Mixing and Scale Affinity Model for Hydraulic Fracturing Fluids

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Introduction

- Concerns about water issues are limiting shale gas production in the U.S.
- One effective way to address a number of these issues is to re-use produced water in subsequent wells.
- Mixing/Scale Affinity Model facilitates the creation of engineered waters for HVHF re-use by predicting:
  - mixed water chemistry,
  - scaling potential that may result from mixing different water sources.

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Project Overview

- Describe the major treatment technologies available:
  - Capabilities (constituents/concentrations treated, volumes, and efficiency)
  - Operating parameters (mobile/ stationary, temperature limitations, etc.)
- Identify regulatory constraints of each state
- Assess disposal options
- Develop a tool that will help an operator make decisions about the best water treatment approach for a given shale gas project.

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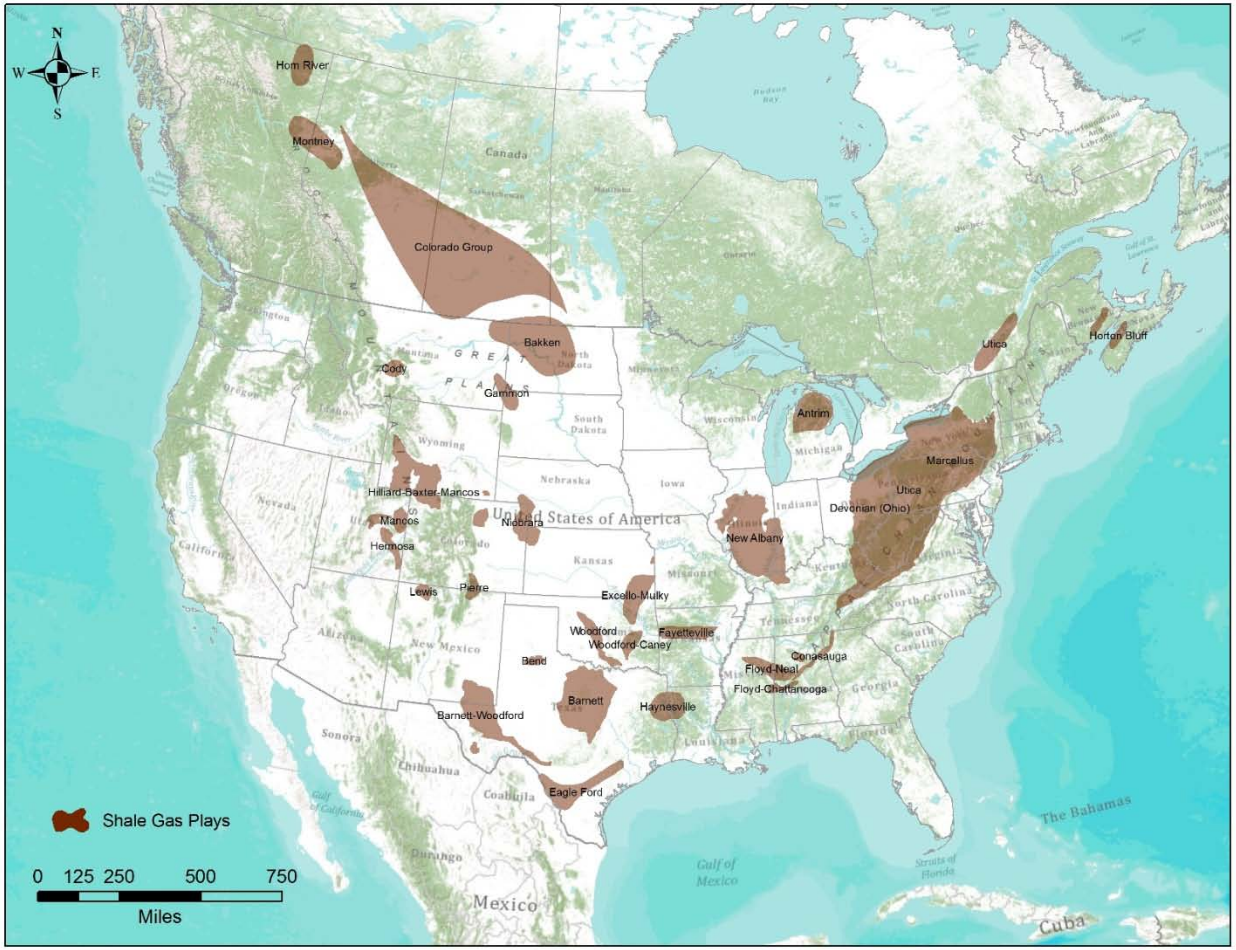
North American Shale Gas Plays



