RESERVOIR SOLUTIONS

Published quarterly by Ryder Scott Co. LP June–August 2012/Vol. 15 No. 2

# Bakken downspacing has upside, study shows

Infill drilling optimization is crucial to maximize economic returns and estimated ultimate recoveries from oil and gas fields. Particularly in low-permeability formations and unconventional resource plays, drilling more wells per number of acres (downspacing) is often necessary to boost producing rates and incremental recoveries of oil and gas from a reservoir.

But at what point does greater well density merely accelerate production without adding the necessary incremental increase in aggregate volumes to offset additional drilling and operating costs?

Optimal well spacing (distance between each well) is determined in part by considering the point at which an additional infill well in the pattern will interfere with the drainage area of the other wells. The question of what is the best well density per acre also hinges on a careful analysis of estimated discounted net present values and other criteria under varying downspacing scenarios and economic sensitivities.

## Inside Reservoir Solutions



A Fidelity E&P Co. rig drills in the Bakken shale at twilight. The company has targeted infill drilling locations on 640-acre spacing in the East Nesson area.

## Bakken and downspacing

The North Dakota Industrial Commission sets well spacing and density regulations in the state. In 2010, the commission set up 1280-acre drilling units or one well per two 640-acre sections as the standard. Since then, some companies have been allowed to drill on tighter 640-acre spacing. Some have recently downspaced to two wells per section or 320-acre spacing.

One large operator plans to experiment with 160-acre patterns. The Bakken technology play, using horizontal drilling and multi-stage hydraulic fracturing, is only six years old. Despite a push to downspace, industry doesn't fully understand how productive and profitable original and infill wells will be over the full life cycle.

## Ryder Scott analysis

To analyze Bakken infill drilling schemes, the Ryder Scott Denver office evaluated the effects of spacing on EURs and interference. Well-to-well interference is caused, for instance, when a new infill well, drilled between two existing wells, intercepts oil flowing toward those wells thus reducing their productivity and ultimate recoveries.

The firm also analyzed the effects of economics on optimal spacing and pace of development on economics. The Denver office has developed a "mega" database with thousands of producing wells in the play to generate high-confidence reserves estimates. See March 2011 *Reservoir Solutions* newsletter, Page 2.

**Steve Gardner**, vice president and petroleum engineer, examined infill issues by simulating several well layouts representing typical fractured horizontal wells in the Bakken formation.

He based the economic parameters on general knowledge and experience in the play. Reservoir input parameters, held constant throughout the analysis, were as follows: 1280-acre area, 45 ft of net pay, 422 x 211 x 1 grid size of the

***Please see Bakken on Page 3***

# Engineer and evaluator join RS, others promoted

Hurtado

Siyatskiy

A petroleum engineer and reserves evaluator recently joined Ryder Scott. **Dainee Hurtado** is a reservoir engineer in the Houston office. She has 10 years experience as a reservoir engineer and previously worked as a contractor at Ryder Scott.

Before that, Hurtado was a reservoir engineer at RPS Scotia for three years where she concentrated on improving production and optimizing asset values in EOR projects. She prepared reservoir assessments for heavy oil and gas fields in Texas, Mexico, Argentina and Colombia.

