PRE-CALCULATED, PROPRIETARY EUR DATA BASE FROM DRILLINGINFO

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WHITE PAPER
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Executive Summary

Calculation of Estimated Ultimate Recovery (EUR) at the well level is important in analyzing productivity of wells, reservoirs, and leases, as well as understanding and benchmarking operator performance. However, calculating EURs for every well using Decline Curve Analysis (DCA) and updating these values as new well production values are reported is cumbersome, computationally intensive, and highly time consuming when done manually.

Using the internal DCA engine housed within the Drillinginfo web app along with the upcoming release of DI Transform v5.2, Drillinginfo provides a comprehensive and unbiased database of pre-calculated EURs. These EURs are updated regularly as new production information becomes available. They can now be directly used within the various Drillinginfo platforms for analysis of operators, leases, or an area of interest. EURs are delivered monthly through DI Desktop, the Drillinginfo web app, DI Analytics and DI Engineering Explorer.

Introduction

The pre-calculated EURs are referred to as "technically recoverable reserves," as they are solely based on historical production volumes reported to state and federal agencies. No economics are considered (i.e. taxes, capital expenses, operator expenses, oil & gas prices), no completion or operational data are considered (i.e. lateral lengths, various well events), and currently, no analogs are considered for calculating forecasts.

EURs are provided for applicable active entities in the Drillinginfo database. An "entity" is defined as the level at which production is reported for an individual historical stream of production. This level varies due to the reporting procedures enforced by each state agency. Based on this, production could be reported at the zone, well, lease, unit, field, or block levels, depending on the state and country. In some states, which do not exclusively report at the well/zone level, well header information allows a mapping between wells and lease/unit level production permitting the production to be allocated amongst the wells. For example, Texas, Louisiana and Oklahoma have wells that report lease-level production. The processor is not state-specific, meaning every entity is forecasted by the processor if its production stream is eligible for forecasting.

Methodology

The Drillinginfo DCA engine provides automatic curve fitting as well as detection of multiple decline segments and production outliers. The model fit is performed using a constrained non-linear solver (modified Levenberg-Marquardt) that seeks to minimize the sum of the squared errors between the model prediction and actual production values. Missing and zero production values are not used in the model fitting.

Although the Drillinginfo DCA engine has multiple model types available (e.g., stretched exponential, logistic growth, power law), in the first release, Drillinginfo uses the Arps decline curve model to forecast EURs for all entities. The Arps formulation is the most commonly and traditionally used decline curve type for well performance and prediction modeling.

THESE EURS ARE UPDATED REGULARLY as new production information becomes available.

Arps Model

The Arps decline curve model has been in use since the 1940s and follows the equations of J.J. Arps.[1] These include exponential, hyperbolic, and harmonic decline equations. The Arps equation relates the models using three parameters to provide a prediction of production rate at a specific time.

$$q = q_i e^{-D_i t}$$

Arps Exponential Decline Model

$$q = \frac{q_i}{(1+bD_i t)^{\frac{1}{b}}}$$

Arps Hyperbolic Decline Model

Parameters:

- ***qi*** Initial production rate (monthly IPmax)
- ***D_i*** Initial decline rate (Nominal Decline rate)
- ***b*** Hyperbolic exponent, also called the b-factor controlling decline degradation (shape factor)
- ***t*** Time (month)

Modified Hyperbolic Arps Model

The modified hyperbolic decline method uses both the Arps hyperbolic and exponential decline models, switching between them at a given terminal decline rate. The terminal decline rate (D_{term}) is assumed as 5% in the first release. Using this method results in finite EUR predictions because the exponential model forces the production rate to eventually go to 0.

$$q = \frac{q_i}{(1+bD_i t)^{\frac{1}{b}}}$$

Decline changes from hyperbolic to exponential.

Parameters:

- ***D_{term}*** terminal decline rate
- ***D_i*** initial decline rate

The main steps followed in calculation of EUR are summarized below:

When production data arrive from the governing agency, they are loaded into the Drillinginfo ingestion database.