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High Volume Hydraulic Fracturing

- Hydraulic fracturing requires 3 to 7 million gallons of water for each horizontal shale gas well
- Water can be obtained from multiple sources:
  - Groundwater
  - Surface water
  - Municipal water
  - Produced water
- 15 - 50 % of this water is returned during flow back

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Water Issues for Shale Gas

- Withdrawals – potential impacts to environment and other users
- Transportation – road, noise and traffic impacts
- Management of produced water
  - Limited UIC disposal capacity
  - Potential impacts to receiving streams from treated discharge
- Cost

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Re-Use of Produced Water

- Produced water can be re-used in subsequent hydraulic fracture operations
- Blended with fresh water
- Can address many water issues
  - Withdrawals
  - Transportation
  - Disposal
  - Cost

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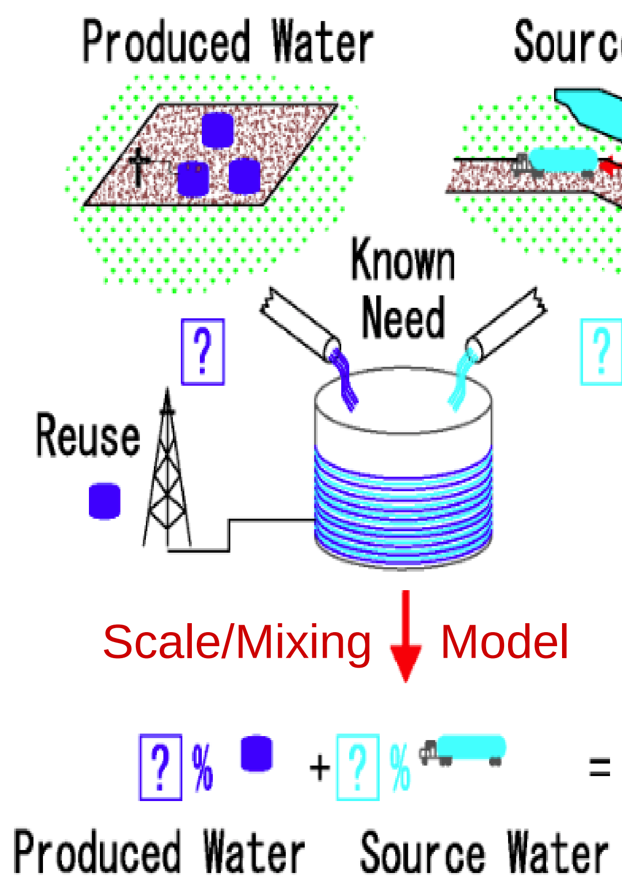
Considerations for Re-Use

- Quality of the produced water can affect performance of the fracture fluid
- Mixing produced and fresh water has an effect on scale tendencies of fracture fluid



Engineered Water
(volume and quality of water that meets operator's needs)

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Issues with Produced Water Re-Use

- Mixing
  - Produced water volumes re-used are typically 15% to 25% of subsequent fracture treatment volume
  - Remaining water is typically fresh water from other sources
  - These two waters typically have different water chemistries prior to mixing
- Scale
  - Mixing of two waters with different chemistries can create mineral equilibrium issues
  - Mixed water may precipitate minerals (form scale)
  - Scale can create production issues by clogging piping, tubing, or formation permeability

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What is Scale?

