# A CASE STUDY THAT EXAMINES THE USE OF NODAL ANALYSIS IN PREDICTING THE MAGNITUDE OF THE IMPACT OF INFILL DRILLING ON A GAS GATHERING SYSTEM

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## ABSTRACT

Nodal analysis is an approach for modeling a system of components to determine the impact of changes to any component in that system. It is a tool typically employed to ensure production is maximized in individual producing wells. However, this tool can also be used to analyze pipeline systems to study the impact of changes in deliverability. This case study reviews the process used and the recommendations made from a nodal analysis that was performed to assess the impact on wells already producing into the same gas gathering system from the infill drilling of 13 additional wells.

The nodal analysis approach began by developing an inflow and outflow performance model for the existing wells and gas gathering system. Once this model was validated, a prediction was developed to determine the inflow and outflow performance over time to include the new wells to be drilled. This performance over time prediction was then used to evaluate the benefits of making changes to the existing gas gathering system. This paper provides a review of the nodal analysis process taken and a lookback to compare the actual performance to the predicted performance.

## INTRODUCTION

Nodal analysis is typically a tool to analyze wellbore deliverability as a function of artificial lift capacity. It can also be used to analyze pipeline systems for bottlenecks and other restrictions that may exist. The approach taken for this analysis follows these steps to help insure credible results:

1. Define the Node
2. Determine the Inflow Performance
3. Determine the Outflow Performance
4. Perform Nodal Analysis and Validate the results using actual data
5. Determine future inflow performance
6. Perform Nodal Analysis prediction of future performance
7. Validate the results using actual data
8. Evaluate options

## BACKGROUND

Development drilling of 13 wells on the 03A well pad was done in 2012. This well pad is next to the 03B well pad in which all wells have been on production for several years. Both well pads share a gas gathering system.

In early 2013, six (6) of the 13 wells were completed and brought online. The impact to the wells on the 03B well pad was an immediate line pressure increase of approximately 40 psi and an associated reduction in production of 0.6 MMCFPD (Figure 1). A concern was raised as to what the production impact would be after the remaining seven (7) wells on the 03A pad were completed.

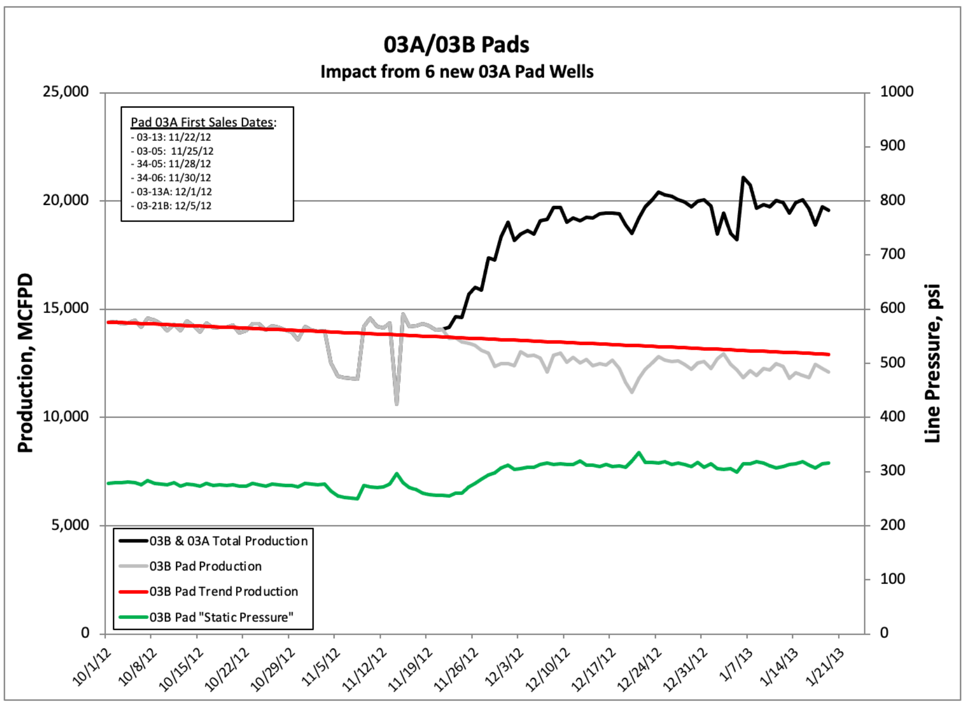


*Figure 1: Impact on Line Pressure from Production from 03A Pad Wells*

To address this observation, a model was developed, using nodal analysis, to predict the performance of the production and gas gathering system serving the 03A and 03B well pads. The purpose of this model was to predict the performance of the wells on the 03B well pad from the additional backpressure from the new 03A pad wells planned to be completed in late 2012 and early 2013.

## INFLOW PERFORMANCE PREDICTION

In any Nodal analysis, the definition of the node must be determined and used consistently throughout the analysis. For purposes of our evaluation the Node is defined at the inlet to the gas gathering line and the pressure and the flow in/out of this point is determined at the gas flow meter.

Inflow performance can be predicted by use of various methods as discussed in the literature[1]. In this evaluation, the inflow performance was determined using a “typical”

Inflow Performance curve developed from the existing wells on the 03A well pad using the Fetkovich method[2].