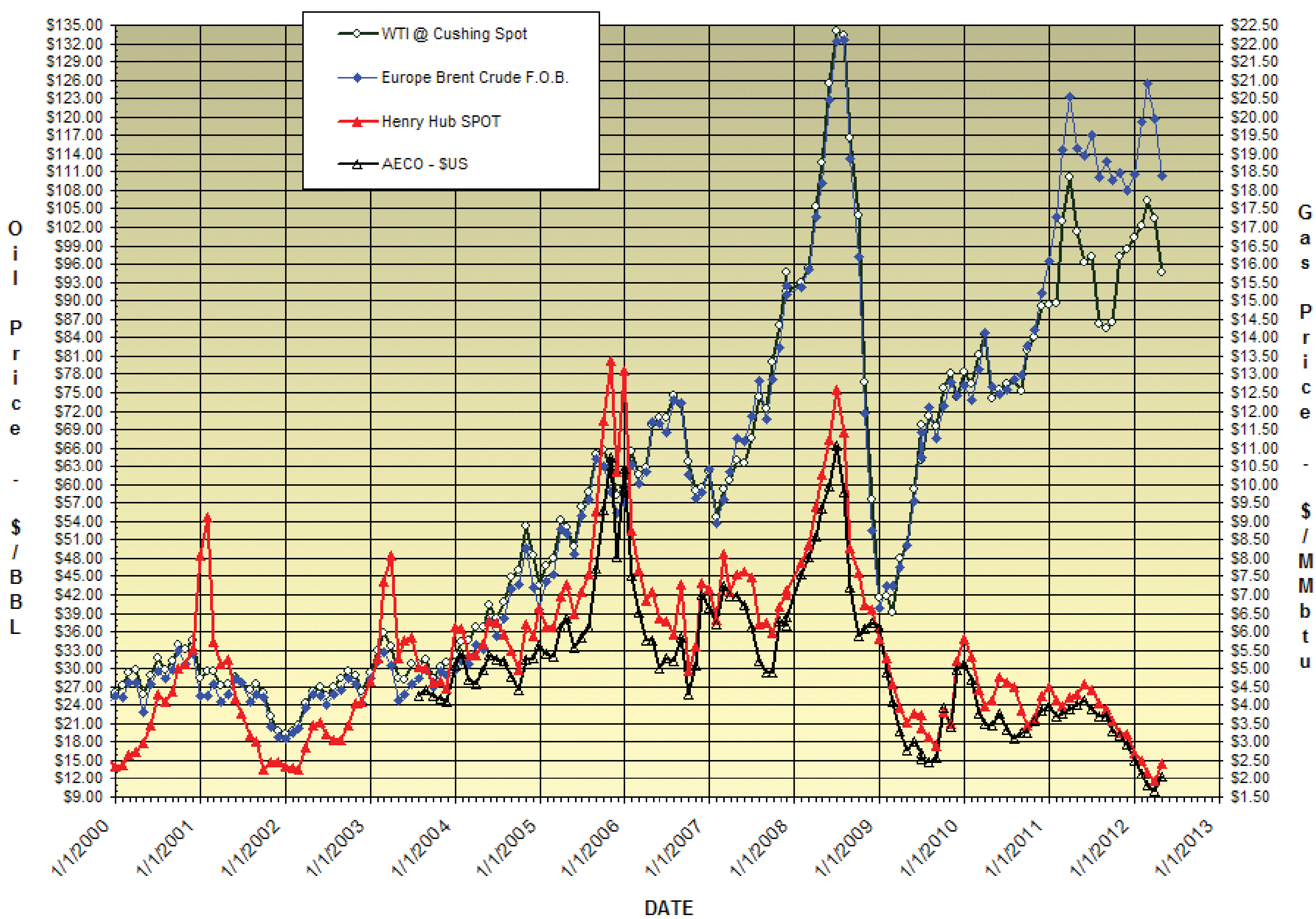
Hurtado was a reservoir development engineer at Petroleos de Venezuela SA from 1995 to 2003. She evaluated and managed mature heavy oil reservoirs under waterflood and the completion of injectors and producers. Hurtado identified and implemented infill drilling opportunities. She analyzed production performance data and recommended procedures to improve well performance.

Hurtado focused on field development for exploiting complex reservoirs in the Lake Maracaibo area of Venezuela and analyzed potential development opportunities for the Santa Rosa gas field also in Venezuela. She has a BS degree in petroleum engineering from Zulia University in Venezuela.

**Anton M. Siyatskiy** joined the Calgary office as a

*Please see Siyatskiy on Page 8*

## Price history of benchmark oil and gas in U.S. dollars




Published, monthly-average, cash market prices for WTI crude at Cushing (NYMEX), Brent crude and Henry Hub and AECO gas.

***Bakken—Cont. from Page 1***

cells, 8.4 percent porosity, 35 percent water saturation, 16.1 MMBO of OOIP, 6,900 psi initial reservoir pressure, 1,000 psi FBHP and initial rate of 1,100 bfpd. The following results are presented on an unrisked basis.