- A deposit or coating formed on the surface of metal, rock, or other material.
- Scale has traditionally been controlled through the use of scale inhibitor chemicals.
- Scale inhibitor: chemical treatment used to control or prevent scale deposition in the production conduit or completion system.

Examples of heavy scale precipitation
Photo Source: Statoil

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Why a Mixing/Scale Model?

- Mixing can be viewed as a simple volumetric TDS calculation where one plus one equals two, when in reality chemical interactions can occur such that one plus one does NOT equal two in the mixed solution.
- The chemical composition of dissolved solids can make a big difference in scale formation.
- Fluid chemistry can be used to predict the scale forming potential that results from mixing multiple waters.
- Understanding scale mineral speciation helps operators and service companies select optimal treatment chemicals and concentrations.

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The Model

- Predicts resultant chemical composition of mixed waters, allowing the user to see how waters are predicted to react when mixed.
- Addresses the mixing of multiple source waters, identifying the affinity for scale formation and the potential species of scale formed.

- Provides the ability to analyze multiple water sources and mixing ratios to identify the most favorable mix ratio of available waters to meet specified targets for quality parameters.

The Mixing Model

- Uses an established and verified aqueous geochemical model developed by the US Geological Survey: PHREEQC.
- Allows user to input multiple source water compositions and analyze the resultant chemical composition of water by mixing of different ratios of these fluids.
- The program predicts speciation formation through the calculation of saturation-indices, allowing the user to identify potential for the formation of the most common Carbonate and Sulfate Scale forming species.
- Model reacts mixed water solutions by allowing water chemistry to come to equilibrium on select species and then allows user to use that reacted water in subsequent modeling.

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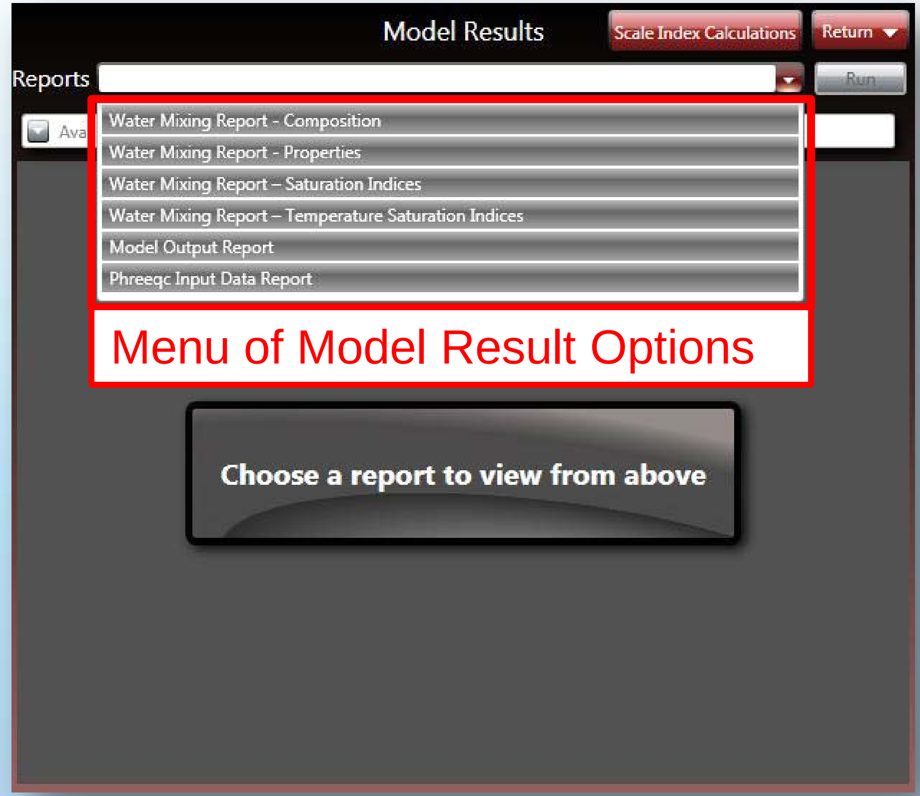
Mixing Model Outputs