- The production stream is analyzed and a 'last 12 month GOR' value is calculated to assign a primary product to the entity. Forecast is calculated only for the primary product, while EUR of the secondary product is based on the calculated GOR. This calculation is discussed in detail in the next section.
- The model also checks to see if the production stream has more than six months of overall declining production and only estimates reserves if this criterion is met. This is done to provide reasonable production forecasts. Using a shorter amount of production data can lead to unreasonable forecasts due to the limitation of the Arps model in forecasting early-time data in unconventional wells.
- In case of inclining production, any months prior to the month of maximum production are linearly interpolated from that maximum. This is not used in the calculation of production forecast for the entity.
- Using the Arps equation, the Drillinginfo DCA engine solves for the most appropriate model parameters (*qi*, D_i, *b*) which minimize the sum of squared errors to the actual production values. The algorithm constrains the ranges of values these parameters may have. For example, *b*-factor is constrained between 0 and 2.
- Drillinginfo provides two types of fit to the production data—full-fit and segmented-fit solutions. In a full-fit solution, the entire production stream is considered in calculation of the EUR. In a segmented-fit solution, the latest time segment is used for forecasting and calculation of EUR. Drillinginfo provides fit parameters and EUR values for both types of solutions. These two fit types are explained in detail in the following sections.

Forecast Settings

The definitions below list the assumptions and the values provided to the DCA engine. Currently, all entities use the same values for each of these parameters:

- **Termination Rate (Q_{limit})**—The rate at which the product/phase becomes

1. Arps, J.J.: *Analysis of Decline Curves,* Trans. AIME, 160, 228-247, 1945.

uneconomical. When a forecast hits this rate, it stops.

- **Oil = 1 Bbl/day**
- **Gas = 25 MCF/day**
- **Forecast Time Limit = 50 years**—This value determines the maximum year to which the forecast created by the fit calculation will run should it not reach the Termination Rate (Q_{limit}) at an earlier time.
- **Terminal Decline/Transition rate = 0.05 (nominal)**—Once the slope of a harmonic or hyperbolic decline reaches this value, the decline will transition into an exponential decline. The DCA methodology employed here is that of 'Modified Hyperbolic'.
- **b-factor bounds**—The upper and lower bounds on the exponent that will be allowed on a decline fit are min = 0 and max = 2.0.
- **'Goodness of Fit' test**—The model calculates quality of fit based on standard and rank correlation coefficients between the model and actual production values. If either of these values are negative, EUR values are not provided for these entities and are set to Null. This test is done to provide quality EURs. **Figure 1** is an example of a production stream for which a decline curve solution was derived. However, correlation between the predicted production values from the model with the actual reported production is insufficient to warrant EUR forecasting (standard correlation = -0.361 and rank correlation = -0.164).
- **Inactive or Plugged and Abandoned well status**—If the well status is not 'Active', EUR is set to the cumulative volume reported till date for that well.

Additional information on the parameters and settings described in the previous sections, are discussed in detail below.

Gas to Oil Ratio (GOR) Calculation

If an entity produces both oil and gas, they are not forecasted separately. The methodology used for forecasting oil vs. gas is as follows:

1. Calculate GOR using the last 12-month gas cumulative volume divided by last 12-month oil cumulative volume. This value is calculated every time an entity's production history changes. Recalculating GOR each time new production is reported allows the forecast to adjust as GOR changes through time.
2. Identify the primary product/phase using GOR:
    a. If GOR > 20,000 CF/BBL, then the primary product is gas.
    b. Else, the primary product is oil.
3. Calculate the Remaining Recoverable Reserves (RRR) of the primary product. Then apply GOR to the RRR to estimate the non-primary product's forecast:
    a. If Primary Product = gas:
        i. Gas EUR = Cum Gas + Gas RRR
        ii. Oil EUR = Cum Oil + (1/GOR * Gas RRR)
    b. If Primary Product = oil:
        i. Oil EUR = Cum Oil + Oil RRR
        ii. Gas EUR = Cum Gas + (GOR * Oil RRR)

Segmented-Fit vs. Full-Fit Solutions

Identification of possible change in decline curve behavior (i.e., a new segment) is performed by analyzing changing statistics in the normalized residuals between model and actual production values. A normalized residual is the difference between the actual production value and the predicted value of the current model divided by the predicted value. The initial current model is the full-fit model. A z-score for a given month is then defined as the normalized residual value minus the running average divided by the running standard deviation of normalized residuals. If the z-score exceeds a specified threshold, it suggests the start of a candidate new segment. The default threshold is 3. A new segment must include a series of at least five production values.

