FOAMED CEMENT UTILIZATION ON AN INFILL DRILLING PROJECT – WATER FLOOD – GRAYBURG FORMATION – SOUTHEAST NEW MEXICO – NEED FOR ZONAL ISOLATION—CAS E HISTORY

George Tullos and Greg Minnery, ChevronTexaco
Prentice Creel, James Haest, and Janie Snelson, Halliburton

ABSTRACT

An infill drilling project was undertaken in the Eunice Monument South Unit (EMSU) to help balance the current water flood and strategically place producers and injectors into a smaller spacing and configuration. Past developments and treatments to better flood the units were initiated in 1996 to characterize the reservoir and improve the flood conformance. Knowledge gained led to the implementation of the infill drilling EMSU project and identified the criterias needed to offset the problems that would be faced. Crossflows and high water influxes would be encountered, and determination of a system to gain the best possible zonal isolation during the primary cementing operations was established in the planning process.

Follow-up ultrasonic cement evaluation logs were run to determine the performance and integrity that was achieved.

Controlled injection profiles in the newly developed injection wells and the ability to control the placement of fracture stimulation in new producers were reflected in the well's performance.

INTRODUCTION

The EMSU is located in southeastern Lea County, New Mexico, approximately 15 miles southwest of Hobbs, New Mexico, along the northwestern edge of the Central Basin Platform. The original Eunice pool was discovered in 1929 and developed on 40-acre spacing. Oil production peaked in 1937 at 25,542 barrels of oil per day (BOPD).

The EMSU produces from the Grayburg formation in Southeast New Mexico. An infill drilling project was undertaken to help balance the current waterflood and strategically place producers and injectors into a smaller spacing and configuration. Past efforts with developments and treatments to better flood the unit were implemented within a field-wide, multi-team major project initiated in 1996 to characterize the reservoir and help improve the flood conformance wherever possible. Knowledge gained during this project led to the implementation of the infill drilling project and developed the criteria's needed to offset the problems that would be faced in this unit. Crossflows within the reservoir and high water influxes would be encountered and determination of a system to gain the best possible zonal isolation during the primary cementing operation was established in the planning process.

The operator has been operating two adjacent waterflood units in the EMSU; the Eunice Monument South Unit (EMSU - 14,190 acres) and the Eunice Monument South Unit B (EMSUB -3,000 acres). The EMSUB shares a common unit boundary along the northwestern border of the EMSU (southeast comer of the EMSUB). EMSU was unitized February 1, 1985, with water injection commencing November 1986. EMSUB was unitized December 1, 1990, with water injection commencing March 1991. Both units were developed on 40-acre well spacing with SO-acre 5-spot patterns. EMSU and EMSUB produce oil primarily from dolomites of the Grayburg formation. A minor amount of oil is produced from the overlying lower Queen (Penrose) formation. The underlying San Andres formation, a waterdrive reservoir, is used for supply water. Hydrocarbon entrapment in the field is controlled by a combination of structural-stratigraphic trapping located along the northwest margin of the Central Basin Platform.

LITHOLOGY

The Grayburg formation is a carbonate ramp environment, relatively thick and porous to the southwest (more packstones/grainstones) and thin and tight to the northeast (more wackestoneslmudstones). Sets of parasequences stack to form six recognizable zones based on correlations of relatively thin (approximately 2' to 10' thick), generally impermeable sandstones (siliciclastics). The zonal markers that can be correlated across most of the unit are made up of dolomitic sandstones (subarkose to calclithites), which are composed of well-sorted and very fine-grained siliciclastic sand. These siliciclastic “markers” are very well-developed to the northeast in the back-shoal environment, which makes zonal correlations fairly obvious and straightforward. To the southwest, however, in the high-energy shoal environment, these siliciclastic markers are much less developed, and confidence in the zonal correlations deteriorates. These siliciclastics tend to be very porous but are impermeable and act as vertical barriers to fluid movement. The general lack of siliciclastics to the southwest in the high energy shoal environment—where thick, porous, grain-rich parasequences tend to stack—has produced a more homogeneous reservoir that has more of a bottom- and edgewater drive component. To the northeast, in the back-shoal environment, the siliciclastics tend to vertically compartmentalize thinner, less porous and more muddy parasequences that promote more of a solution gas-drive component.

Zones 1, 2, and 3 are very clean dolomites (floodable reserves, solution gas drive). The top of Zone 1 is the top of the Grayburg formation. Generally, Zone 1 has been processed by waterflooding. Because it is tight in the northeastern half of the field, it is more brittle and tends to be more fractured than the rest of the Grayburg section. The lower half of Zones 1 and 2 have the most high-permeability streaks (solution- enhanced grainstones typically 18 in. to 4 ft. thick) and tend to have edgewater drive connected to the Grayburg shoal along the southwest of the field.

Zone 4 is elastic rich (silty/sandy) and forms a pressure barrier. It is vertically impermeable and can have good porosity zones. This zone has a karsted surface in its upper portion.

Zone 5 is typically water drive (3 to 20% oil cut), and Zone 6 overlies the top of the San Andres and contains an unconformity in its upper part. There are oil shows well down into the San Andres formation that lies below the Grayburg formation.

UNIT PROBLEM HISTORY

The past reservoir characterization was enhanced by mapping high-permeability streaks, doing material balance, and analyzing percent pore volume swept calculations in various areas within the unit. Primary problems discovered included water cycling through high-permeability streaks, water injection going into the original gas cap, and wellbore zonal isolation problems on the then current wells. Various treatments including foamed cement squeezes for near-wellbore problems were performed to address the injectivity imbalances and reported in SPE paper 49201.’

INFILL DRILLING PROGRAM PLANS

Addressing the conformance problems indicated the necessity of near-wellbore integrity and competent annular zonal isolation to implement the planned drilling program. To address the possibility of injection into a problematic high-permeability streak interval, it was necessary to gain an annular integrity that would seal off this zone. Due to the ongoing waterflood, a high influx potential existed in portions of the reservoir. To gain a control over the water influxes, the development of and designs for utilization of foamed cement were initiated.

The desire to acquire and maintain integrity behind casings would determine the productive life of the infill wells to be placed in this unit. It was recognized that during the life of many wells, collapse of casings, pitting and corrosion, and unstable annular conditions may end up costing more to control than the initial completion. The flexibility to meet these challenges by utilizing a better understanding of the problems and using developing technology and procedural logic was chosen in order to help make a dramatic influence on completion costs and acquiring successful zonal isolation. Planning was conducted to take the fullest advantage in exploitation of the production reserves and sweep efficiencies. The project began addressing the best options for completing wells using cost effective methods that could provide attributes and properties capable of withstanding detrimental conditions.