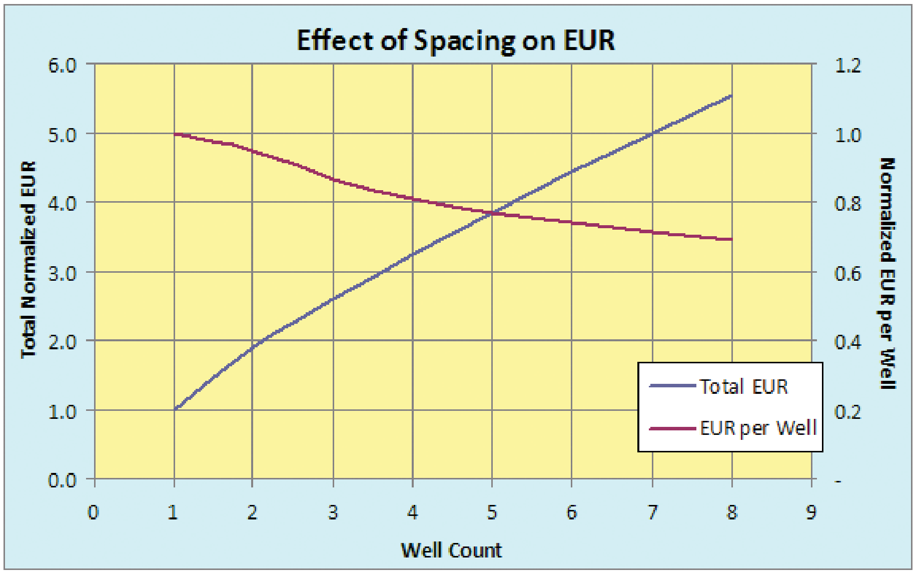



Figure 1. All laterals are equally spaced within a 1280-acre area running lengthwise and are drilled at time zero. The EUR for each well count is normalized by the volume recovered by the one-well scenario.

## Key Points: Spacing and EUR

- Total EUR for the 1280-acre area continues to increase over the range of simulated scenarios.
- EUR per well decreases as well count increases indicating varying levels of interference. For example, with four wells, each recovers approximately 80 percent of a single-well scenario while the total EUR is more than three times that of a single well.
- EUR alone is not sufficient to determine optimal spacing. Economics are required.

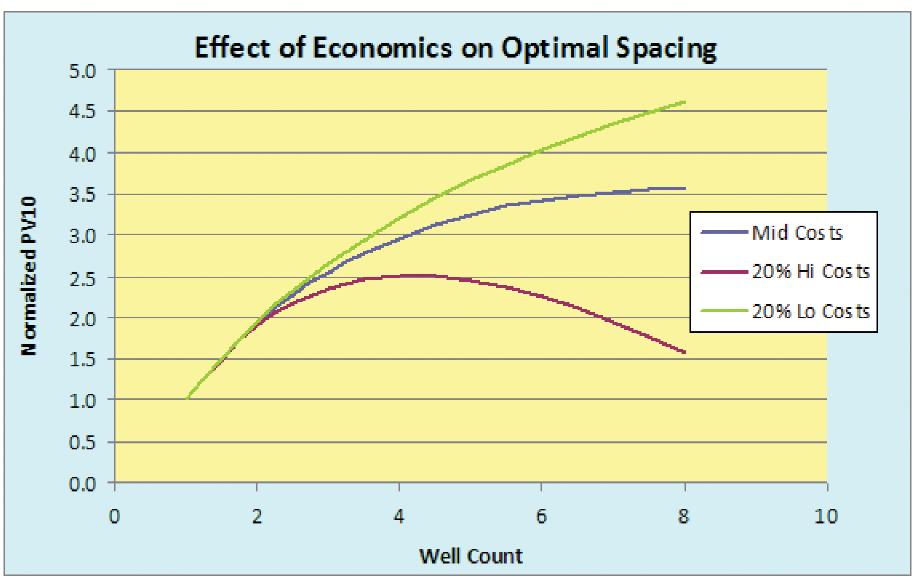



Figure 2. Sensitivity to economics was investigated by varying development and operating costs plus or minus 20 percent. Similar sensitivities could include changing product prices. The PV10 for each well count is normalized by the PV10 of the one-well scenario. As in Figure 1, all laterals are equally spaced within a 1280-acre area and are drilled at time zero.

## Key Points: Economics, spacing

- Economics degrade with increasing well density. Higher well density can still be profitable, but provides less "bang for the buck."
- The optimal PV10 (peak of the curve) is highly dependent on economic input parameters. For this study, Ryder Scott did not evaluate completion efficiency related to lower or higher initial rates, which can drastically affect PV10 and optimal spacing.
- Over the range shown, results are more sensitive to increasing costs vs. decreasing.