$Q_g = C(P_r^2 - P_{wf}^2)^n$; where

$Q_g$= Production rate, MCFPD

$C$ = reservoir constant

$P_r$ = Static Reservoir Pressure, psi

$P_{wf}$ = Producing Bottomhole Pressure, psi

$n$ = flow constant

The production rate can be determined for any producing pressure if the constants, C and n and the static reservoir pressure are known. Since we don't have measured data for these constants, Pressure/Performance forecasts were determined using Rate Transient Analysis methods and history matched for validation. From these forecasts, the constants and the initial static reservoir pressure could be inferred then validated with actual performance.

$Q_g = C(P_r^2 - P_{wf}^2)^n$; where

$C$ = 1.085 E-5 MCFPD/(psi$^2$)$^n$

$N$ = 0.76

Using these constants, the generic Inflow Performance model developed is shown in Figure 2. This generic model will be used for the existing wells on the 03B well pad and the new wells on the 03A pad. Validation of this model will be tested before the application of Nodal analysis for predictive performance.

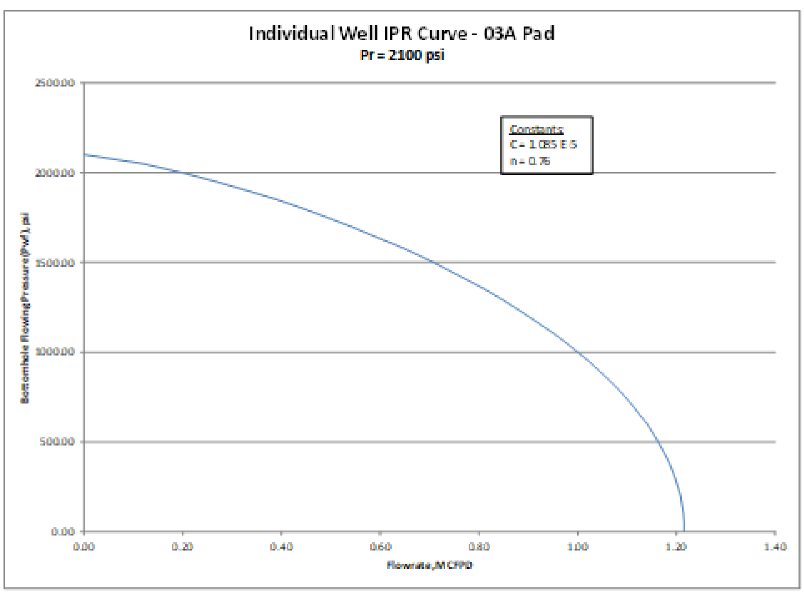


*Figure 2: Generic Inflow Performance Curve for 03A and 03B Pad Wells*

## OUTFLOW PERFORMANCE PREDICTION

The outflow performance is the flowrate through the gas gathering system as a function of the pressure at the node (line pressure). Performance data was available from historical production performance from wells on the 03B well pad coupled with corresponding data from the historical line pressures and the pressures at the compressor station inlet. A series of curves was developed using this data and is shown in Figure 3. As with the inflow performance curve, a validation process will take place to ensure this data is representative of the actual performance.

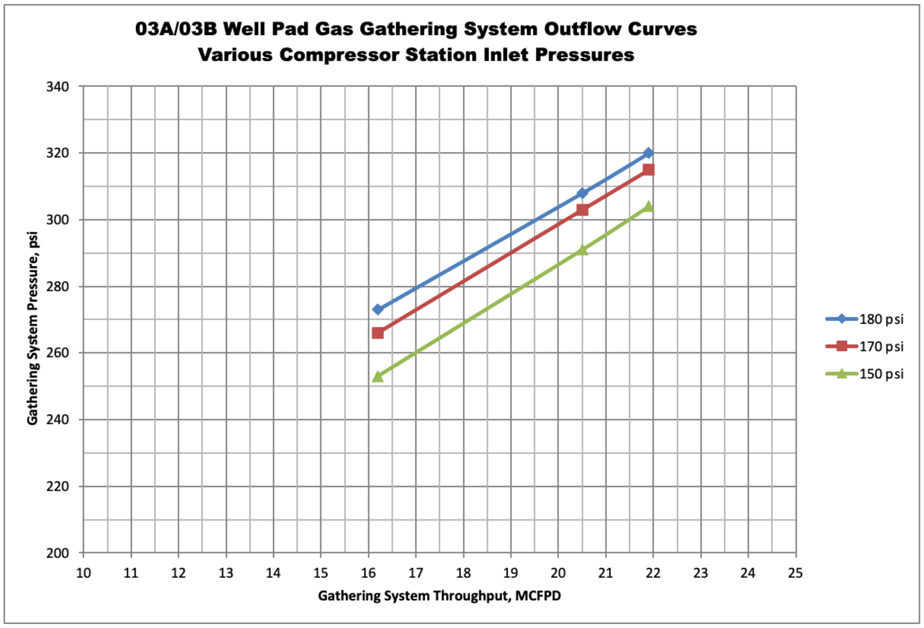


*Figure 3: Outflow Curves for 03A/03B Gathering System*

## NODAL ANALYSIS AND VALIDATION

With the Inflow Performance model in place, the performance of the piping system (Outflow) can be included to perform a Nodal analysis to predict performance of the system by the addition of production from the initial 6 wells from the 03A pad.

The Nodal analysis for the original wells on the 03B pad and the initial 6 wells on the 03A pad is shown in Figure 4 below. The **Black line** is the inflow curve for the original production from the wells on the 03B pad. The estimated/assumed reservoir pressure is 850 psi (equivalent surface pressure of 700 psi). The **Red line** is the outflow curve for the existing pipeline using an estimated plant inlet pressure of 180 psi. The Node is the intersection of these 2 curves and represents the “system parameters”.