The DCA engine is instructed to fit the entire production history or segment the production into trends and determine the best trend to be used in the forecast. The following examples employ the same production stream with both types of fits applied and describe its effect on the decline parameters.

The production stream for the well shown in **Figure 2**, illustrates a smooth behavior of declining production over time. The Arps model fit for this stream has the parameters values of 22,601 Bbl for *qi*, 0.716 for D_i and 2.0 for the *b*-factor. Because no segmentation was identified for the full-fit and segmented-fit solutions, both fits give the same forecasted EUR of 341,934 Bbl. The next example shows very different results for full and segmented-fit solutions.

In **Figure 3**, it is obvious the nature of the production trend radically changes in late 2014. The full-fit model has the parameters of 4677 Bbl, 0.0183, and 1.947 for *qi*, D_i, and *b*. Outlier analysis has identified the production values indicated as red dots as outside the threshold specified. Note these are the much larger production values that appear to constitute a new decline segment. The green dot along the model line denotes where the model changes to exponential terminal decline (default rate is 5% or 0.05). The EUR for this full-fit model is 669,619 Bbl.

The segmented-fit for the production stream in **Figure 4** has identified three decline curve segments. There is a minor change to the primary decline in late 2011 as well as the expected significant change in late 2014. Note only two outliers were detected using the multi-segment model, shown in red. Consequently, the last time segment is used for calculating EUR. It has the following parameter values: 27,092 Bbl, 0.486, 1.495 and 531,622 Bbl for *qi*, D_i, *b* and EUR. The segmented-fit solution predicts 138,000 Bbl less than the full-fit ultimate recovery.

Outlier Detection

Automatic detection of outliers works in an analogous way to the new segment detection. Outliers are distinguished from new segments based on the direction of the deviation and whether potential outliers follow a sequence consistent with a new segment. The default threshold is similarly set to 3.

Forecast Parameter Definitions

The data column names are labeled appropriately to reflect if the data is from a segmented or full-fit solution.

In the Drillinginfo web app, DI Analytics, and DI Engineering Explorer, Oil EUR and Gas EUR values refer to the segmented-fit Oil EUR and segmented-fit Gas EUR respectively.

In DI Desktop exports, segmented-fit column names begin with “BE_” while full-fit column names begin with “FULL_”. Historical forecast parameter values are not presented in the Drillinginfo platforms. Only the delta difference between the current and last EURs is presented in DI Desktop. DI Desktop column names are explained in detail below.

Segmented-Fit Forecast Parameters	
EUR_PRIMARY_PROD-UCT	The primary product (OIL or GAS) determined by the forecast process based on gas-to-oil ratio (GOR).
EUR_CALC_DATE	The date on which the Drillinginfo engine processed this entity.
BE_OIL_EUR	Segmented-fit Oil Estimated Ultimate Recovery. Default aggregation method = sum. (Unit: Bbl)
BE_GAS_EUR	Segmented-fit Gas Estimated Ultimate Recovery. Default aggregation method = sum. (Unit: Mscf)
BE_OIL_DELTA_EUR	The difference (in barrels - BBL) between the last two oil EURs for segmented-fit.
BE_OIL_DELTA_EUR_PCT	The difference (as a percentage) between the last two oil EURs for segmented-fit.
BE_GAS_DELTA_EUR	The difference (in MCF) between the last two gas EURs for segmented-fit.
BE_GAS_DELTA_EUR_PCT	The difference (as a percentage) between the last two gas EURs for segmented-fit.
BE_B_FACTOR	This is the b-factor, or "hyperbolic exponent" for the segmented-fit trend, not the full production history.
BE_INITIAL_RATE	(Qi) Initial rate (BBL or MCF) of the primary product for the segmented-fit. Note this is the rate at the beginning of the segmented-fit trend, which is not necessarily the same as the rate at time zero (FIRST_LIQ or FIRST_GAS at FIRST_PROD_DATE).
BE_FINAL_RATE	Final rate (BBL or MCF) at termination date of primary product for the segmented-fit.
BE_END_DATE	Forecast termination date of primary product for the segmented-fit.
BE_INITIAL_DECLINE	Di: Initial decline of the primary product for the segmented-fit. Units are in effective secant. This is the initial decline of the segmented-fit trend, which is not necessarily the same as the rate at time zero. The initial decline at time zero is in FULL_INITIAL_DECLINE.
BE_OIL_RRR	Remaining/forecasted oil for the segmented-fit.
BE_GAS_RRR	Remaining/forecasted gas for the segmented-fit.