***Please see Bakken on Page 4***

# Rietz to present at SPE event in London

"Reserves: Where commercial and technical interests unite" will be presented by **Dean Rietz**, managing senior vice president at Ryder Scott, on June 27 at the Society of Petroleum Engineers London First Annual Conference and Exhibition. The two-day event at Savoy Place focuses on managing risk and adding value throughout the upstream oil and gas life cycle

Rietz will summarize the concept of reserves and why all aspects of the oil and gas industry rely on sound reserves estimates. Emphasis will be placed on the inherent uncertainty associated with estimating reserves as well as facets built into the process to address risks associated with recovery.

Next, comparisons will be made to point out the similarities and differences between the main standards (definitions) used to quantify reserves throughout the world. Finally, discussion will be directed to addressing some of the subtle but important nuances in obtaining reliable estimates.

The presentation is posted at www.ryderscott/Presentations/index.php.

***Bakken—Cont. from Page 3***

| Internal Economic Hurdles | | | | | |
|---|---|---|---|---|---|
| Well Count | Norm. F&D Cost | Norm. PV10 | Norm. PV15 | Norm. PV20 | Norm. PV25 |
| 1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 2 | 1.05 | 1.93 | 1.96 | 1.97 | 1.98 |
| 3 | 1.15 | 2.56 | 2.64 | 2.68 | 2.71 |
| 4 | 1.23 | 2.97 | 3.08 | 3.13 | 3.13 |
| 5 | 1.30 | 3.24 | 3.34 | 3.35 | 3.28 |
| 6 | 1.35 | 3.42 | 3.47 | 3.41 | 3.23 |
| 7 | 1.40 | 3.53 | 3.51 | 3.35 | 3.02 |
| 8 | 1.44 | 3.57 | 3.48 | 3.20 | 2.69 |

Table 1. Two examples of types of internal economic criteria are shown: Finding-and-development costs and returns. Peak returns are highlighted in yellow. The PV10 peaks in the eight-well scenario. The F&D cost for each well count is normalized by the F&D cost per barrel for the one-well scenario. Similarly, the present value per barrel for each well count is normalized by the PV per barrel of the one-well scenario. As before, all laterals are equally spaced within a 1280-acre area and are drilled at time zero.

## Key points: Internal Economic Hurdles

- Selection of the optimal well density depends upon any given company's particular internal economic hurdles. (Any number of criteria could be shown. These are only examples.)
- F&D costs per incremental volume increase with well count because each additional well has fewer incremental reserves.
- As the hurdle rate increases, the optimum well density, i.e. peak return, highlighted in yellow, decreases.

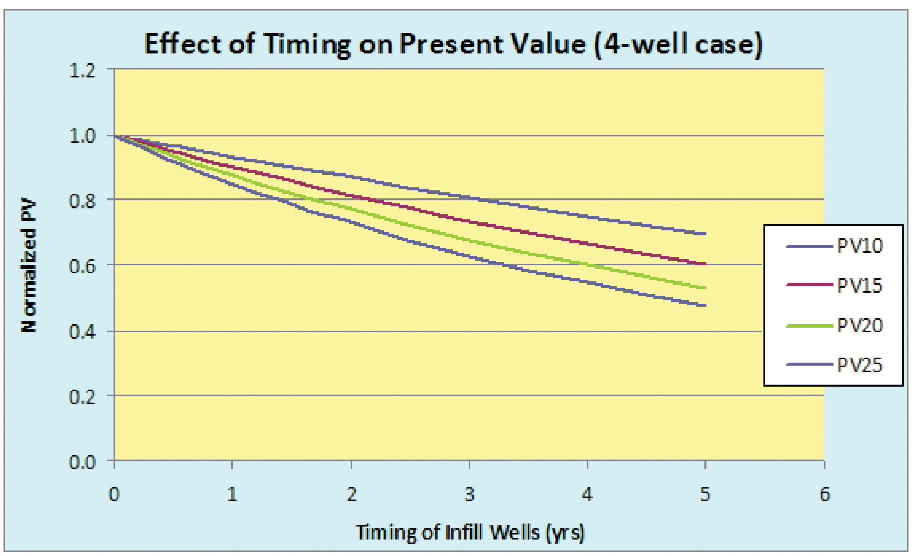



Figure 3. Often the initial well is drilled to hold the lease and infill wells are added later. Here the four-well scenario was run with the first well drilled at time zero and with the three infills all added simultaneously at a future time. The PV for each delayed scenario is normalized by the PV of the four-well scenario at time zero. As before, all laterals are equally spaced within a 1280-acre area.