The **Green Lines** in Figure 4 are the predicted inflow performance by the addition of production from 6 new wells into the system. Inflow Performance curves are additive so the dashed green line for the six new wells can be added to the existing system Inflow Performance (black line) which results in the new system performance shown in green.

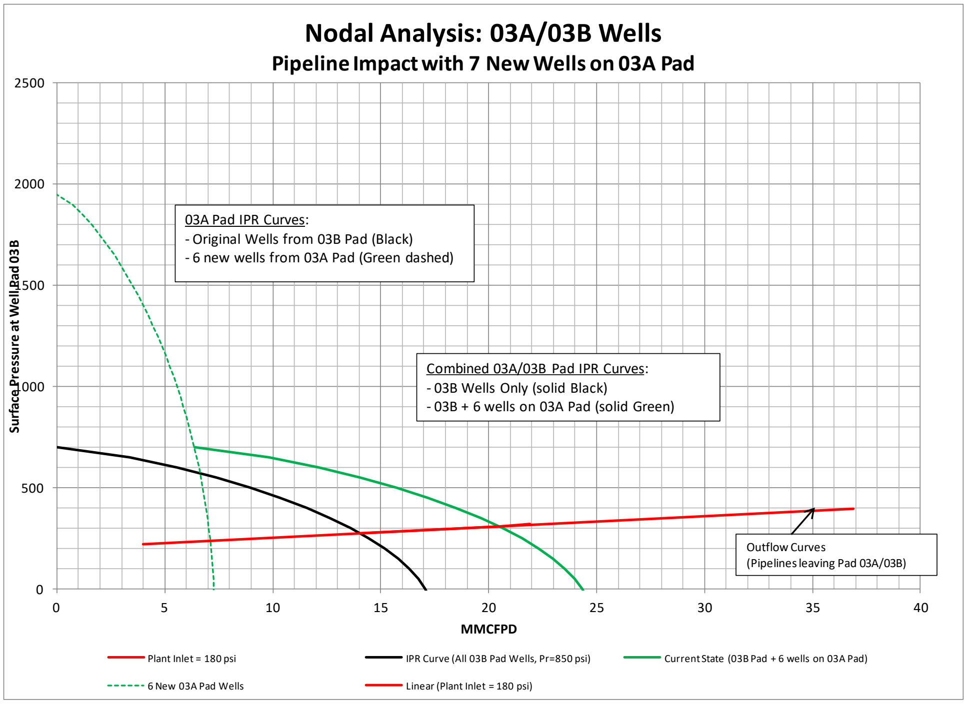


*Figure 4: Nodal Analysis for Existing 03B wells and 6 new 03A wells*

The critical points of any Nodal Analysis are those points in which the Inflow curve intersects with the Outflow curve. An expanded view of Figure 4 is shown in Figure 5 below to better visualize the nodes. The nodes are circled in the plot and the performance at these points is noted.

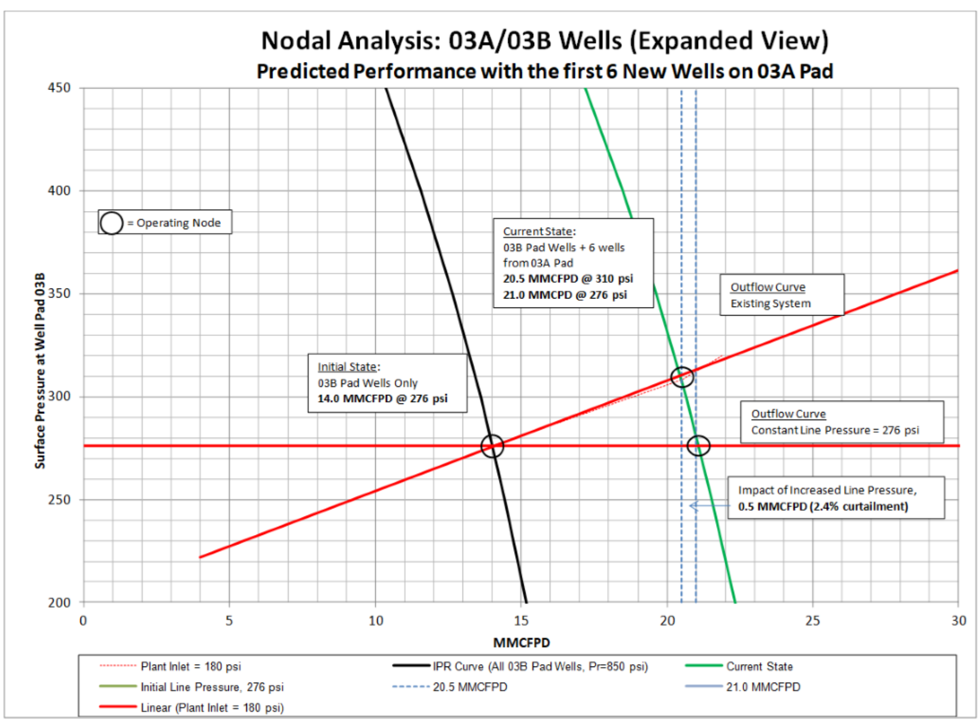


*Figure 5: Expanded view Nodal Analysis showing production from 6 wells on 03A pad*

The expanded NODAL Analysis shows the **Initial State** (before the addition of production from the 03A pad) and the **Current State** (which includes the addition of 6 wells from the 03A pad). As a check on the accuracy of our model the predicted performance by adding production from the 6 new wells from the 03A pad result are compared with actual performance and summarized in Table 1.

| | **Predicted** | **Actual** |
|---|---|---|
| **Initial Production from 6- 03A Wells, MMCFPD** | 20.5 | 20.4 |
| **Initial Line Pressure, psi** | 310 psi | 316 psi |
| **Production Curtailment (03B Wells) due to Line Pressure Increase, MMCFPD** | 0.5 | 0.6 |

*Table 1: Actual vs. Predicted Performance Results by putting six 03A pad wells online.*

The predicted performance compares very favorably with actual performance, giving credibility to the model. This credibility allows us to further expand the system predictions by adding production from the remaining 7 wells on the 03A pad.

