Waterfracs: A Perspective of 8+ Years of Intense Study and a Review of 60+ Years of Field Work

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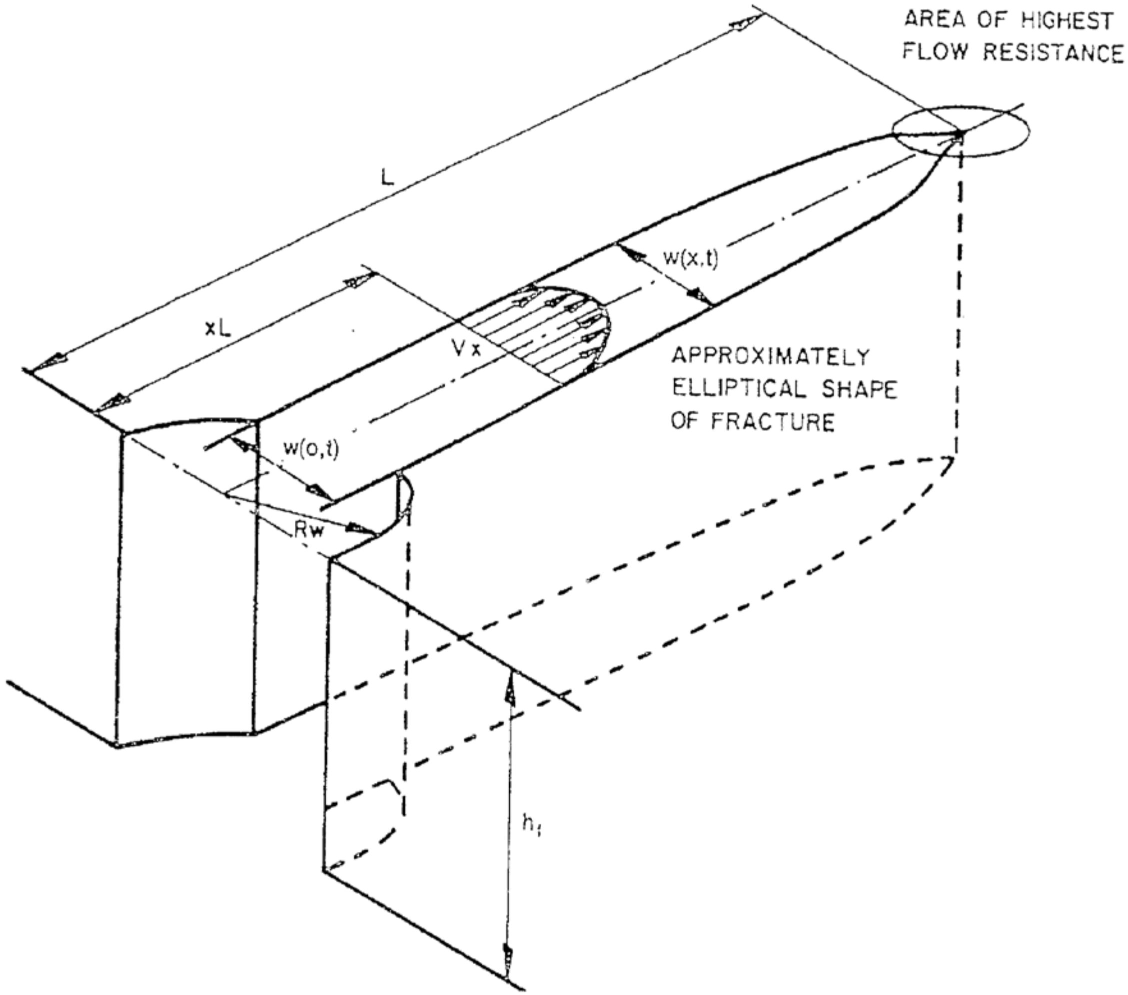
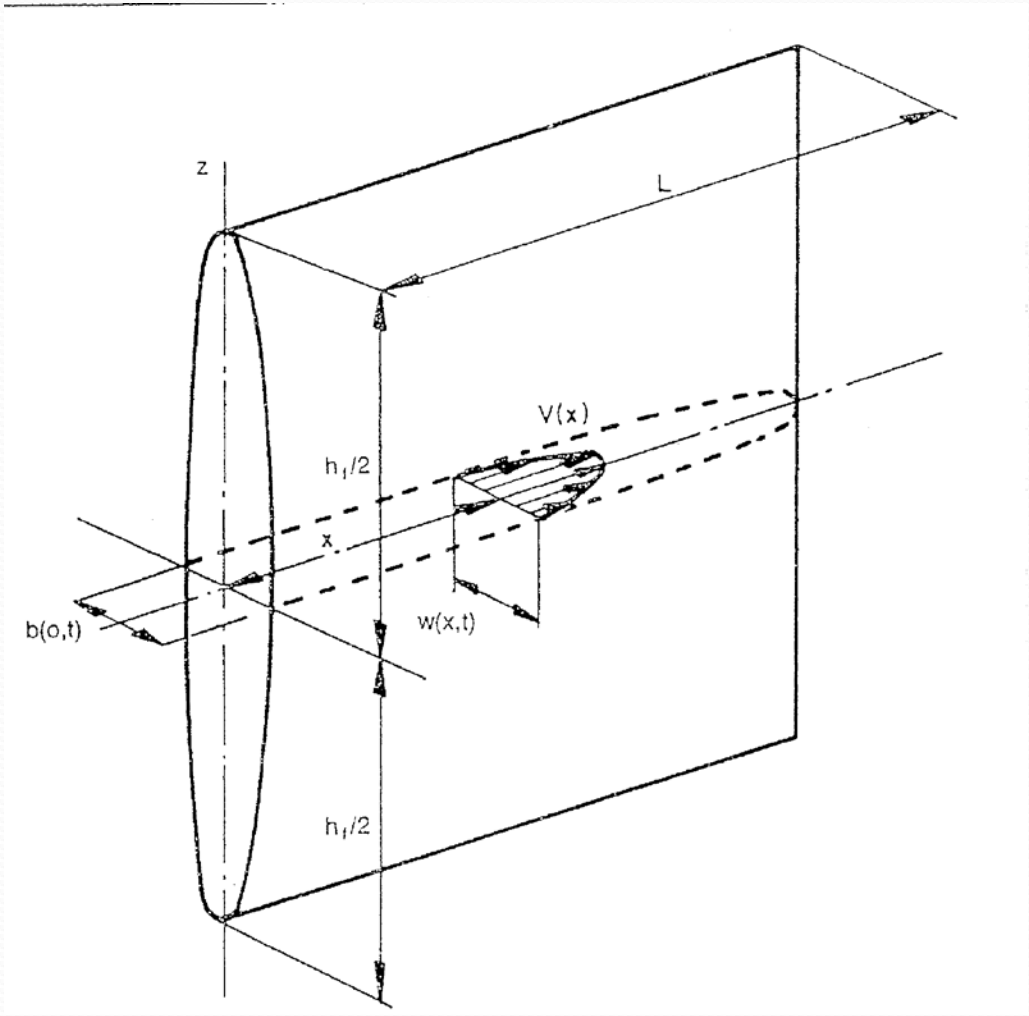
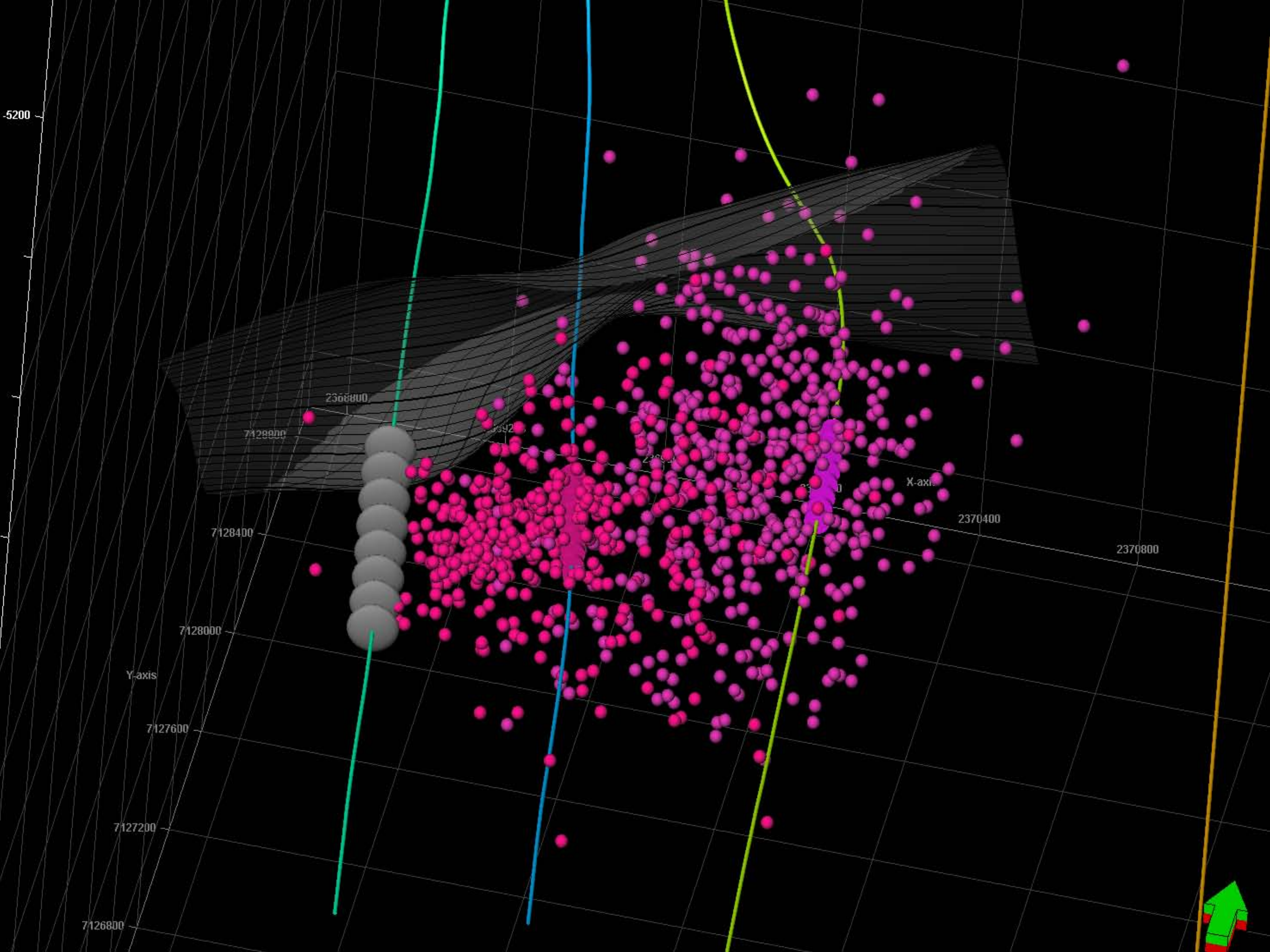
Waterfracs “A Perspective”