## Key Points: Pace of development and economics

- Even after a development spacing plan is selected, project economics are affected by the pace of development.
- As one might expect, the degradation of economics is more pronounced at higher hurdle rates.

"Optimum spacing density is largely a question of economics." —Gardner

Gardner

## Conclusions

- Optimum spacing density is largely a question of economics. Overall EURs for a 1280-acre area generally increase with downspacing but incremental recoveries decrease with each infill because of interference.
- Optimum spacing density depends on reservoir quality, local cost and price environment and internal economic criteria.
- Even after development spacing is planned, the pace of development still needs to be factored into project economics.
- Optimum spacing density varies depending on assumptions in a given model and economic parameters. In this model, if development and operating costs exceed the base-case (mid) costs by 20 percent, then four wells per 1280 acres is an optimum case for maximum cash flows discounted at 10 percent per year. Using a base-case cost scenario, 160-acre spacing is optimum.

In practice, optimum densities vary widely for the 200,000-square-mile, heterogeneous Bakken formation. No one size spacing plan fits all.

For more information, please e-mail Gardner at steve_gardner@ryderscott.com.

*Editor's Note: The results of the Ryder Scott simulation presented herein are highly dependent on models and assumptions, which do not necessarily approximate the specific circumstances of a particular area or operator. The conclusions of the simulation study are intended for instructive purposes only and are not directly applicable to specific projects.*

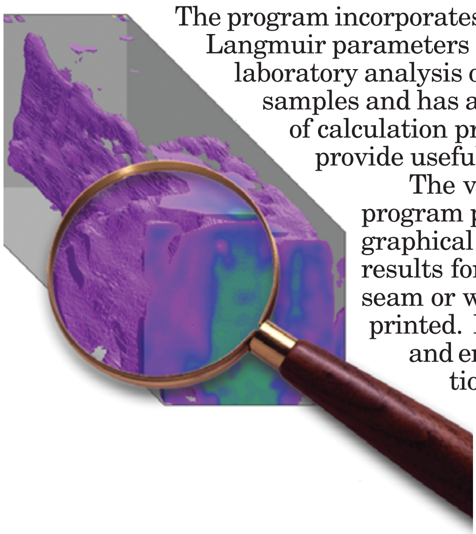
# New versions of Ryder Scott add-in applications for Excel rolled out as latest freeware offering on website

Ryder Scott released the latest Microsoft Office 2010-compatible versions of its Reservoir Solutions freeware programs on its website at www.ryderscott.com/Software/RS-Downloads. The petroleum engineering and geoscience add-in applications for Microsoft Excel are used in more than 80 countries by an estimated 10,000 users.

The new versions are compatible with all versions of Excel released after Excel 97, and include for the first time, versions written in native file formats for Excel 2007/2010, including 64-bit versions. This latest iteration of Reservoir Solutions software incorporates two complete versions—one for Excel 2003 and earlier and the other for Excel 2007/2010.

The following summaries describe the capabilities and functions of each spreadsheet application.

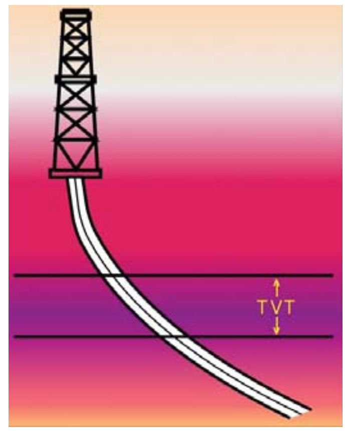
The **rscCBM** program provides the user with versatile coalbed methane volumetrics analysis tools.



The program incorporates standard Langmuir parameters obtained from laboratory analysis of coalbed core samples and has a feature-rich set of calculation procedures to provide useful, reliable results.

