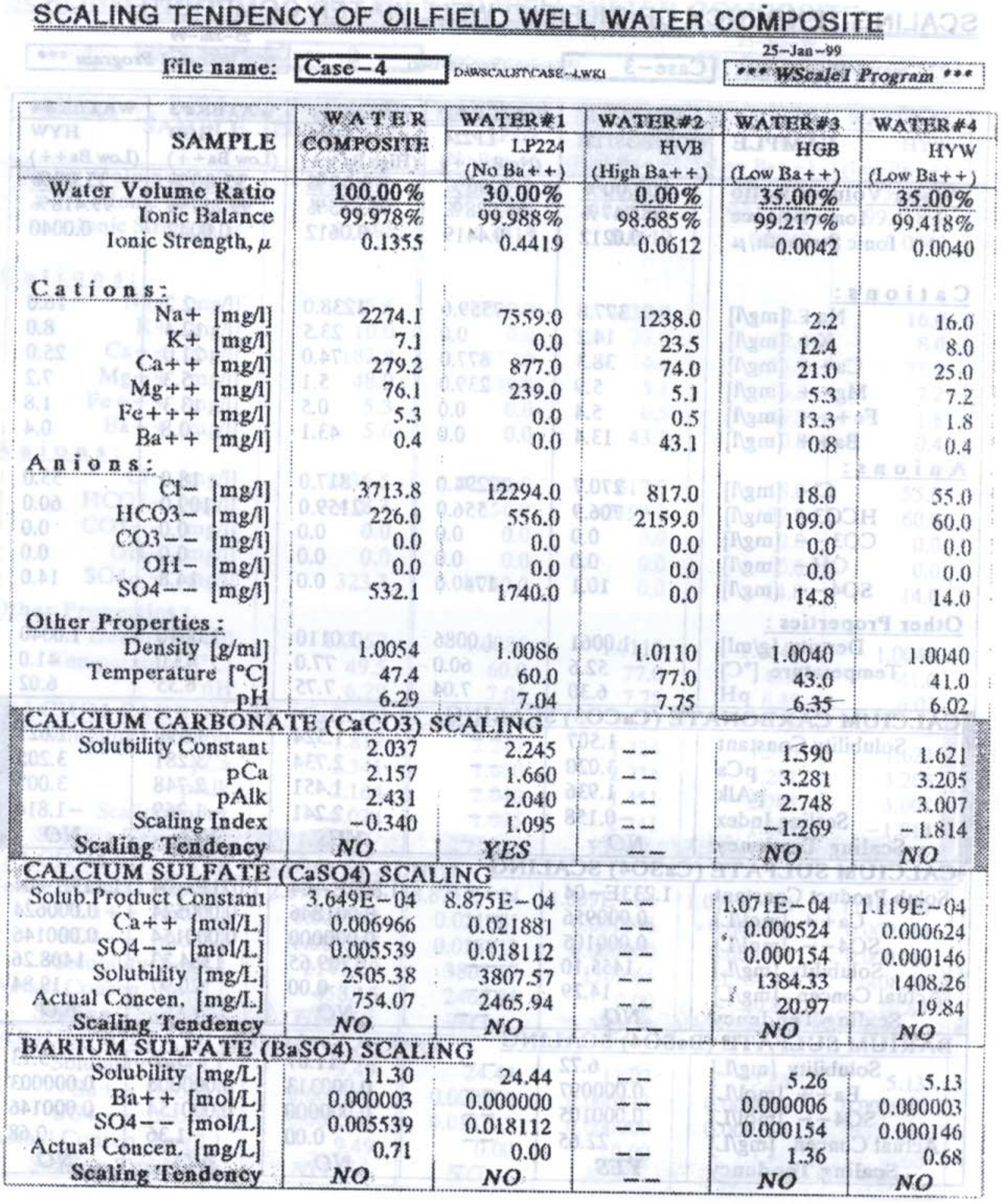
25-Jan-99

*** WScale1 Program ***

File name: Case-3 D:\WSCALE\CASE-3.WK1

SAMPLE	WATER COMPOSITE	WATER#1 LP224 (No Ba++)	WATER#2 HVB (High Ba++)	WATER#3 HGB (Low Ba++)	WATER#4 HYW (Low Ba++)
Water Volume Ratio	100.00%	0.00%	30.00%	35.00%	35.00%
Ionic Balance	98.747%	99.988%	98.685%	99.217%	99.418%
Ionic Strength, μ	0.0212	0.4419	0.0612	0.0042	0.0040
Cations:					
Na+ [mg/l]	377.8	7559.0	1238.0	2.2	16.0
K+ [mg/l]	14.2	0.0	23.5	12.4	8.0
Ca++ [mg/l]	38.3	877.0	74.0	21.0	25.0
Mg++ [mg/l]	5.9	239.0	5.1	5.3	7.2
Fe+++ [mg/l]	5.4	0.0	0.5	13.3	1.8
Ba++ [mg/l]	13.4	0.0	43.1	0.8	0.4
Anions:					
Cl- [mg/l]	270.7	12294.0	817.0	18.0	55.0
HCO3- [mg/l]	706.9	556.0	2159.0	109.0	60.0
CO3-- [mg/l]	0.0	0.0	0.0	0.0	0.0
OH- [mg/l]	0.0	0.0	0.0	0.0	0.0
SO4-- [mg/l]	10.1	1740.0	0.0	14.8	14.0
Other Properties:					
Density [g/ml]	1.0061	1.0086	1.0110	1.0040	1.0040
Temperature [°C]	52.6	60.0	77.0	43.0	41.0
pH	6.30	7.04	7.75	6.35	6.02
CALCIUM CARBONATE (CaCO3) SCALING					
Solubility Constant	1.507	--	1.324	1.590	1.621
pCa	3.020	--	2.734	3.281	3.205
pAlk	1.936	--	1.451	2.748	3.007
Scaling Index	-0.158	--	2.241	-1.269	-1.814
Scaling Tendency	*NO*	--	*YES*	*NO*	*NO*
CALCIUM SULFATE (CaSO4) SCALING					
Solub.Product Constant	1.233E-04	--	1.809E-04	1.071E-04	1.119E-04
Ca++ [mol/L]	0.000956	--	0.001846	0.000524	0.000624
SO4-- [mol/L]	0.000105	--	0.000000	0.000154	0.000146
Solubility [mg/L]	1455.10	--	1709.65	1384.33	1408.26
Actual Concen. [mg/L]	14.29	--	0.00	20.97	19.84
Scaling Tendency	*NO*	--	*NO*	*NO*	*NO*
BARIUM SULFATE (BaSO4) SCALING					
Solubility [mg/L]	6.72	--	11.07	5.26	5.13
Ba++ [mol/L]	0.000097	--	0.000313	0.000006	0.000003
SO4-- [mol/L]	0.000105	--	0.000000	0.000154	0.000146
Actual Concen. [mg/L]	22.65	--	0.00	1.36	0.68
Scaling Tendency	*YES*	--	*NO*	*NO*	*NO*

Figure 7
Scaling tendency report for "Case-3"