The 2001 drilling program consisted of placing infill producers and injectors to take advantage of the flood unit. Planned waterflood performance and predicted results would be to gain additional production and develop a more efficient sweep of OIP (oil in place).

The drilling project began in 2001 and consisted of 13 identified locations in the unit. The wells were drilled to the bottom of the Grayburg formation, and a planned 5 ½ in. casing was to be set and cemented. Based on the past evaluations, the primary cementing designs called for foamed cement slurry to be placed behind casing in one stage with a follow-up cap squeeze (placing densified slurry down the annulus between the surface and production/injection casing). The cap squeeze helped gain control over the energized slurry and helped develop a desired density profile within the annulus. Past reports and SPE papers describing techniques and methods in applying foamed cement during primary operations were studied. [2, 3, 4, 9, 10, 12, 15]

To evaluate the performance of the foamed cement, follow-up ultrasonic cement evaluation logs were run. The performance and integrity that was achieved was compared to former conventional cementing, initial foamed cementing attempts, and the final process utilized in foamed cementing.

As with any undertaking, the results of achieving a controlled injection profile in the newly developed injection wells and the ability to better control the placement of fracture stimulation in the new producers would be reflected in the performance of the wells over time. The performance of the newly developed wells is given for review.

PROJECT TEAM FOR CAPTURING BEST PRACTICESAND OPERATIONAL PROCEDURES

To address possible problems with influxes and crossflows of water while drilling into this unit's pay, a project team was formed. The team was be made up of reservoir engineering, production engineering, drilling engineering and operations, and advising specialists. Designs utilizing energized slurries and their placement behind casing on the production strings were investigated. Simulation analyses were performed with input from the witnessed features and conditions of the waterflood unit noted in the prior conformance workovers.

Locations of the planned infill drilling sites were determined from internal reservoir simulation modeling and information from detailed performance and investigative studies. A map showing the location of the unit is attached. [Fig 1]

CEMENTING OPERATIONS PLANNED STEPS

Preparations were set in place to perform energized cementing operations on the newly drilled injection and production wells. A list of rig operational procedures was combined with cementing service company's operational procedures to provide the best possible circumstances for the success of the energized cement jobs. The operational procedures were reviewed with the cementing service company's personnel and were modified to contain their recommendations for additional processes that would help contribute to the success of the energized cement jobs.

LOGISTICAL STEPS FOR JOBS:

1. Once casing is on bottom, prior to beginning the cement job, test close the casing-rams and pump through the choke, setting up choke valves as appropriate. Have plug assemblies loaded prior to job initiation. Make the annular squeeze connection for the post-job annular cap squeeze and close in.

2. Start the cement job with the casing rams in the open position. The casing should be able to be reciprocated or rotated while cement is traveling across the pays.

3. The casing rams should not be closed until the return rates begin to increase, indicating the energized cement or a foamed preflush is nearing the surface. Close the casing rams and direct flow through the blowout preventer (BOP) manifold with a controlled backpressure applied. Use care not to exceed design parameters on the amount of backpressure being applied in reference to the formation fracturing pressure limitations on the various intervals under consideration.

4. Monitor cement densities, rates of nitrogen, and foamer-stabilizer chemicals to meet design criteria. Once foamed spacer or foamed cement begins to circulate to surface, the backpressure control should have been implemented based on the rate changes and simulation design monitoring. Holding backpressure on the surface allows the control of downhole pressures and flow rates. The ideal control at surface should direct the flow safely to the pits via a staked-down line and maintain a designed backpressure. These backpressures are based on the simulation design to help ensure the well is not broken down due to exceeding fracturing pressures.

5. After dropping the top wiper plug, displace the job to land the plug at the float collar placed above the casing shoe.

6. After landing the top wiper cementing plug, close in the annular returns and monitor the pressure for increases due to trapped frictional effect.

7. Check the casing for flowback. If floating equipment is satisfactorily sealing backflow, the casing may then be re-pressured to a satisfactory pressure for collapse reduction. This is also a monitoring pressure to help restrict the collapse condition. Once the cap squeeze is completed, this trapped interior casing pressure should be released to help ensure best bonding.

8. The cap squeeze is done down the well's annulus valve on the wellhead. Connections should have been made during the job set-up. Care needs to be made in pumping the cap squeeze in pressure observations. The ener gized cement is compressible, and because the nitrogen is tied up in the slurry, the cap can be used to displace the foamed cement back down the annulus with compression. There will be a leading edge mixing due to the differences in viscosity. At least a 3-4 BPM rate should be achieved down the annulus to gain displacement efficiency. Once the cap is placed, the rig crew can close in the annulus valve on the side of the wellhead. Open the BOP's chokes and valves to allow the release of the trapped energized cement in this now-isolated system. It is then normal to wash out these lines and BOP controls to the pit. Some rigs do not have a way to wash the lines and do it with hoses. The BOP controls and lines need to be reconnected to the well for the following "wait-on-cement-time'' (WOC) test.

9. WOC a minimum of 4-6 hours or longer if samples are not firm. Waiting 6 hours is recommended before opening the valves to allow blow-down and determination of static conditions. If the well is static, the process of unbolting the BOP and dropping in casing slips may be made. Care should be taken to not jerk too hard on the casing while placing the slips (rattling) because this could cause a debonding and loss of cap integrity. The energized cement can resurface and be out of control.

10. Bleed trapped energy slowly. Shut in the annulus longer if cement returns or if nitrogen does not bleed off within 3-4 minutes. A typical set up for performing an energized foamed cement job is shown in an attached figure. [Fig 2]

DRILLING ENCOUNTERS

Monitoring the drilling for witnessed influxes and losses was conditional. Historically, depths associated with local area encounters of a water influx or possible cross flowing of flood injectant were noted. Few anomalies were noted, due to the ability to maintain circulation while drilling and utilize drilling mud with sufficient density to apply hydrostatic weight above the intervals' pore pressure on the well. Speed and efficiency of drilling was promoted. Variations in the required depth of the surface casing would be conditional to the project.