The volumetrics program presents a graphical representation of results for each zone, seam or well, which can be printed. Data validation and enhanced navigation are used extensively. In each case where calculated results are anticipated in the program, the user may optionally override such calculations. Those changes will be evident to the user by a change in background color. That is especially important when no lab data is available and calculations are entered manually rather than basing them on Langmuir parameters.

The templates in rscCBM are large by design and use "frozen panes" to facilitate data entry and visualization of graphical results. That could create difficulties for users with low-resolution graphics displays. To compensate, the program automatically detects the user's display settings to set or eliminate frozen panes.




**TruVert 2-D** provides a sophisticated calculation procedure to determine true vertical thickness (TVT) and net pay in deviated wellbores that penetrate dipping reservoirs. While the computation procedures are relatively simple, manual TVT calculations can be very time consuming and often confusing. With TruVert 2-D, the user enters measured-depth log data, either measured or subsea contact depths and standard directional survey data for rapid, accurate calculation results.

TruVert 2-D enables the advanced user to emulate heterogeneous reservoir stratigraphy, providing net pay calculations by phase. As a bonus, TruVert 2-D incorporates Excel's versatile graphics-handling capabilities to provide the energy professional with printer-friendly, hard-copy output of individual reservoir geometry.

**RyVOL** facilitates the preparation of volumetric reserves estimates for oil and gas wells and reservoirs. The menu-driven program provides templates for either oil or gas reservoirs and allows the user to determine such fluid and reservoir properties as gas deviation factors, pseudocritical temperatures and pressures, oil- and gas-formation volume factors and calculated solution gas-oil ratios.

Volumetric in-place and recoverable reserves are based on user input for reservoir volumes and recovery factors. Secondary product recovery is calculated either as a percentage of product in-place or as a ratio relative to primary product. RyVOL works with the Reservoir Solutions Modules freeware program.

**Reservoir Gas Analysis Software** (ResGAS) computes critical pressures and temperatures and specific gravities and heating values of a gas stream. The application works with the Reservoir Solutions Modules program.

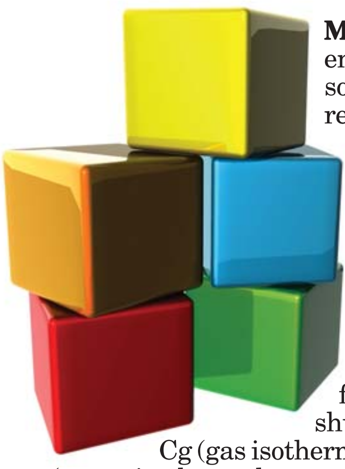
The computation of gas properties

*Please see ResGas on Page 6*

*ResGas—Cont. from Page 5*

includes corrections for contaminants and adjustments for condensate content. ResGAS also calculates wet gas in place and recoverable wet-, dry- and sales-gas volumes as well as recoverable condensate volumes.

ResGAS computes the estimated recovery of propane, butane and sulfur and approximates the BTU content of separator and gas sales. A user must enter separator-gas component percentages derived from laboratory analysis and other data input, including well and reservoir parameters and recovery factors.



**Reservoir Solutions Modules** 1.0 gives reservoir engineers the capabilities to solve common problems requiring the calculation of oil and fluid properties, such as pseudocritical properties, compressibilities and formation-volume factors. Included in the program are functions for calculating Tc (pseudocritical temperature), Pc (pseudocritical pressure), Z factor (real gas deviation), shut-in bottomhole pressure, Cg (gas isothermal compressibility), Cw (water isothermal compressibility), Co (oil isothermal compressibility), Bo (oil formation volume factor) and Bg (gas formation volume factor).

**QuickLook** economics evaluation software gives the user a simple, fast tool to compute screening economics for prospects, evaluate workovers and recompletions and run preliminary lending economics. The user can run complete reserves and cashflow projections for individual wells or properties.

QuickLook computes up to four distinct product streams, two oil and two gas, and secondary product streams based on gas-oil ratios or condensate yields. The program provides options for exponential, hyperbolic, harmonic and manual product projections. A user can also subtract or add together streams. QuickLook also has multiple expense, tax and investment-parameter options as well as a provision for abandonment costs.

The **Material Balance** application automatically calculates original gas in place (OGIP), estimated ultimate recovery (EUR), BHP/Z vs. cumulative gas production and Tc and Pc properties from gas gravity while adjusting for contaminants. Using the popular Cullender-Smith (1956) method as modified by Ryder Scott, the utility software also predicts shut-in bottomhole pressures from tubing pressures in gas wells.