The model prediction for the original conditions in which only the wells from the 03B well pad are producing show an operating condition at the node of 14.0 MMCPD at a line pressure of 276 psi. With the addition of production from six wells on the 03A well pad, the model predicted operating conditions were 20.5 MMCFPD at a line pressure of 310 psi.

Had there been no impact to the gas gathering system pressure, the actual production rate would have been 21.0 MMCFPD. Therefore, the added production from the six new wells resulted in a line pressure increase of 34 psi and a production curtailment of 0.5 MMCFPD. These results compare well with the actual operating conditions before and after the wells on the 03A well pad were brought on line (Figure 1).

## INFLOW PERFORMANCE PREDICTION OVER TIME

Planning for pipelines and artificial lift can be improved if the future inflow performance can be estimated. The present worth net value of the wells can be improved if multiple pipelines in the gas gathering system over the life of the well can be minimized. An estimation of the future inflow performance at corresponding reservoir pressures will give the designer an idea of the range of production capability the gas gathering pipelines is needed.

The Fetkovich[3] future inflow performance curves are a function of the changes in reservoir pressure (Pr) over time. To account for this, the coefficient C is adjusted for the future and is a function of the ratio of Pr (present) and Pr (future). A graphical representation of the current and future inflow performance estimations is shown in Figure 6. The Fetkovich method is viewed to provide a conservative estimation of future performance.

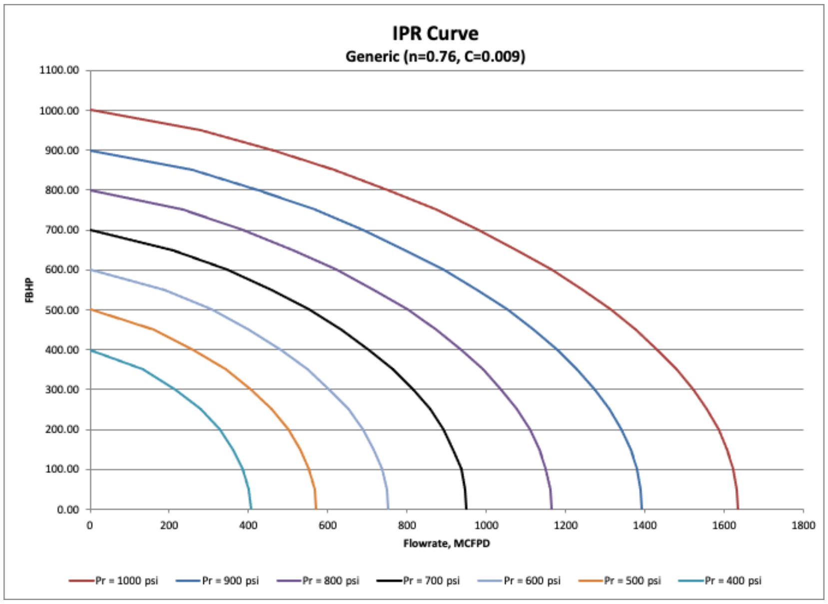


*Figure 6: Graphical depiction of Fetkovich method of Inflow Performance prediction as a function of reservoir pressure.*

The reservoir pressure declines with time. The constants in the Inflow Performance equation remain the same with varying static reservoir pressures, thus the inflow performance can be determined for any well as the reservoir pressure declines. The prediction of how fast it declines is based on RTA work and suggests it may decline by 14% in the first 6 months, 17% over the first 12 months and 19% over a 2-year period. Using this assumption, inflow curves were constructed for 3 different time periods: Time 0, 6, 12 and 24-months, as shown in Figure 7. This allows us the opportunity to evaluate the impact on production for various scenarios of line pressures over time.

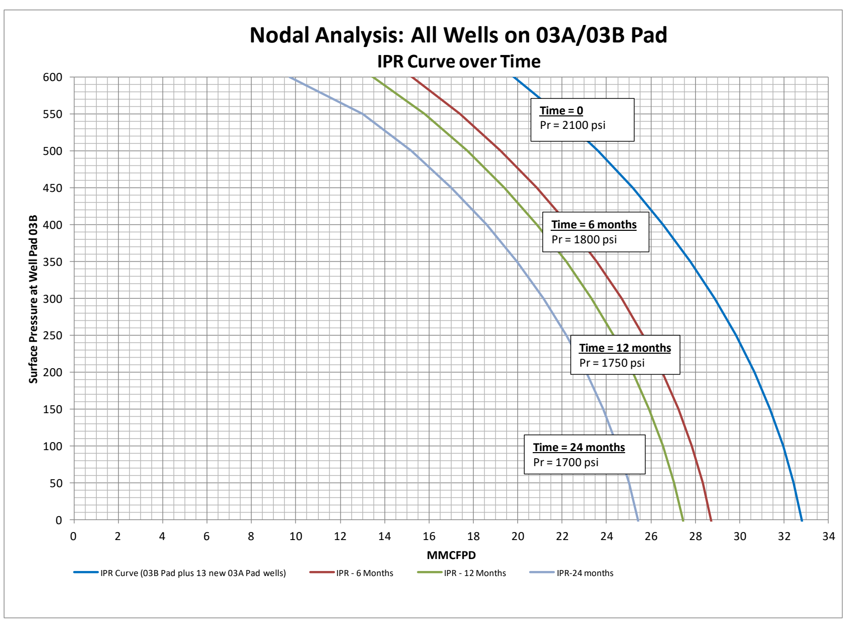


*Figure 7: Inflow Performance Curves over Time using pressure depletion assumption.*