JOB HISTORIES

Initial energized cementing jobs were performed by the operator's alliance service provider and evaluated based on post-job log analysis. Specialized ultrasonic logging was performed utilizing a 360-degree investigation and attenuations to develop the evaluations. There were problems with bonding aspects and apparent stability of the slurry. Log analysis indicated gas channels had developed within the slurry body in the annulus with potential for communication. Also, returns did not indicate the desired stability based on separation of the gas, foamed components, and liquid phases. Due to the poor performance of the energized slurry to withstand influxes both during placement and the static final placement, operations chose to investigate another service provider.

SPECIALIZED PROCESS UTILIZED TO PERFORM PRIMARY CEMENTING OPERATIONS

The new service provider was asked to redevelop former computer simulation designs and do the work on the remaining wells in the infill drilling projects. A redesign utilized energized slurry to cover the annulus from surface through the production/injection interval. The variation on the leading filler slurry was based on consideration for hydrostatic loading pressures. The tail-in 'pay' slurry was designed for maximized compressive strength and attributes to withstand influxes. Zonal isolation and integrity around the casing for placement control while fracture stimulating production wells was important. Annular isolation was also needed to help ensure control over selective injection intervals on planned injection wells.

At the planning stage, proprietary wellbore simulation software was used to provide a comprehensive, interactive system of both static and dynamic modeling for the cementing operation. This analysis system was necessary to help for design and implement the optimum fluid program for each cementing job prior to performing the job. Details on this design program are referenced. [6]

DESIGN CRITERIA AND CONSIDERATIONS FOR PRIMARY CEMENTING

A computer simulation program that addressed aspects of performing the primary cementing jobs was developed. Information was gathered describing wellbore conditions, tubulars, and drilled hole sizes, fluids including muds, spacers, cement, etc., reservoir properties, pore pressure data for the intervals, and fracturing pressure data for the encountered intervals. Laboratory analyses on the rheology of the various fluids that would either be within the wellbore or pumped during the operation were included in the design program. Laboratory analysis was also performed to determine the pump time, fluid loss, free water, and cement slurry strength developments for quality assurance. The data was input on the computer simulation program for evaluation. Repeated analysis was performed based on design evaluations and tailored to each well. The most important quality assurances considered were the ability to evaluate such conditions as placement through the job, aspects of remaining above pore pressure but below fracturing pressure at any depth of the well from start to finish in the job, and performing this in simulation prior to performing the actual job.

The conditional reviews and operations included computer design analysis of the energized cement densities once circulated to surface at the completion of the primary operation, and the capability to design a desired slurry density profile in the annulus following the cap annular squeeze. These design analyses accounted for the desired foamed constituent make-up for its final placement in the wellbore with the effect of compressional conditions during the final cap squeeze. [Figs 6 and 7]

During pumping operations, energized foamed cement can develop high dynamic-flow shear stress giving it increased mud-displacement and annular filling capabilities. The internal gas (nitrogen) used to foam the system allows the slurry to maintain hydrostatic pressure over the well during the system's transition period (liquid state to a solid state). Consequently, the energized slurries can effectively control gas migration and formation-fluid influx, which can help limit migration channels in set cement sheaths. [12, 14] Energized foamed cement is more resistant to both temperature and pressure-induced sheath stresses giving it ductility. Its internal microscopic bubbles allow crystalline bonds to flex without breaking. This feature was important for integrity on the tail-in slurry that would be perforated for production and injection. [5, 7, 8]

Once computer design evaluations were made, the operation procedure and logistical steps were reviewed and used to maintain quality assurances. Job volumes, slurry designs, laboratory analyses, and setting up the jobs were built into a process. The jobs were monitored with a data collection system and evaluated for design match.

Laboratory analyses resulted in comprehensive materials testing and evaluations to help ensure use of the right mix for the jobs.

Energized primary foamed cement jobs were performed on the remaining infill well development projects. All but one well was shown to have acceptable zonal isolation from surface to total depth (TD). On one well, the occurrence of a high-pressure crossflow through the center of the well's pay zone, directed from an offset injection (west) to a down structure offset production well (east), caused a portion of the coverage behind casing in the middle of the pay interval to not have annular integrity. Utilizing knowledge gained from the initial conformance workovers in this unit,' a follow-up foamed cement squeeze was performed to establish integrity within this section.

During actual jobs, the cement unit used an automatic density control system to produce consistent slurry at the desired density, along with automatically controlling both the foamer/stabilizer injection unit's rate and nitrogen unit's rate according to the slurry pump rate. [Figs 3, 4, 5, 6] Follow-up cap annular squeezes were performed, and all wells were controlled with no follow-up squeeze required. [Fig 7]

POST-CEMENT ANALYSIS AND EVALUATION

A follow-up logging evaluation was performed and reviewed. If evaluations indicated possible modifications or designs were needed to improve the wellbore integrity, these were investigated and performed.

Because of the poor acoustic properties of foamed cement, a cement bond log (CBL) will only indicate marginal zonal isolation when 100% mud displacement may be achieved. This logged response is not unusual, and an alternative method of evaluating energized foamed cement with ultrasonic logging tools has been developed. [11, 13, 15] This method evaluates the impedance variation exhibited by the foamed cement instead of the measured value of the cement's impedance. The sonic and ultrasonic logs can be used to demonstrate cement-integrity data. The cement-evaluation logs from the initial project's foamed-cemented wells were compared to the later foamed-cemented wells, showing variances in adequate zonal isolation through the annulus. Previously foamed-cemented wells showed a poor zonal isolation compared to later foamed-cemented wells with zonal isolation. [Figs 8 and 9]

The ultrasonic tools can provide the most beneficial data when evaluating the placement and bonding of foamed cements. These tools can provide an indication of casing-to-cement bonding. Instead of a separate source and receiver, the ultrasonic source and receiver are packaged together as a transducer. When a signal emitted by a transducer encounters an acoustic interface (for example, between casing and annular material outside casing), some the signal energy is reflected at the interface, and some is transmitted across the interface. The fractional amounts of reflected and transmitted energy depend on the acoustic impedances of the materials at the interface.

The ultrasonic scanning or imaging acoustic tool uses a single rotating ultrasonic transducer to produce high-resolution circumferential data. Data for both cement evaluation and casing evaluation are obtained in the same run or pass. The rotating transducer can provide 36 to 200 measurements per depth sample, depending on the service company provider. Depth-sample rates range from 2 to 12 samples per foot, again depending on the service company.