With the **Flowing Pressure Analysis** program, a user can evaluate the performance of producing gas or gas-injection wells. The program enables the user to calculate flowing bottomhole pressures (FBHP) for gas wells. The application also automatically computes associated backpressure equation parameters and displays a traditional log-log backpressure curve at the user's option.

For producing wells, absolute open flow (AOF) potential is also calculated. Static bottomhole pressure (SIBHP) can be determined from shut-in tubing pressure (SITP). The application integrates techniques derived from Cullender-Smith and Turner, Hubbard and Dukler (1969). Ryder Scott modified those algorithms for today's high-speed computers.


With **LogWizard**, a user analyzes density-neutron or sonic logs using either of two templates and calculates the following petrophysical values based on user-selected methods:

- Shale content—Applicable to consolidated and unconsolidated formations
- Total porosity—Uses arithmetic-average or sum-of-squares method
- Effective porosity—Uses arithmetic-average or sum-of-squares method
- Formation water saturation—Solves using Archie or modified Simandoux algorithms

For sonic logs, the program template uses interval transit time to calculate uncorrected sonic and effective porosities. For water-saturation and shale-content computations, LogWizard includes visual basic functions that can be exported or linked to other Excel applications.

Based on user-selected criteria, LogWizard calculates gross reservoir sand thickness and net pay thickness as well as average porosities and water saturations for pay sections. The program also incorporates an Rw calculator to assist users in computing formation water resistivity from log data. The template also contains areas for entering core data or notes.

**RamBal** is an easy-to-use, Excel-based tool for material balance calculations to help predict future performance of abnormally pressured, unconventional gas fields. The algorithm compensates for reservoir rock and water compressibility in determining both OGIP and recoverable reserves and accounts for finite downdip free water expansion. The program requires

*Please see Rambal on Page 7*

# Following proper well-testing guidelines assures that key data is valid and available for reserves evaluations

Oetama

Before conducting well tests, knowing more about what procedures and types of data are needed for reserves evaluations helps in planning. Oil and gas companies don't want to sadly lack key information after testing.

**Teddy Oetama**, senior petroleum engineer, provides well test design, analysis and supervision for companies needing expert assistance.

General guidelines for testing a well are as follows:

1. Estimate reservoir and fluid properties, i.e., pressure, temperature, net pay, porosity, water saturation, permeability, FVF, viscosity and compressibility.
2. Conduct geological interpretations to determine possible flow boundaries, either stratigraphic or structural.
3. Make sure that test (flow) time duration is long enough to scan the reservoir for predetermined areas of investigation and anticipated flow boundaries, if any.
4. If pressure buildup is conducted, shut-in duration should be approximately the same as the flow time. A buildup test is preferred to drawdown, because it provides better reservoir characterizations.
5. Minimize wellbore storage by testing with packers, tubing and a downhole shut-in tool.
6. Install downhole pressure and temperature gauges in the tail pipe section below packer. Electronic gauges are preferred to mechanical ones.
7. The gauges should be able to handle anticipated maximum pressure and temperature.
8. The gauge clock time should be long enough for the anticipated test duration.
9. Have surface surveillance to monitor downhole pressure over time.
10. Clean up the well to recover wellbore fluid and mud filtrate.
11. Test the well from lower to upper intervals sequentially.
12. Continuously monitor and record pressure and fluid rates over time.
13. Strive to have a constant and sustainable rate for considerable long duration in days preferably.

Once the test is completed, flow the well with the lowest possible rate. When the rate is stabilized, conduct fluid sampling. Bottomhole fluid sampling is preferred. Otherwise conduct surface sampling. Measure fluid rates accurately during sampling.

For more information, contact Oetama at teddy_oetama@ryderscott.com.

# Public sources for oil and gas pricing data are handy for use in estimating petroleum reserves and cashflow profiles

Ryder Scott uses benchmark pricing data from the following public sources as a start in determining oil and gas pricing used in reserves reports.