## NODAL ANALYSIS MODEL OVER TIME – VALIDATE WITH ACTUAL DATA

To validate the model, including the assumptions of pressure depletion versus time, comparison with actual performance by adding the first 6 wells was done. Figure 8 shows an expanded view of the Nodal Analysis showing inflow performance curves predicted for 6, 12 and 24-months. The actual performance of the system at 4 months (most recent data) is 18.1 MMCFPD at 298 psi. This compares well with the 6-month prediction of 17.8 MMCFPD at 296 psi giving credibility to the model. The model results compare very well to the historical performance as shown in Figure 9.

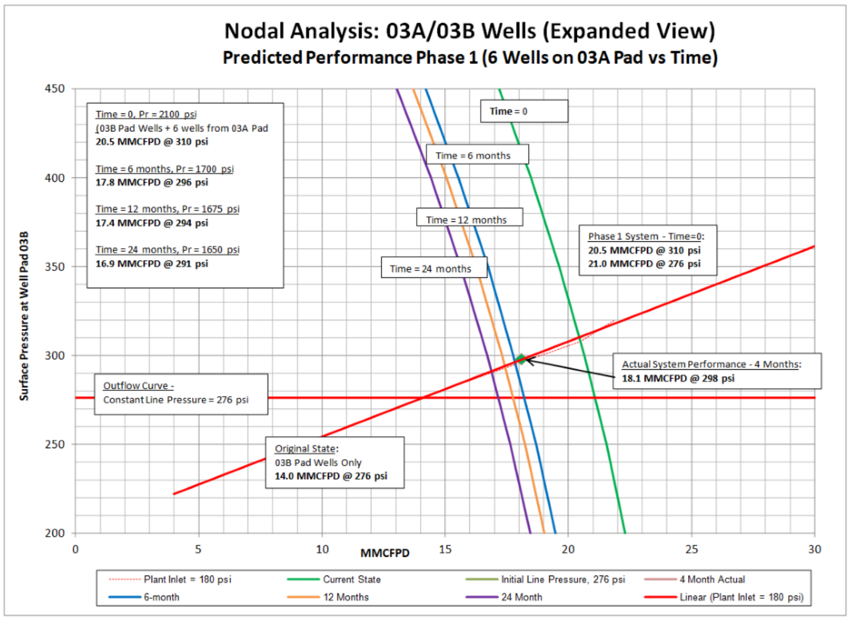

*Figure 8: Nodal analysis of performance of 03A &03B wells over time.*

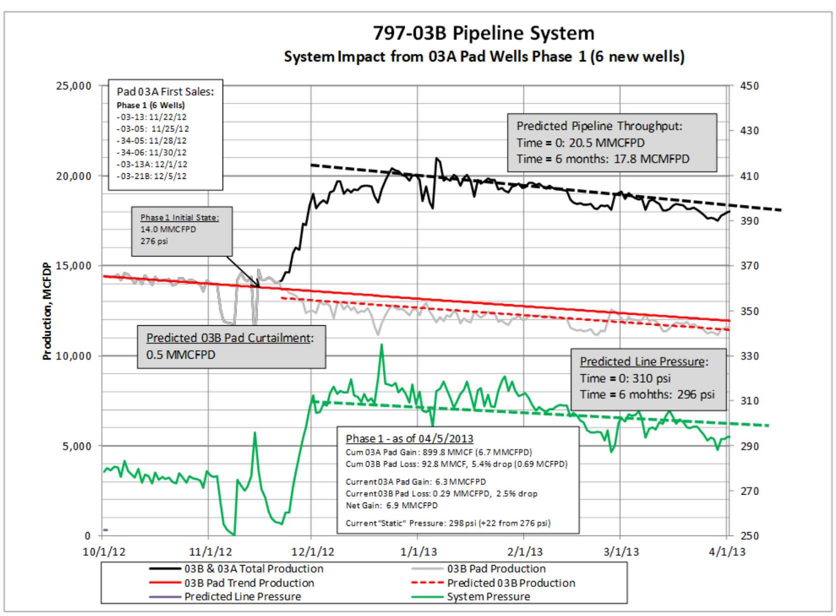

*Figure 9: Comparison of actual vs. predicted performance of 03A &03B wells over time.*

## PREDICTED PERFORMANCE – 7 ADDITIONAL WELLS FROM 03A PAD

By validating that the model can predict performance over time with confidence allows the evaluation of various scenarios for the system, such as the impact of installing a larger gathering pipeline. Three scenarios were evaluated: 1) current piping configuration, 2) evaluating deliverability at a constant line pressure, and 3) installation of an a 6" pipe for use by the wells on the 03A pad only.

## SCENARIO 1: CURRENT PIPELINE CONFIGURATION

Scenario 1 assumes no change to the current pipeline configuration. As shown in Figure 7, the additional production from the new wells on the 03A pad will result in a total throughput of 25.2 MMCFPD at an estimated wellhead pressure of 337 psi.