- Reports on water quality changes from mixing prognosis: provides both simple mix and reacted water qualities
- Graphs on changes in Water Quality due to mixing
- Reports on precipitating and/or dissolving minerals due to mixing
- Results of mixing model are transferred to the Scale Affinity Model



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Mixed Water Quality Outputs

- Outputs document changes to specific parameters

Water Mixing and Scale Affinity Model

Version 1.00.000

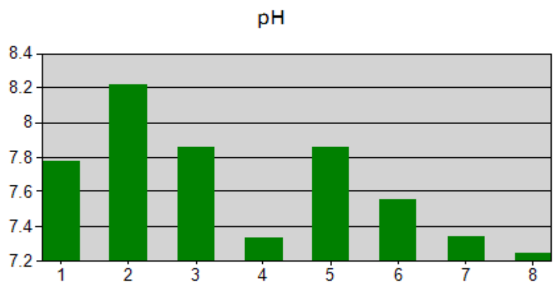
Water Mixing Report - Properties

Model Run: **brian 2**

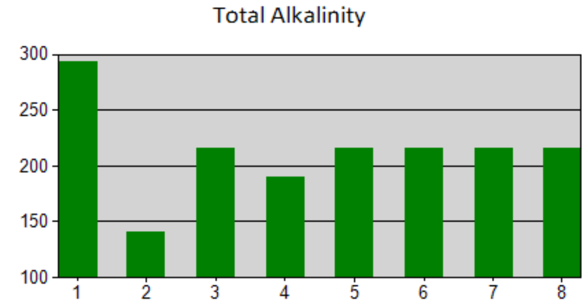
Model Description

Solution	Water Name
1	MIX using : [Scale Calc Test Water]: 50% ,[Produced Water]: 50%
2	REACTION TEMPERATURE for [Solution From Step: 1] @ : 25°
3	REACTION TEMPERATURE for [Solution From Step: 1] @ : 50°
4	REACTION TEMPERATURE for [Solution From Step: 1] @ : 75°
5	REACTION TEMPERATURE for [Solution From Step: 1] @ : 90°

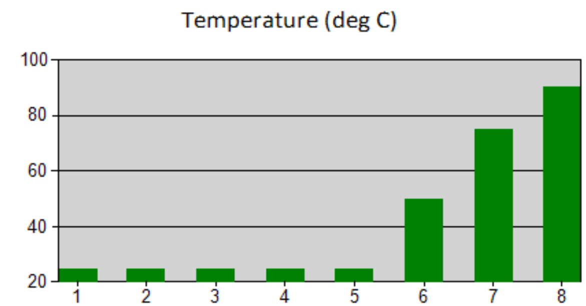
Solution	pH
1	7.78
2	8.22
3	7.86
4	7.337
5	7.86
6	7.559
7	7.342
8	7.246



Solution	Alkalinity as CaCO3, ppm
1	293.46
2	141.48
3	216.26
4	190.08
5	216.26
6	216.26
7	216.26
8	216.26



Solution	Temperature (deg C)
1	25
2	25
3	25
4	25
5	25
6	50
7	75
8	90



Mixed Water Composition Output

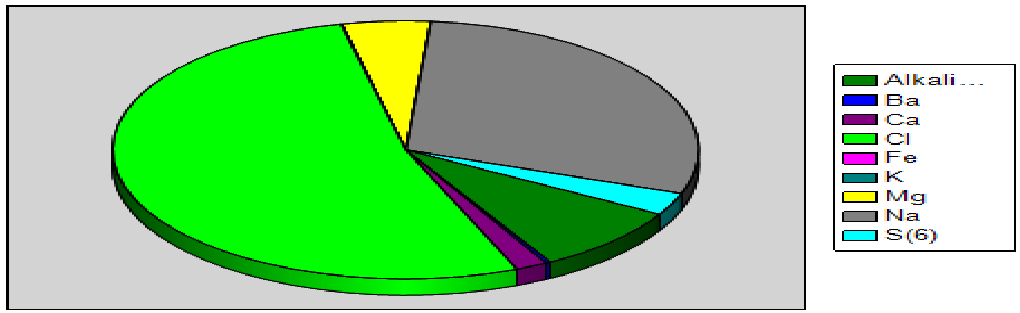
Water Mixing Report - Composition Model Run: **brian 2**