- **WTI Cushing crude oil spot price** —Wall Street Journal web page: http://online.wsj.com/mdc/public/page/2_3023-cashprices.html?mod=mdc_pastcalendar
- **Brent crude spot price** —U.S. EIA web page: http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=D
- **Mont Belvieu propane spot price** —U.S. EIA web page: http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=eer_epllpa_pf4_y44mb_dpg&f=d
- **Plains All American Pipeline posted oil prices** —Plains web page: http://www.paalp.com/fw/main/Crude_Oil_Price_Bulletins-1363.html
- **Chevron California posted oil prices** —Chevron Crude Oil Marketing web page: http://crudemarketing.chevron.com/crude/north_american/bulletin_archive.aspx
- **Gas prices** —Natural Gas Intelligence (paid subscription): http://intelligencepress.com/

The firm makes no claims or warranties regarding the accuracy of information on those web sites. Users are encouraged to verify or confirm prices from other sources. Prices on those sites also do not reflect differentials.

**Fred Ziehe**, managing senior vice president, is an expert in oil and gas pricing. For more information, contact Ziehe at fred_ziehe@ryderscott.com.

*Rambal—Cont. from Page 5*

only commonly available reservoir pressures, temperature data and gas properties and includes "calculators" and tips to help experienced petroleum professionals assess appropriate compressibility coefficients as well as the conversion of separator gas components to reservoir (wet gas) conditions.

A user's manual is included in an Excel file accessible from the engineering menu. As is the case with all posted freeware, the material balance application produces presentation-quality, on-screen views and printer-friendly, hard-copy output.

Editor's Note: Ryder Scott does not guarantee or warrant the accuracy or reliability of the Reservoir Solutions software and disclaims its fitness for any particular purpose.

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***Siyatskiy—Cont. from Page 2***

reserves evaluator. He has more than seven years experience in Russia and the FSU in reservoir engineering and reserves evaluation in sandstone and carbonate oil and gas deposits. Siyatskiy also has broad experience in traditional reservoir engineering evaluation techniques such as decline-curve analysis, log and volumetric analysis, well-test analysis, material-balance calculations, PVT analysis and other reservoir engineering applications.

Previously, he worked at DeGolyer and MacNaughton as a reservoir engineer for four years. Siyatskiy conducted reserves audits for major oil and gas companies, such as Rosneft and GazpromNeft, in Russia. He estimated in-place hydrocarbons and reserves, analyzed field development plans and prepared production forecasts.

Before that Siyatskiy was a reservoir engineer at West Siberian Resources Ltd. He conducted hydrodynamic modeling, prepared production forecasts and mapped reservoirs. Siyatskiy also was a specialist in hydrodynamic modeling at Pechoraneft Co. He started at JSC Enconco in 2003 and became a reservoir engineer there in 2005. Siyatskiy has a bachelor's degree in reservoir engineering from Gubkin Russian State Oil and Gas University in Moscow.

The following Ryder Scott personnel were promoted to the following positions: **Mike Stell**, technical coordinator and advising senior vice president–enhanced recovery; **Jeff Wilson**, managing senior VP and group leader; **John Hanko**, senior VP–group coordinator; **Bruce Palmer**, VP–technical specialist; **Ryan Wilson**, VP–project coordinator; **Marylena Garcia**, **Hugo Ovalle**, **Ali Porbandarwala**, **Lucas Smith** and **Lehi Woodrome**, senior petroleum engineer; **Christine Neylon**, petroleum engineer; **Kosta Filis**, **Josh Posey** and **Chris Wagner**, engineering analyst; **Crystal Cao**, senior engineering technician and senior economist and **Claudia Oramas**, senior engineering technician.

# RS reserves conference set for Friday, September 14 at the Hyatt Regency

The 8th Annual Ryder Scott Reserves Conference will be held on Friday, Sept. 14 at the Hyatt Regency hotel in downtown Houston. Last year, more than 280 were in attendance at the one-day conference, making it the single largest gathering of senior reserves evaluators.

At press time, the agenda had not been set. For more information on the event, please email pam_leslie@ryderscott.com.

**Publisher's Statement**

*Reservoir Solutions* newsletter is published quarterly by Ryder Scott Co. LP. Established in 1937, the reservoir evaluation consulting firm performs hundreds of studies a year. Ryder Scott multidisciplinary studies incorporate geophysics, petrophysics, geology, petroleum engineering, reservoir simulation and economics. With 130 employees, including 90 engineers and geoscientists, Ryder Scott has the capability to complete the largest, most complex reservoir-evaluation projects in a timely manner.



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