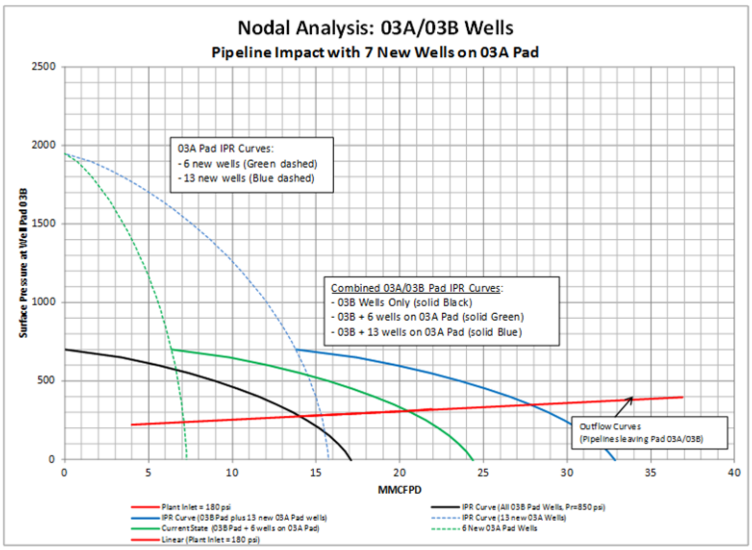


*Figure 10: Nodal Analysis for Existing wells plus 7 new wells on 03A pad*

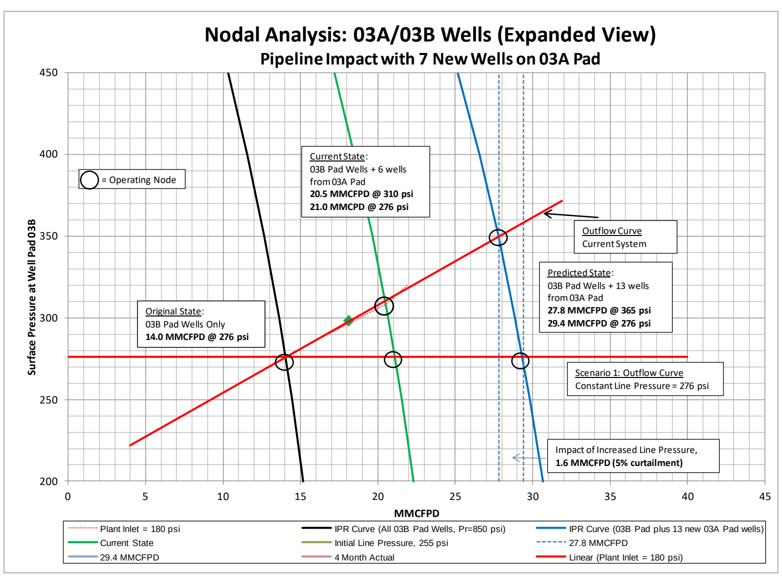


*Figure 11: Expanded View of Nodal Analysis for All wells on 03A & 03B pads*

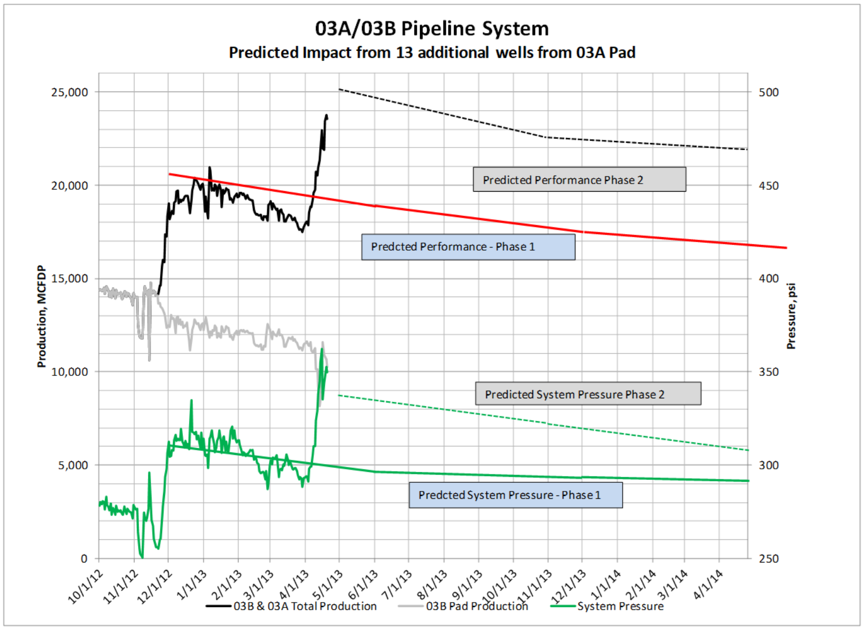


*Figure 12: Production Curve with predicted performance from Nodal Analysis*

The predicted production and line pressures as the reservoir pressure declines are shown in Table 2.

| | Predicted MMCFPD | Predicted Line Pressure |
|---|---|---|
| **Initial** | 25.2 | 337 |
| **6-months** | 22.6 | 322 |
| **12-months** | 22.0 | 319 |