Model Description

Solution	Water Name
1	MIX using : [Scale Calc Test Water]: 50% ,[Produced Water]: 50%
2	REACTION TEMPERATURE for [Solution From Step: 1] @ : 25°
3	REACTION TEMPERATURE for [Solution From Step: 1] @ : 50°
4	REACTION TEMPERATURE for [Solution From Step: 1] @ : 75°
5	REACTION TEMPERATURE for [Solution From Step: 1] @ : 90°

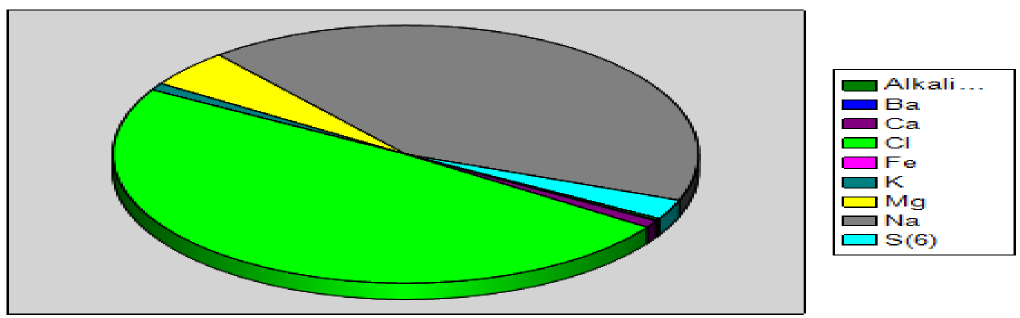
Real Water 1 "Test Water 1 " Composition

Ion	ppm
Alkalinity	293.46
Ba	25
Ca	48.5
Cl	1293.05
Fe	2.1
Mg	82.2
Na	463.97
S(6)	188.98



Real Water 2 "Test Water 2 " Composition

Ion	ppm
Alkalinity	141.48
Ba	119.84
Ca	411.67
Cl	19327.49
K	398.61
Mg	1290.02
Na	10754.34
S(6)	2708.29



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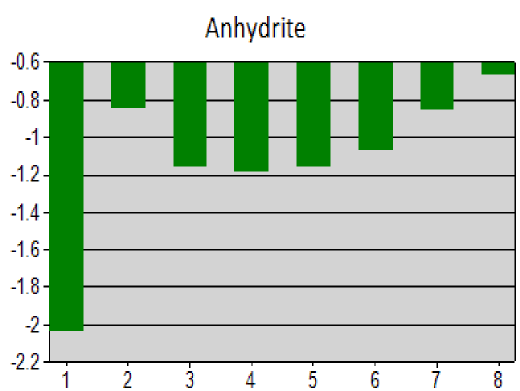
Mineral Saturation Indices Output

Water Mixing Report – Saturation Indices Model Run: brian 2

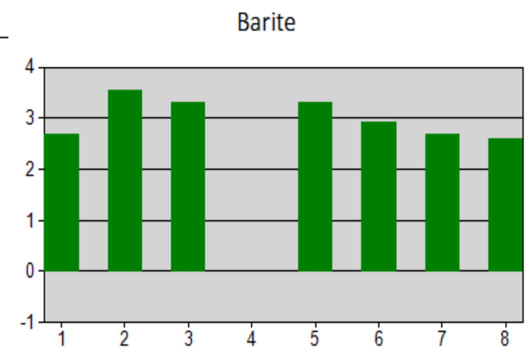
Model Description

Solution	Water Name
1	MIX using : [Scale Calc Test Water]: 50% ,[Produced Water]: 50%
2	REACTION TEMPERATURE for [Solution From Step: 1] @ : 25°
3	REACTION TEMPERATURE for [Solution From Step: 1] @ : 50°
4	REACTION TEMPERATURE for [Solution From Step: 1] @ : 75°
5	REACTION TEMPERATURE for [Solution From Step: 1] @ : 90°