RESULTS OF INJECTION WELL PERFORMANCES PROJECT

After the desired injection intervals were perforated, wells were tested for profiles. It was discovered that the injection was more controlled and did not enter the high-permeability streaks normally thieving fluid in the unit. The lower half of Zones 1 and 2, which have the highest permeability streaks (solution- enhanced grainstones typically 18in. to 4ft. thick), tended to have the highest injectivity and are mostly processed. Project desire was to gain a better profile on injection and reduce the fast tracking injection to offsets. Evaluations have been made on the newly developed injection wells and they have reduced entry into the high permeability intervals and are providing offset response.

PRODUCTION WELL PERFORMANCES

Following the initial change in service providers on the foamed-cementing operations, stimulation processes were also performed by the new provider on the next project's development wells. The improvements were in (1) differences between production comparing poor zonal isolated wells to ones that indicated quality isolation and (2) production improvements based on new stimulation techniques introduced by the service provider. [Figs 10, 11, and 12].

ECONOMICAL BENEFITS

Follow-up evaluations showed the improvements in production giving an economical benefit to the project. Treatment costs were increased, but the results in production and apparent impact in gaining improved flood sweeps made up for this. [Figs 13 and 14]

CONCLUSIONS

To control detrimental conditions that can impact performance in primary cementing operations on gas or water-flooded units, these conditions should be identified and addressed during the well construction phase. Understanding the types and effects of conditions that are present in these pressure-driven units helps address the selection and techniques needed to gain better zonal isolation methods on new wells. There needs to be an understanding of the properties that may be available for addressing the needs required for a solution. Energized cement systems can bring better results if used in a best practices process. Utilization of computer design simulation analysis can tailor primary cementing jobs and help investigators account for complex conditions that occur during placement from start to finish on a job. The best available systems (chemical and mechanical) for generating and stabilizing energized foamed cement can indicate the best performance in zonal isolation. Laboratory analysis should be conducted. Training operators in this process can help ensure the best on-site performance. Integrity analysis may be determined from ultrasonic logging analysis to help ensure wells are bonded. Production and injection performance are the final evaluation of success.

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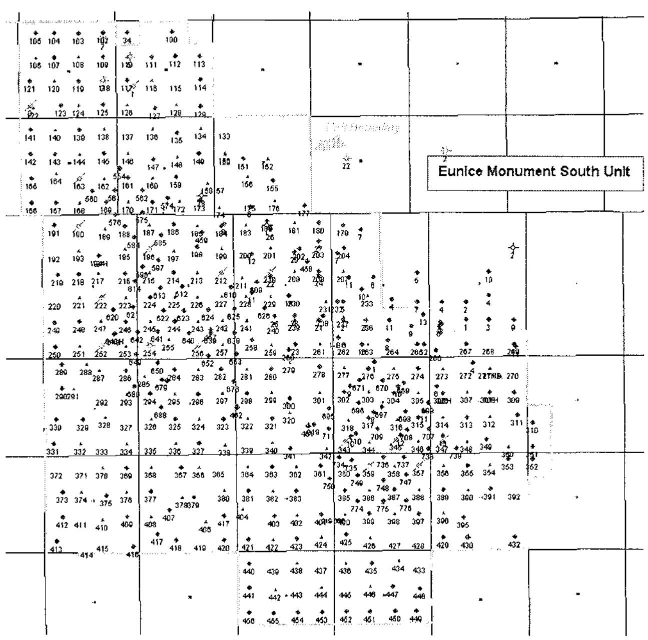