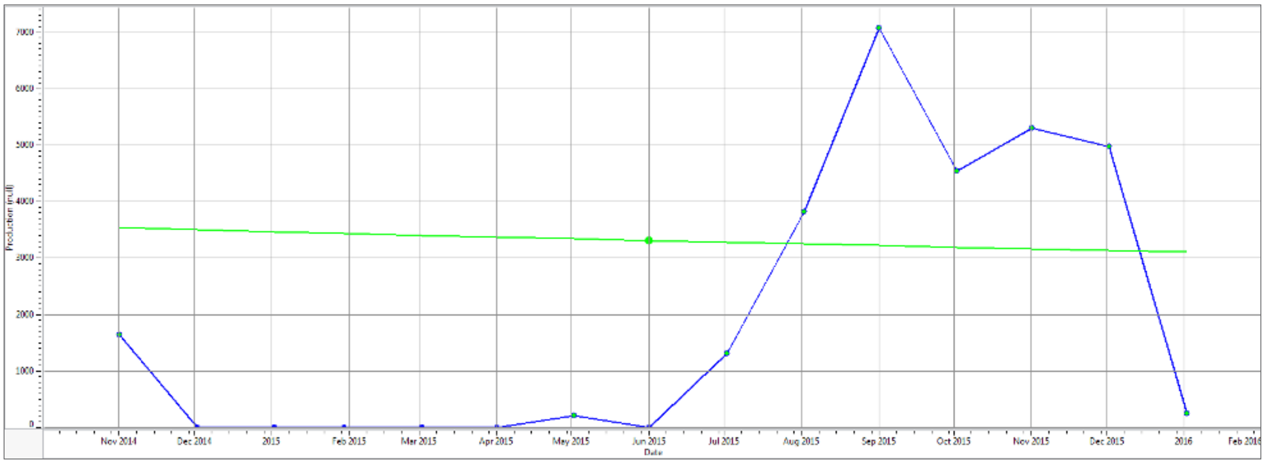
Full-Fit Forecast Parameters	
FULL_OIL_EUR	Full-Fit Oil Estimated Ultimate Recovery
FULL_GAS_EUR	Full-Fit Gas Estimated Ultimate Recovery
FULL_B_FACTOR	The b-factor for the entity, or "hyperbolic exponent". This is the b-factor for the full-fit trend (i.e. the b-factor which represents the entire production history). Default aggregation method = average.
FULL_FINAL_RATE	Qf: Final rate (BBL or MCF) at termination date of primary product for the full-fit. Initial rate for the entire production history is in the column named FIRST_LIQ or FIRST_GAS.
FULL_END_DATE	Forecast termination date of the primary product for the full-fit.
FULL_INITIAL_DECLINE	(Di) Initial decline of the primary product for the full-fit. Units are in effective secant. Default aggregation method = average.
FULL_OIL_RRR	Remaining/forecasted oil for the full-fit.
FULL_GAS_RRR	Remaining/forecasted gas for the full-fit.