*Table 2: Predicted Performance - No System Change*

## SCENARIO 2: PIPELINE UPGRADE TO MAINTAIN SAME INITIAL SYSTEM PRESSURE OF 276 PSI

Scenario 2 assumes there a pipeline can be installed that is of sufficient size to maintain a line pressure of 276 psi, the original system pressure before any additional production was realized from the 03A pad wells. This is not possible, but it shows the magnitude of the opportunity. Reference the Nodal Analysis shown in Figure 8, the predicted production versus time is summarized in Table 3.

| | Predicted MMCFPD | Predicted Line Pressure |
|---|---|---|
| **Initial** | 26.5 | 276 |
| **6-months** | 23.6 | 276 |
| **12-months** | 22.9 | 276 |

*Table 3: Predicted Performance – Maintain Initial Line Pressure of 276 psi*

## SCENARIO 3: INSTALL A 6" LINE FROM 03A PAD TO 09A FOR USE BY 03A WELLS ONLY:

This scenario attempts to determine the production impact of installing a new 6" pipeline to service wells on the 03A pad. Production from the 03B pad would continue to use the existing pipelines in place.

The Nodal analysis for this Scenario must be done separately for each well pad as each pad will realize different outflow conditions. Figure 9 shows the analysis for the 03A pad wells versus time.

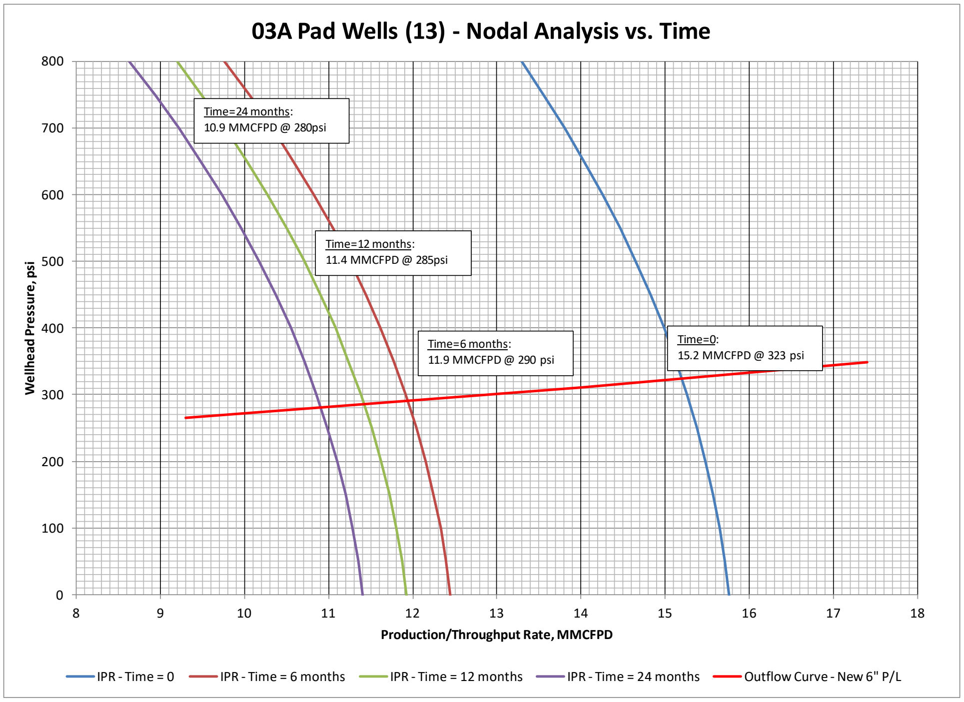


*Figure 13: Scenario 3 – Well Pad 03A Nodal Analysis*

The summary of the predicted performance is tabulated below.

| | **Predicted MMCFPD** | **Predicted Line Pressure** |
|---|---|---|
| **Time = 0 (Initial)** | 15.2 | 323 |
| **Time = 6 (Current)** | 11.9 | 290 |
| **Time = 12 (6-months)** | 11.4 | 285 |
| **Time = 24 (18-months)** | 10.9 | 280 |

*Table 4: Predicted Performance for Scenario 3 - 03A Pad Wells Only*

Figure 10 below shows the Nodal analysis results for the 03B pad wells only. The results are tabulated in Table 5.