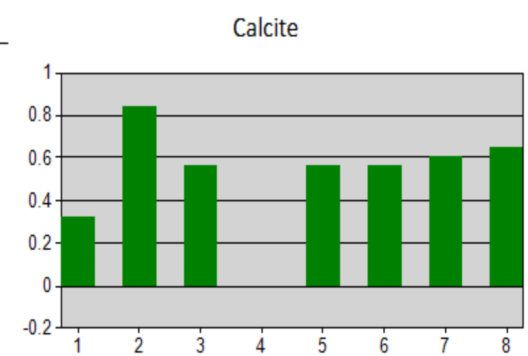
Solution	Type	SI
1	Real Water	-2.04
2	Real Water	-0.84
3	Mix.	-1.16
4	Mix.	-1.18
5	Temp.	-1.16
6	Temp.	-1.07
7	Temp.	-0.85
8	Temp.	-0.66



Solution	Type	SI
1	Real Water	2.7
2	Real Water	3.55
3	Mix.	3.31
4	Mix.	0
5	Temp.	3.31
6	Temp.	2.93
7	Temp.	2.69
8	Temp.	2.6



Solution	Type	SI
1	Real Water	0.32
2	Real Water	0.84
3	Mix.	0.57
4	Mix.	0
5	Temp.	0.57
6	Temp.	0.57
7	Temp.	0.61



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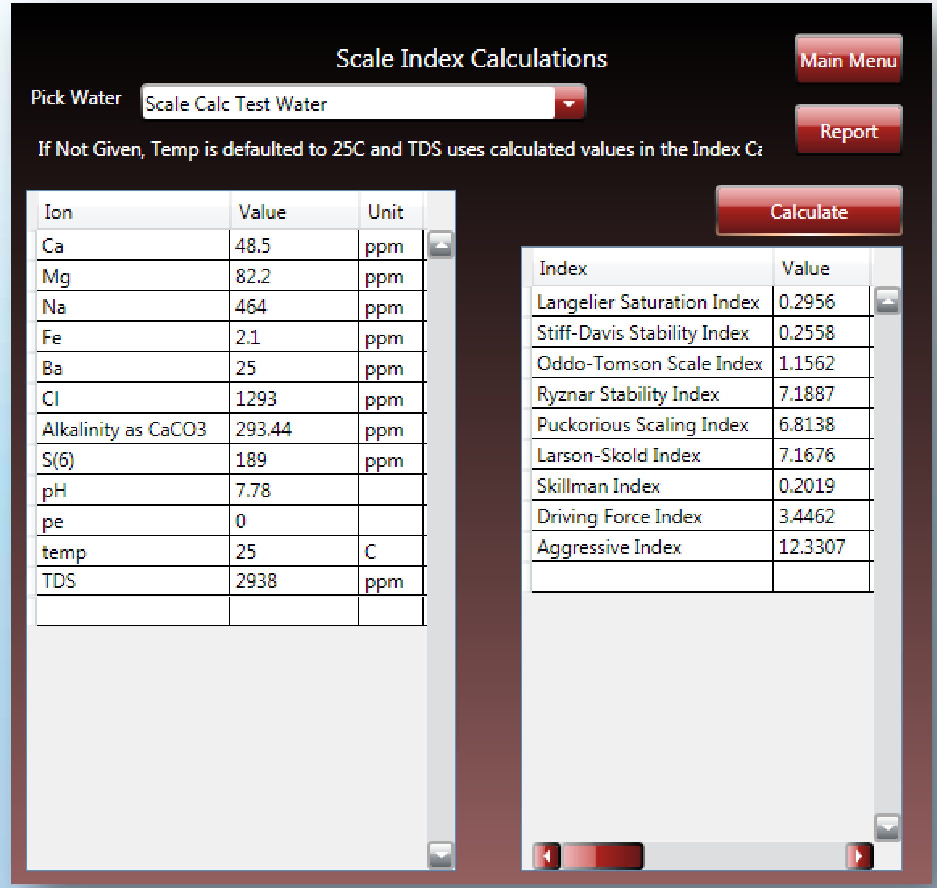
Scale Affinity Model