Conclusion

Drillinginfo provides an unbiased, comprehensive database of pre-generated EURs and decline curve parameters for more than 90% of active entities. Both full-fit and segmented-fit EURs and their corresponding parameters are reported. This dataset will help save time and take away the cumbersome task of evaluating EURs at the well level, enabling faster evaluation of potential opportunities. Drillinginfo EURs are continuously updated and can be used for operator benchmarking studies and/or reservoir or well-level analysis.

Appendix

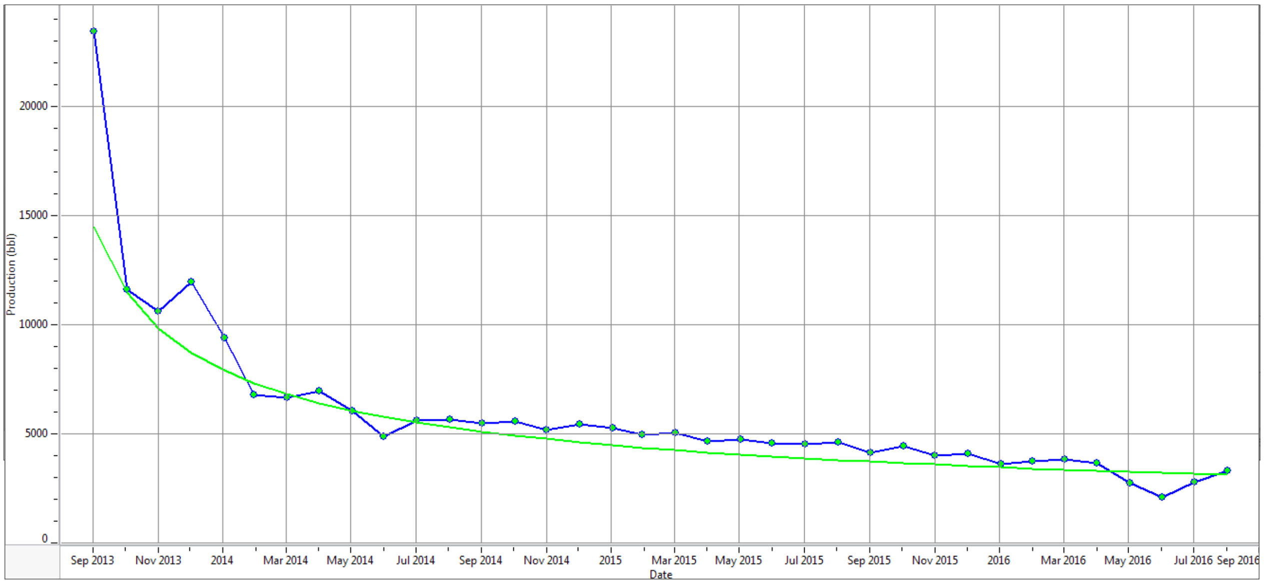
Figure 1



Production stream of an example well, where the ‘Goodness of Fit’ test fails and consequently, EUR is not reported for this well.