Waterfracs “A Perspective”

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Y-axis
7127600
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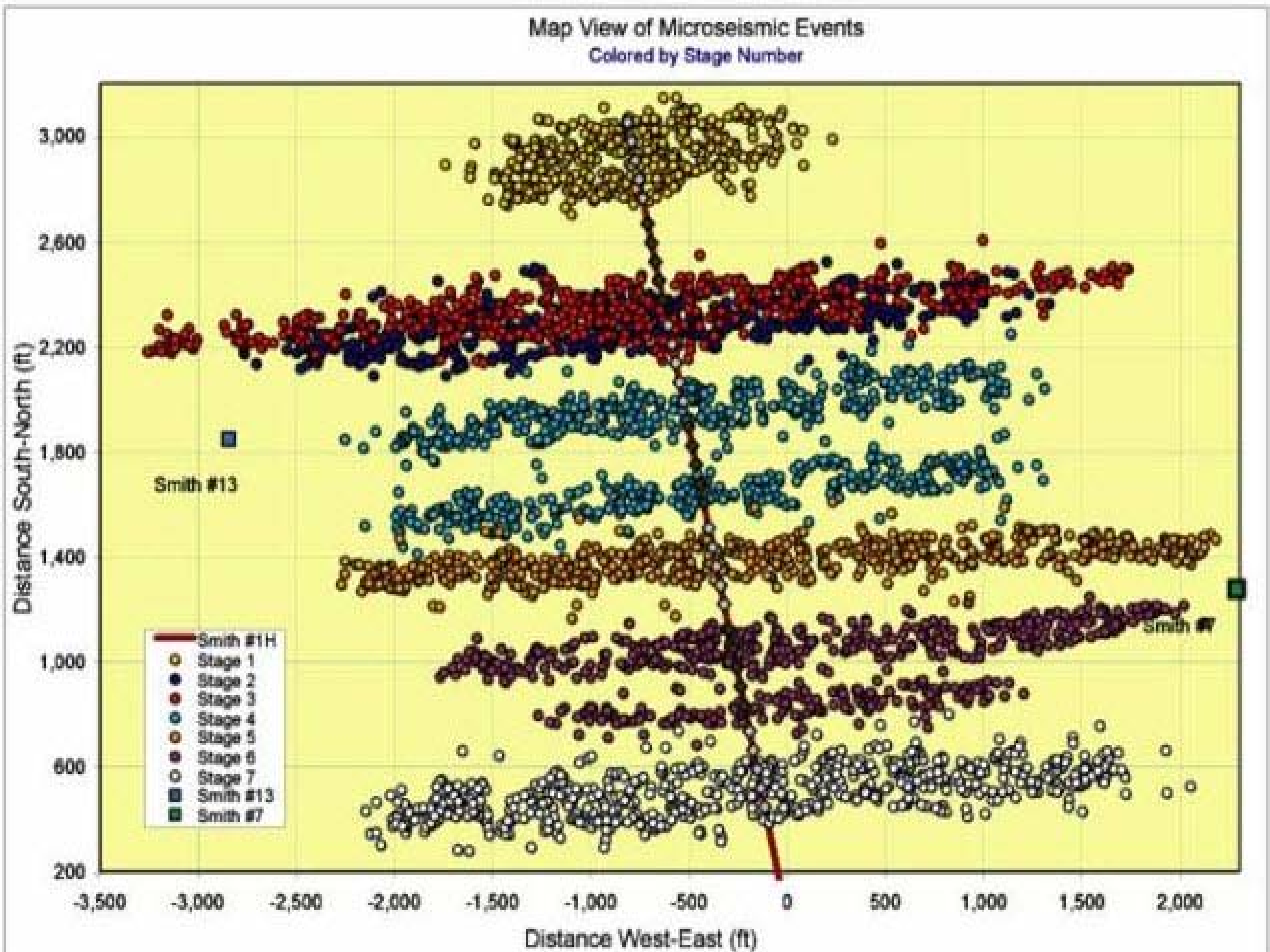
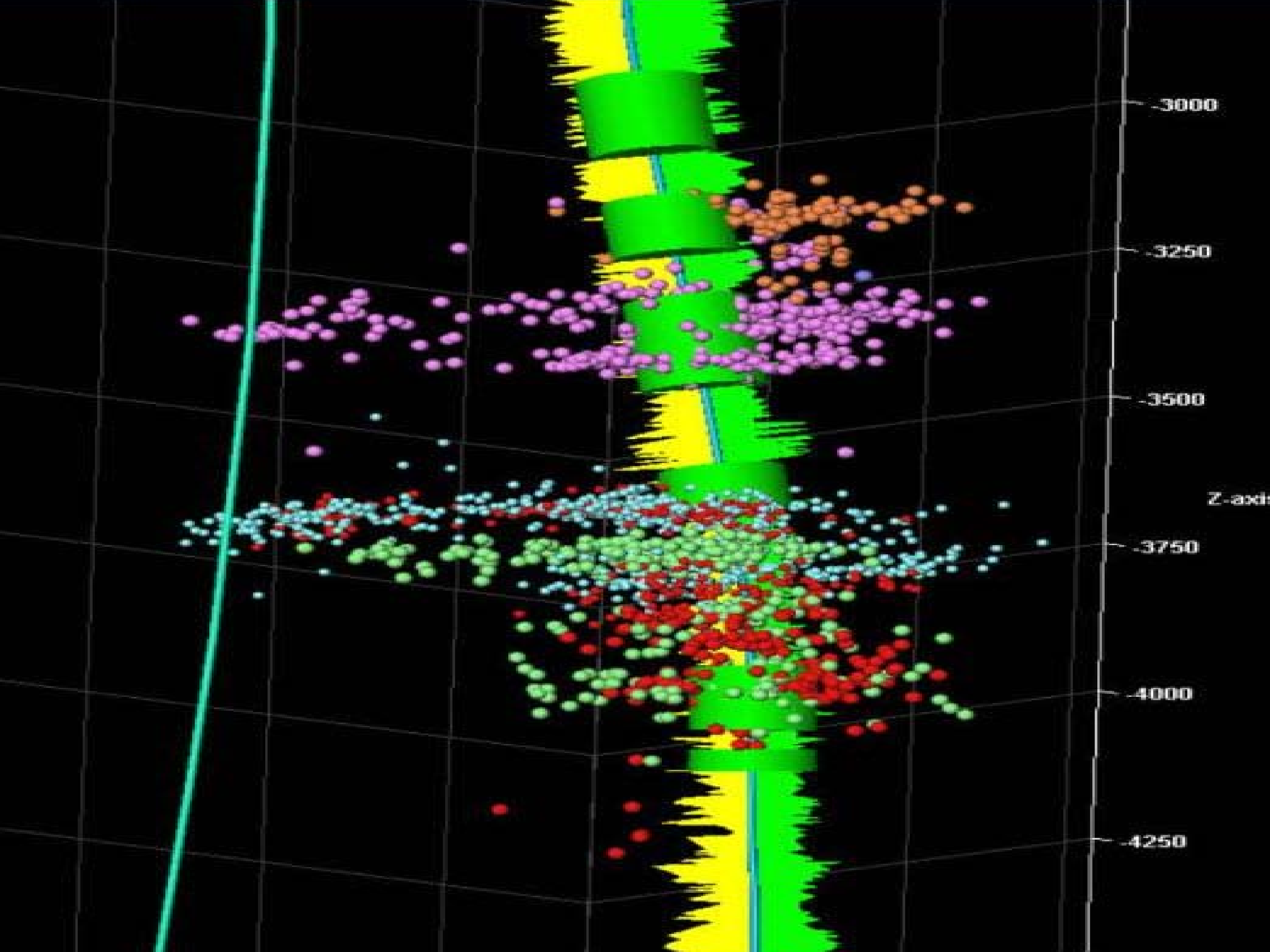