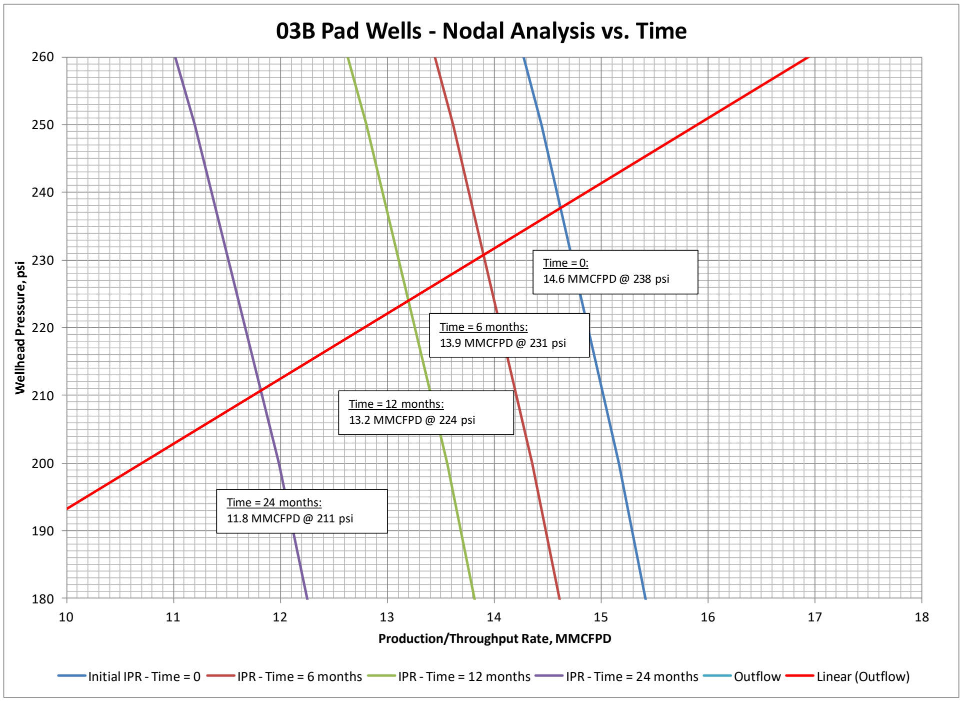


*Figure 14: Scenario 3 – Well Pad 03B Nodal Analysis*

| | Predicted MMCFPD | Predicted Line Pressure |
|---|---|---|
| **Time = 0 (Initial)** | 14.6 | 238 |
| **Time = 6 (Current)** | 13.9 | 231 |
| **Time = 12 (6-months)** | 13.2 | 224 |
| **Time = 24 (18-months)** | 11.8 | 211 |

*Table 5: Predicted Performance for Scenario 3 – 03B Pad Wells Only*

Comparison of the results allows us to quantify the magnitude of Scenario 3 to evaluate the economics for installing the new 6” pipeline.

| | 03A Pad Predicted MMCFPD | 03B Pad Predicted MMCFPD | Sum of 03A and 03B Pad MMCFPD | Current Pipeline Configuration MMCFPD | Difference MMCFPD |
|---|---|---|---|---|---|
| **Time = 0 (Initial)** | 15.2 | 14.6 | 29.8 | | |
| **Time = 6 (Current)** | 11.9 | 13.9 | 25.8 | 25.2 | 0.6 |
| **Time = 12 (6-months)** | 11.4 | 13.2 | 24.6 | 22.6 | 2.0 |
| **Time = 24 (18-months)** | 10.9 | 11.8 | 22.7 | 21.4 | 1.3 |

*Table 6: Predicted Performance for Scenario 3*

Figure 11 shows the predicted production performance for the scenario to install an additional 6” pipeline versus the predicted performance using the current piping system.

Accelerated production of 0.8 BCF can be realized by installing the additional 6” pipeline over the 1st 18 months from installation.

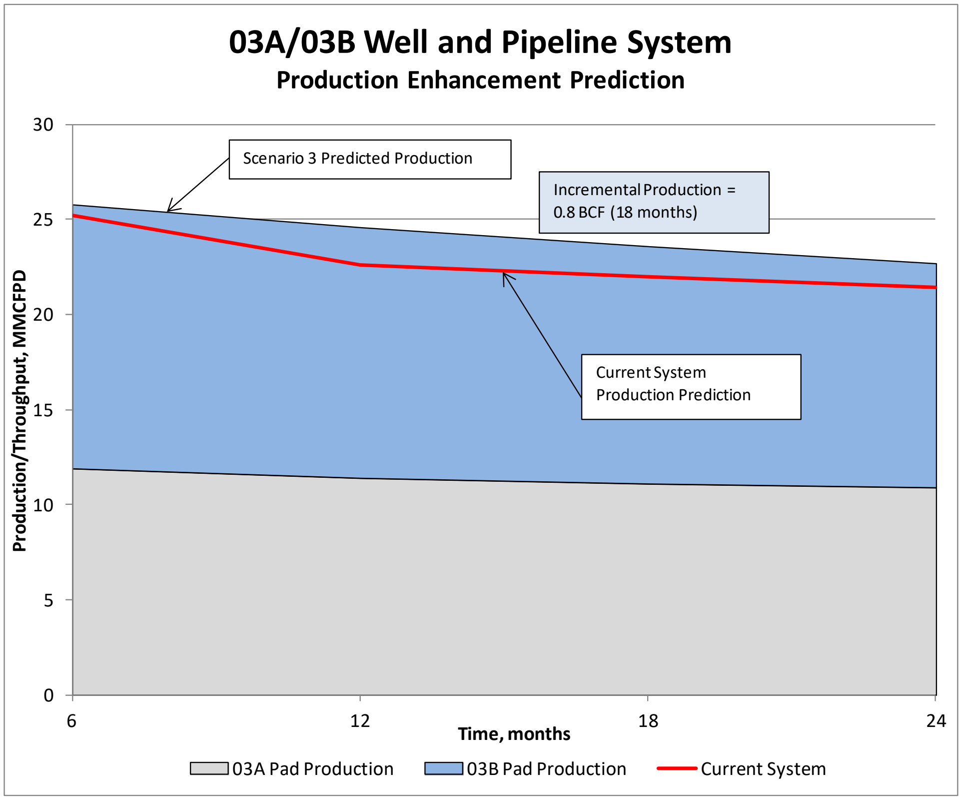


*Figure 15: Production Impact vs. Time for various scenarios*

## CONCLUSIONS

Nodal analysis is a very useful tool in evaluating performance of gathering systems as well as assessing the performance of artificial lift equipment. A methodical approach to conducting the Nodal analysis led to a very credible prediction of the magnitude of the impact to production from existing wells on the 03B well pad. This allows the engineer to evaluate several options to mitigate the impact with a high degree of confidence in the outcome.

## REFERENCES


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3. Beggs, Dale: “Production Optimization Using NODAL Analysis”, OGCI 2003, pp 40-45.