SCALING TENDENCY OF OILFIELD WELL WATER COMPOSITE

File name: Case-4 D:\WSCALE1\CASE-4.WK1

25-Jan-99

*** WScale1 Program ***

SAMPLE	WATER COMPOSITE	WATER#1 LP224 (No Ba++)	WATER#2 HVB (High Ba++)	WATER#3 HGB (Low Ba++)	WATER#4 HYW (Low Ba++)
Water Volume Ratio	100.00%	30.00%	0.00%	35.00%	35.00%
Ionic Balance	99.978%	99.988%	98.685%	99.217%	99.418%
Ionic Strength, μ	0.1355	0.4419	0.0612	0.0042	0.0040
Cations:					
Na+ [mg/l]	2274.1	7559.0	1238.0	2.2	16.0
K+ [mg/l]	7.1	0.0	23.5	12.4	8.0
Ca++ [mg/l]	279.2	877.0	74.0	21.0	25.0
Mg++ [mg/l]	76.1	239.0	5.1	5.3	7.2
Fe+++ [mg/l]	5.3	0.0	0.5	13.3	1.8
Ba++ [mg/l]	0.4	0.0	43.1	0.8	0.4
Anions:					
Cl- [mg/l]	3713.8	12294.0	817.0	18.0	55.0
HCO3- [mg/l]	226.0	556.0	2159.0	109.0	60.0
CO3-- [mg/l]	0.0	0.0	0.0	0.0	0.0
OH- [mg/l]	0.0	0.0	0.0	0.0	0.0
SO4-- [mg/l]	532.1	1740.0	0.0	14.8	14.0
Other Properties:					
Density [g/ml]	1.0054	1.0086	1.0110	1.0040	1.0040
Temperature [°C]	47.4	60.0	77.0	43.0	41.0
pH	6.29	7.04	7.75	6.35	6.02
CALCIUM CARBONATE (CaCO3) SCALING					
Solubility Constant	2.037	2.245	--	1.590	1.621
pCa	2.157	1.660	--	3.281	3.205
pAlk	2.431	2.040	--	2.748	3.007
Scaling Index	-0.340	1.095	--	-1.269	-1.814
Scaling Tendency	*NO*	*YES*	--	*NO*	*NO*
CALCIUM SULFATE (CaSO4) SCALING					
Solub.Product Constant	3.649E-04	8.875E-04	--	1.071E-04	1.119E-04
Ca++ [mol/L]	0.006966	0.021881	--	0.000524	0.000624
SO4-- [mol/L]	0.005539	0.018112	--	0.000154	0.000146
Solubility [mg/L]	2505.38	3807.57	--	1384.33	1408.26
Actual Concen. [mg/L]	754.07	2465.94	--	20.97	19.84
Scaling Tendency	*NO*	*NO*	--	*NO*	*NO*
BARIUM SULFATE (BaSO4) SCALING					
Solubility [mg/L]	11.30	24.44	--	5.26	5.13
Ba++ [mol/L]	0.000003	0.000000	--	0.000006	0.000003
SO4-- [mol/L]	0.005539	0.018112	--	0.000154	0.000146
Actual Concen. [mg/L]	0.71	0.00	--	1.36	0.68
Scaling Tendency	*NO*	*NO*	--	*NO*	*NO*

Figure 8
Scaling tendency report for "Case-4"