- Calculates affinity on entered waters or Mixing Model results
- Calculations of multiple scale index values for evaluation and ranking
- Reports include scale indices and conditional statements



Scale Affinity Indices Calculated

- Skillman Index
  - Analysis for $CaSO_4$ Scale
  - Model Limited to Temp of 25°C
- Larson-Skold Index
  - Addresses Chlorides, Sulfates, and Alkalinity
  - Developed for Great Lakes quality cooling water
- Ryznar Stability Index
  - Analysis for $CaCO_3$ Scale
  - Multiple interpretation regimes Ryznar Interpretation(1942), Carrier Interpretation (1965)
- Puckorius Scaling Index
  - Analysis for $CaCO_3$ Scale
- Langelier Saturation Index
  - Analysis for $CaCO_3$ Scale
  - TDS Limit <10,000 ppm
  - Total Hardness <4,000 ppm
- Stiff-Davis Stability Index
  - Analysis for $CaCO_3$ Scale
  - Works for TDS >10,000 ppm
  - Temp Limit <90° C
- Oddo-Tomson Scale Index
  - Analysis for $CaCO_3$ Scale
  - Corrects for multiple phases (water, gas, and oil)
  - Model limits Temp to 25°C
- Aggressive Index
  - Analysis for $CaCO_3$ Scale
- Driving Force Index
  - Analysis for $CaCO_3$ Scale

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Scale Model Output

- Scale calculation report presents:
  - each scale index result,
  - index description for each index result, and
  - the water quality

Water Mixing and Scale Affinity Model

Version 1.00.000

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Scale Calculations Report

Scale Calculations Results

Index Name	Index Result	Index Descriptions
Langelier Saturation Index	0.2956	Water is in Equilibrium with CaCO3. A scale layer of CaCO3 is neither precipitated nor dissolved.
Stiff-Davis Stability Index	0.2558	Water is in equilibrium with CaCO3. A scale layer of CaCO3 is neither precipitated nor dissolved.
Oddo-Tomson Scale Index	1.1562	Water tends to precipitate a scale layer of CaCO3.
Ryznar Stability Index	7.1887	Water is aggressive (Ryznar 1942).Corrosion significant (Carrier 1965).
Puckorious Scaling Index	6.8138	Water is aggressive.
Larson-Skold Index	7.1676	Dissolution of minerals may occur if available. (High rates of localized corrosion may be expected.)
Skillman Index	0.2019	Fixed at a Gypsum Ksp value for 25 C.Dissolve Mineral.
Driving Force Index	3.4462	Scales form.
Aggressive Index	12.3307	Scales form.

Water Property

Phase	Value	Units
Ca	48.5	ppm
Mg	82.2	ppm
Na	464	ppm
Fe	2.1	ppm
Ba	25	ppm
Cl	1293	ppm
Alkalinity as CaCO3	293.44	ppm
S(6)	189	ppm
pH	7.78	
pe	0	
temp	25	C
TDS	2938	ppm

Summary

- Mixing Model
  - Allows user to evaluate multiple water mixes
  - Allows user to analyze mixtures of two or three different waters.
  - Calculates mixed water quality after fluid is allowed to equilibrate
  - Results transfer to Scale Model
- Scale Model
  - Calculates nine scale indices
  - Presents Scale Index interpretation based on reported ranges
  - Documents modeled water quality in output

MODEL INFORMATION

- Software Available at:

  http://www.all-llc.com/projects/produced_water_tool/

- System Requirements:
  - Windows Based Operating System
  - Current Microsoft .NET Framework

Contact & Citation Information

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