Appendix

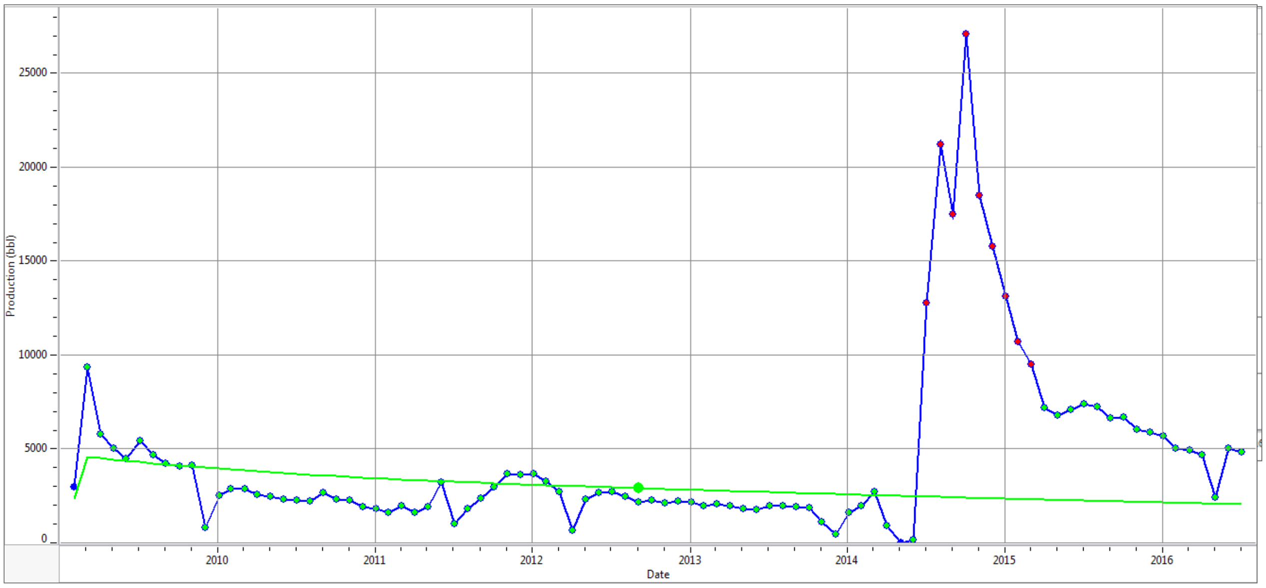
Figure 2



Production stream of an example well.

Appendix

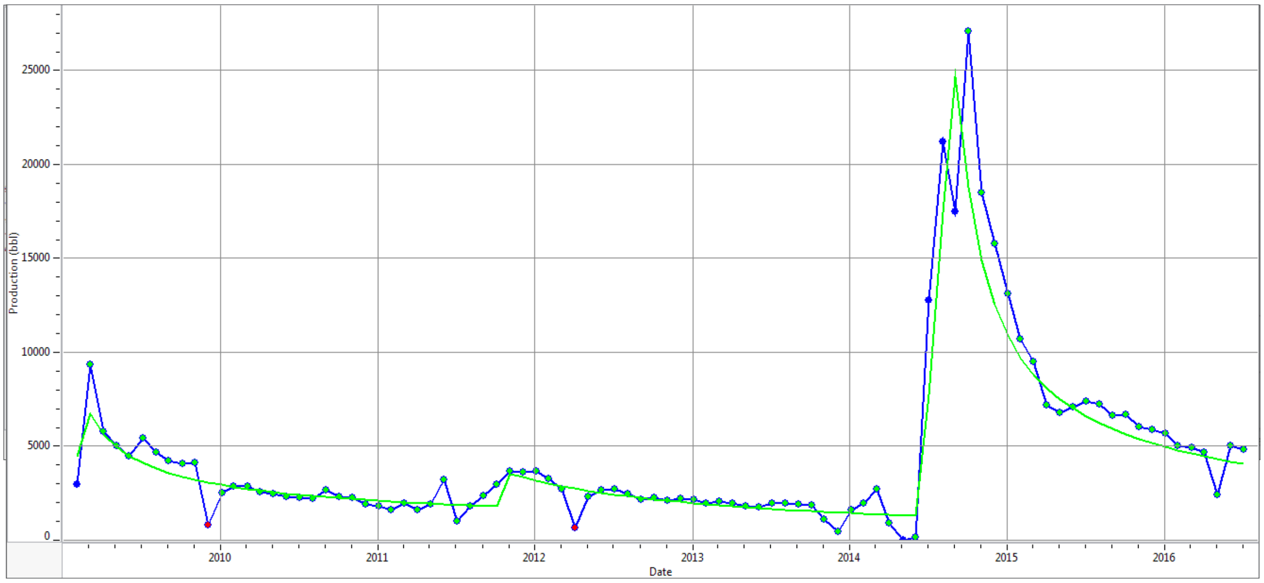
Figure 3



Production stream of an example well, where an obvious change in production is seen in late 2014.

Appendix

Figure 4



Segmented-fit solution shown for example well.