Figure 1 - EMU Unit

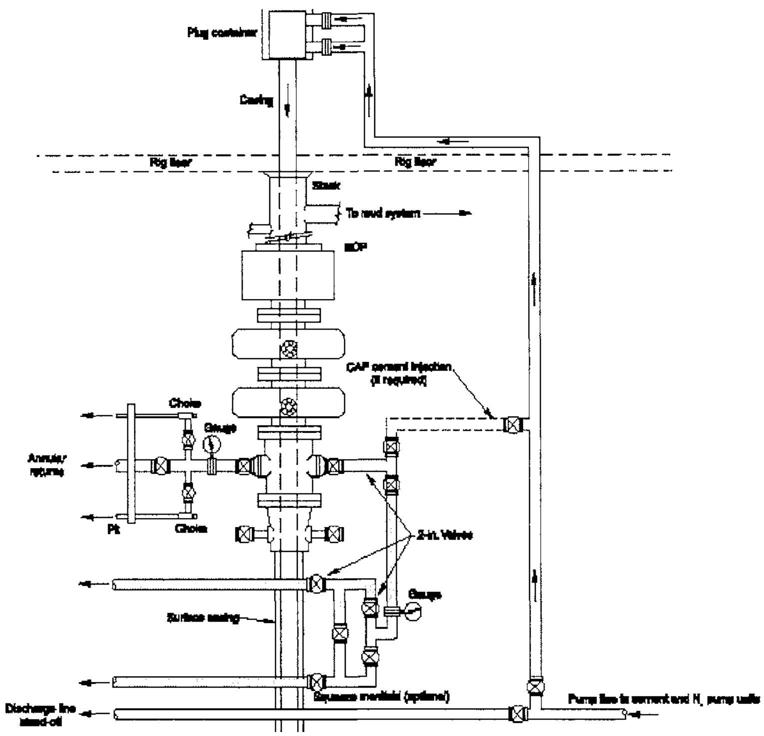

Figure 2 - Well Rig-up

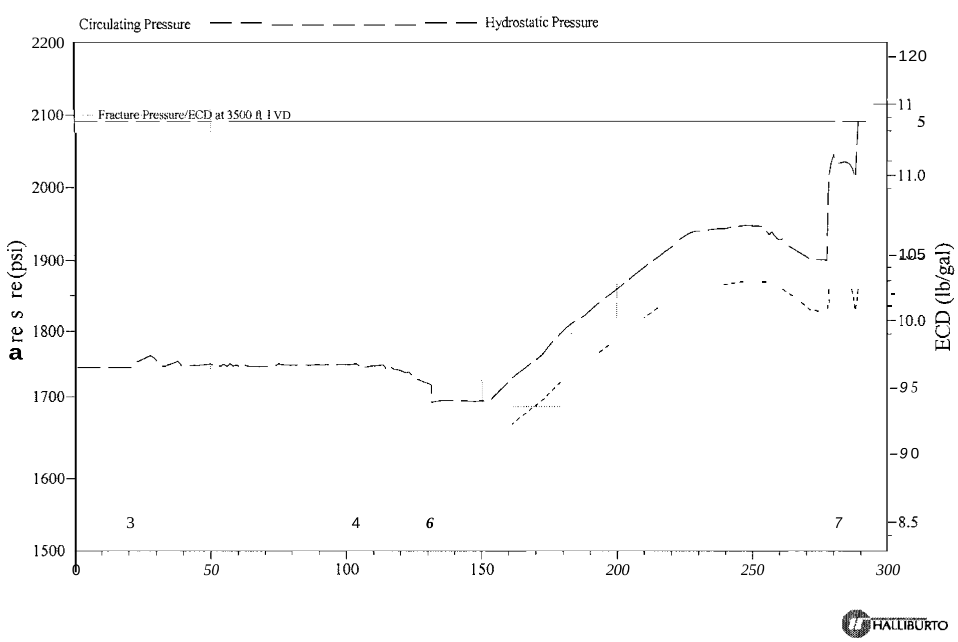

Figure 3- Remaining Below Fracture Pressure

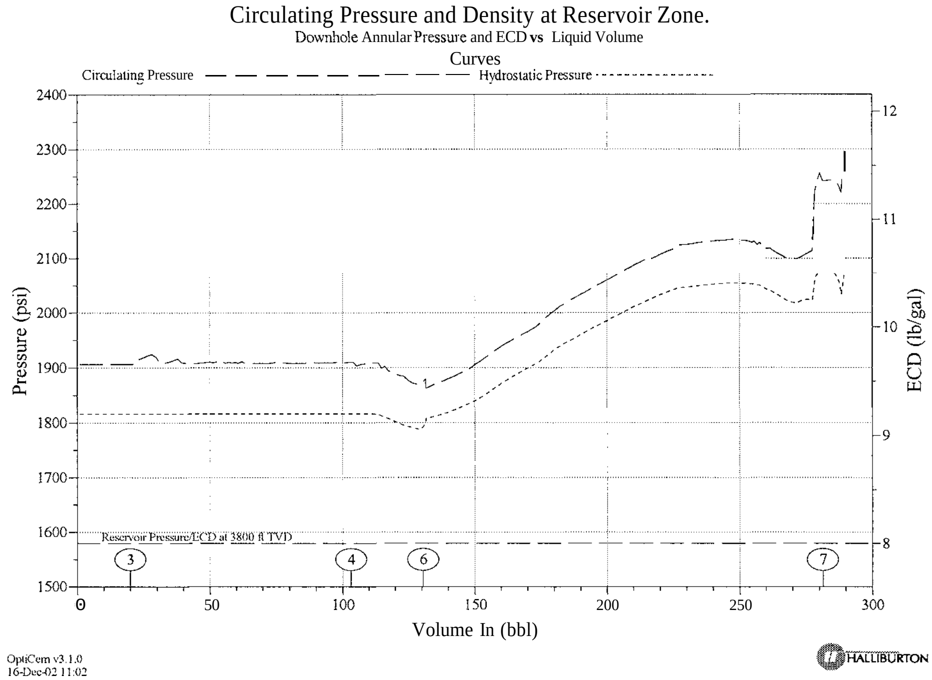

Figure 4 - Remaining Above Pore Pressure

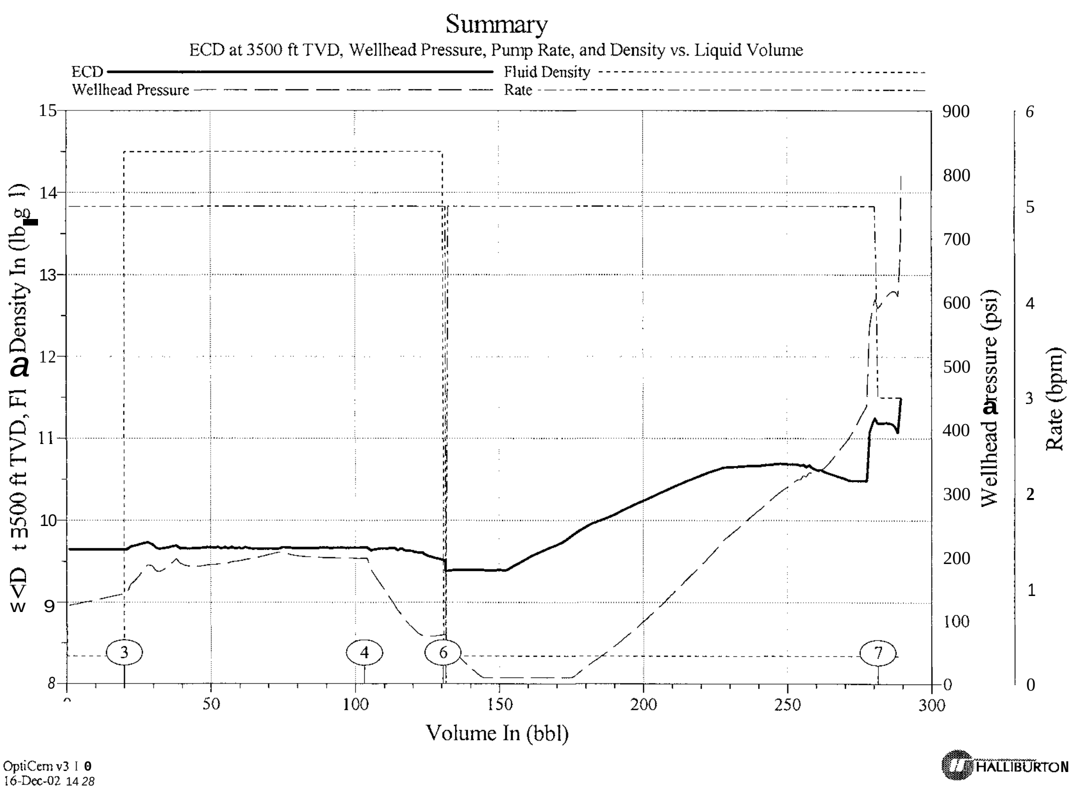

Figure 5 - Summary of ECD, Rate, Density, Volume, and Wellhead Pressures

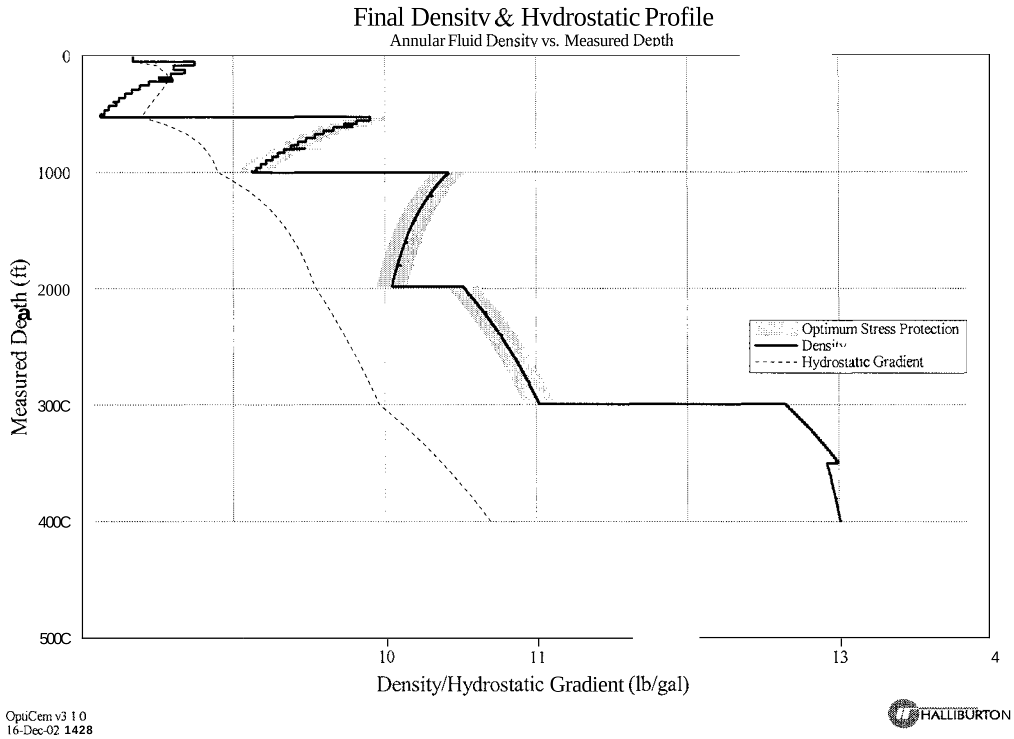

Figure 6 - Density Profile Prior to Cap Squeeze

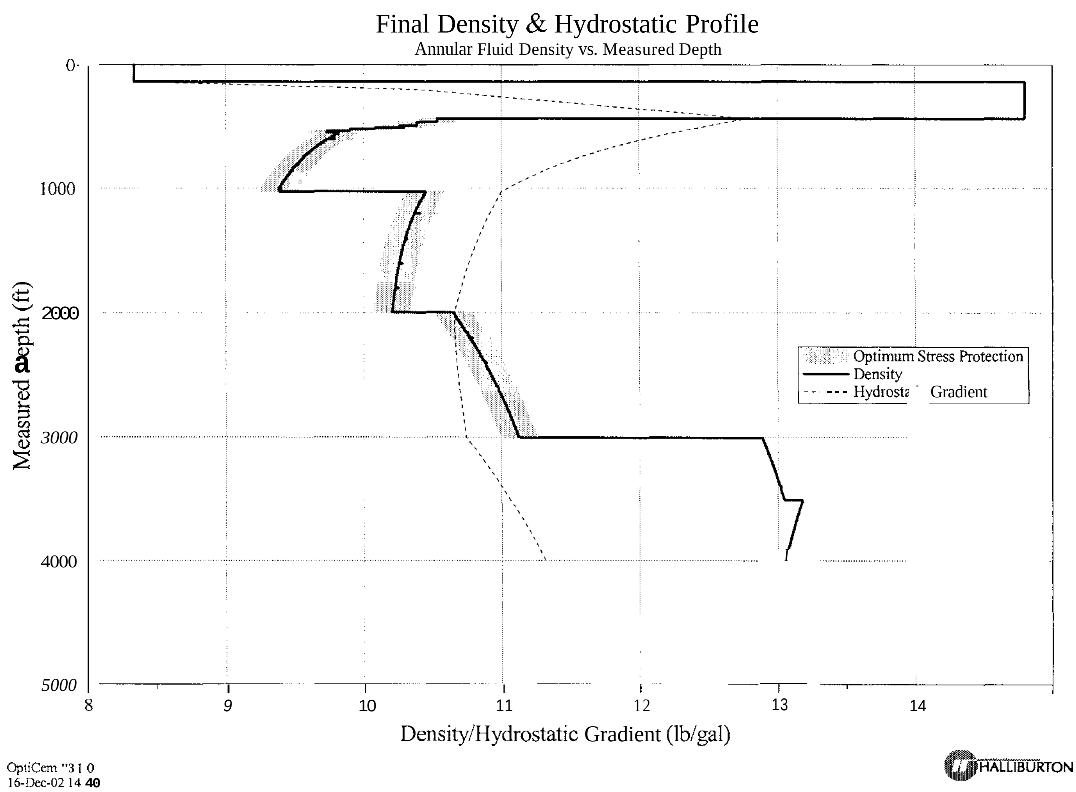

Figure 7- Density Profile Following Annular Cap Squeeze

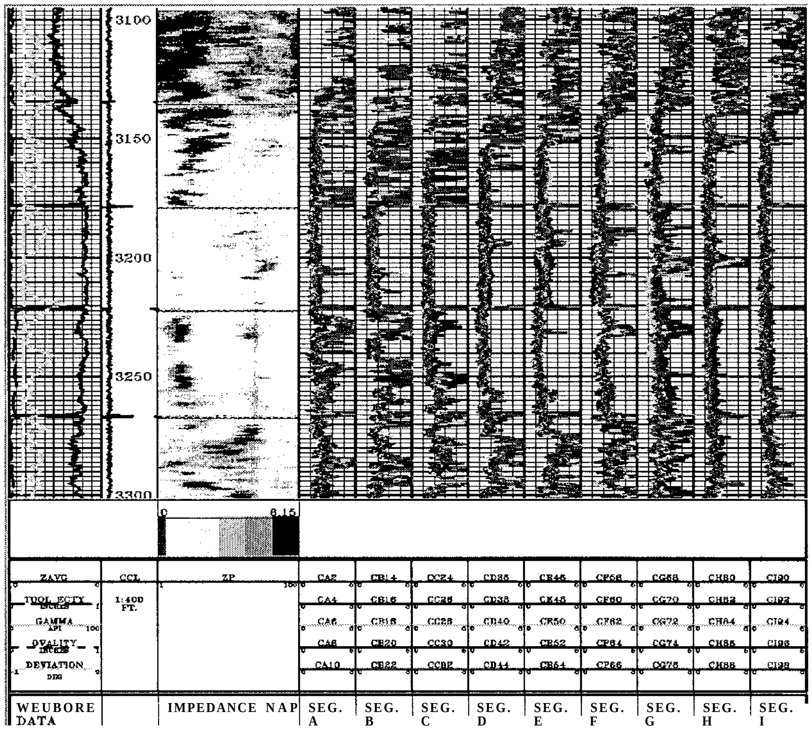

Figure 8 - Evaluation of Prior Foamed Cement Job without Zonal Isolation

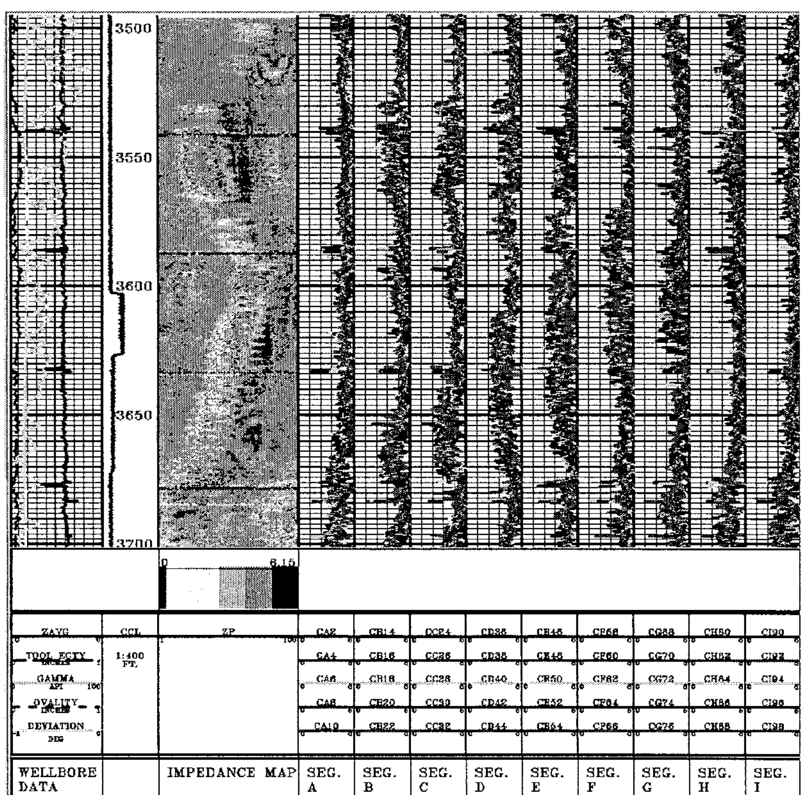

Figure 9 - Evaluation of Foamed Cementing with Zonal Isolation

Wells w/o Zonal Isolation

- Ave. 18 - 10 BOPD
- Ave. 650 - 350 mcf gas
- Ave. 600-800 BWPD

Wells with Zonal Isolation

- Ave. 44 - 31 BOPD
- Ave. 500 - 400 mcf gas
- Ave. 400-600 BWPD

Figure 10 - Comparison in Production and Offset Improvements from Better Injectivity

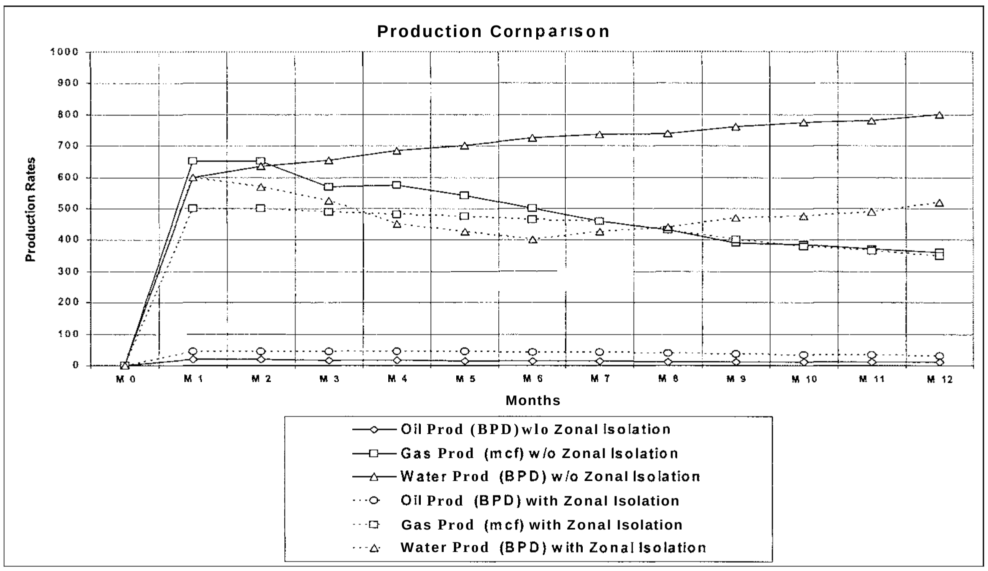

Figure 11- Comparison of Gaining Zonal Isolation vs. Not Gaining This Integrity

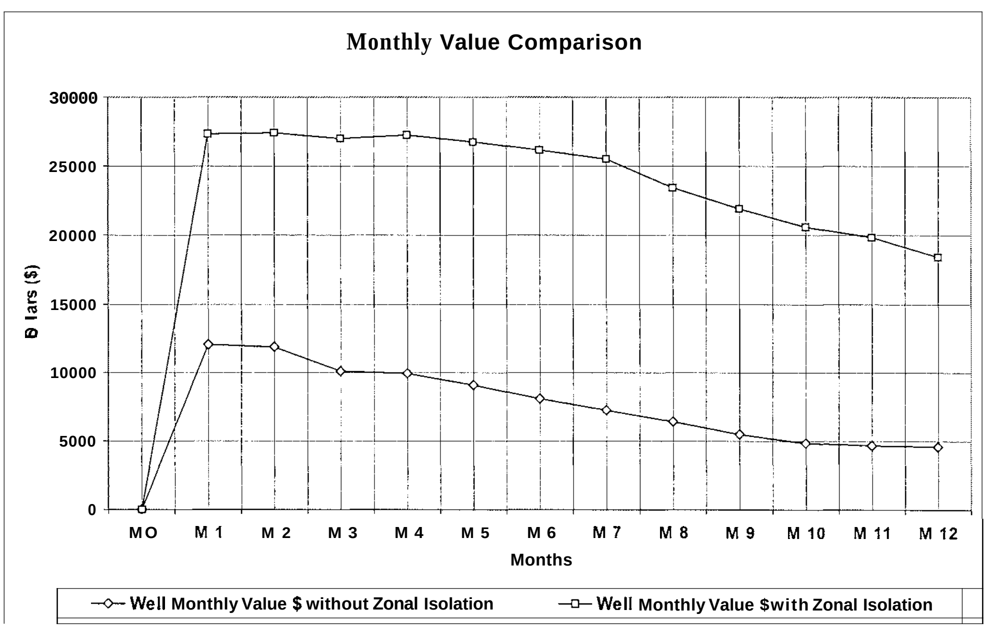

Figure 12- Average per Well: Oil and Gas Production and Water Disposal Costs

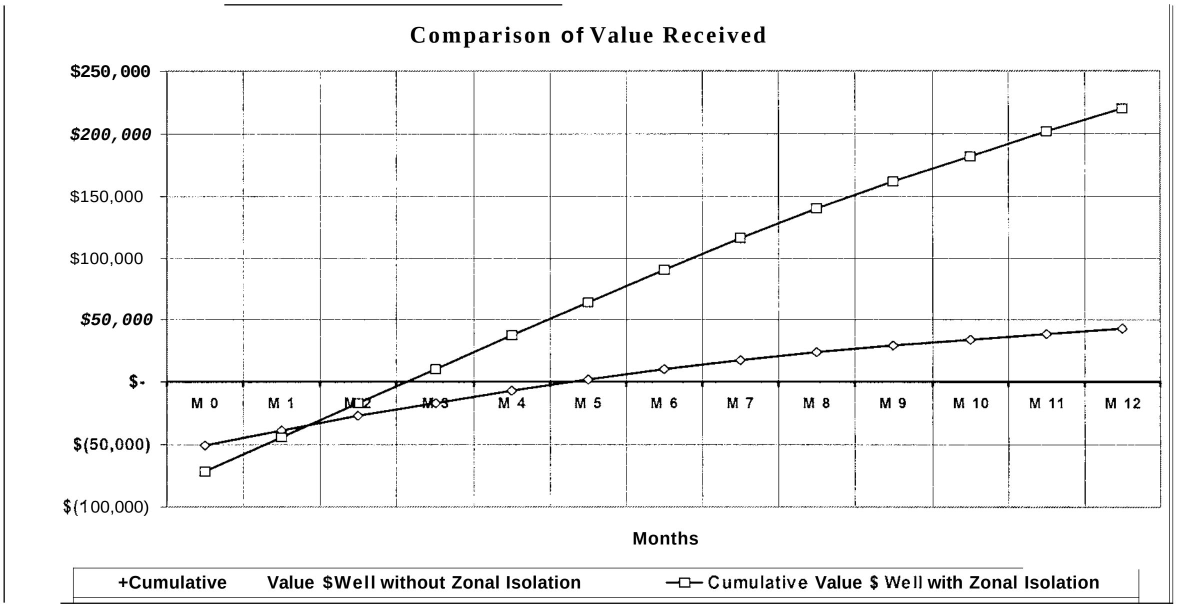

Figure 13 - Comparison of Cumulative Value per Well (1st year) Including Initial Completion Costs

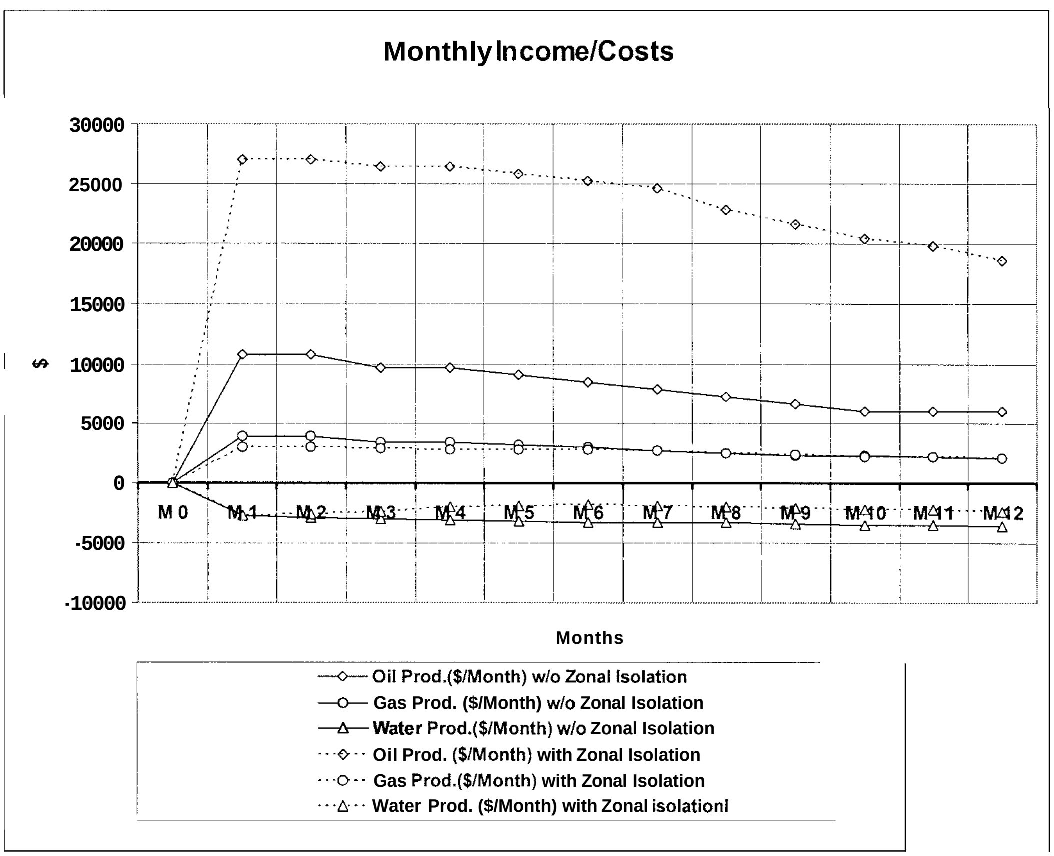

Figure 14 - Comparison of Monthly Income/Costs