Map View of Microseismic Events
Colored by Stage Number
Distance South-North (ft)
Distance West-East (ft)
3,000
2,600
2,200
1,800
1,400
1,000
600
200
-3,500
-3,000
-2,500
-2,000
-1,500
-1,000
-500
0
500
1,000
1,500
2,000
Smith #13
Smith #7
Smith #1H
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
Stage 6
Stage 7
Smith #13
Smith #7


-3000
-3250
-3500
Z-axis
-3750
-4000
-4250

Waterfracs "A Perspective"

- It would be surprising and perhaps unimaginable to some in our industry to find that for more than 20 years, prior to the advent of the age of crosslinked gels, that a large majority of frac treatments were pumped using low viscosity fluids.
- These fluids varied from water only, to lease oil, to in some cases low viscosity linear gels. There were a small amount of jobs done with emulsified fluids and viscous gels prepared with fatty acids and soap. There were excellent results achieved particularly when one looks at the volumes used.

Waterfracs "A Perspective"

- When Exxon introduced "Superfrac" which was fairly quickly followed by crosslinked guars our industry started a movement that went on for more than 35 years where hydraulic fracturing was dominated by ultra high viscosity fracturing fluids.
- It goes without saying that these high viscosity frac fluids achieved a great deal of success in conventional reservoirs dominated by matrix production.

Waterfracs "A Perspective"

- As these new fluids were developed there was a simultaneous development of progressively more complicated frac design models built around the creation of single Planar fractures. This ability to create a dominate fracture is, I believe, the actual reason that has led to the downfall of high viscosity fluids and the growing dominance of water fracs.

Waterfracs "A Perspective"

- Because of the inherent property i.e. ,very high viscosity at low shear, these viscous gels tend to create at least a minimum number or at best a single fracture perpendicular to the least principal stress. This very attribute condemns this type of fluid in naturally fractured reservoirs.

Waterfracs "A Perspective"

- High viscosity fracturing has little or no chance of succeeding in a naturally fractured reservoir due to the fact that any created fracture will simply parallel the natural fractures.
- With low viscosity fluids the fracturing fluids tend to follow the natural fractures. Since many of the shale plays have no significant dominate stress, a very plausible reason for the success of water fracs is presented.

Waterfracs "A Perspective"

- In the past 7-8 years this trend toward high viscosity fluids has been reversed and the majority of all fracturing fluids consist of water sometimes slightly viscosified.
- The widespread success of waterfracs has not been restricted to source rocks but this technology has been transferred to almost all conventional reservoirs where either natural fractures exist or where fracturable rock is present

Waterfracs “A Perspective”

- Why the added emphasis now?

1. Success in the Barnett and Woodford shales.
2. Transferred success in a plethora of very “conventional reservoirs”. Examples are the Cotton Valley, Travis Peak, Granite Wash, Cleveland, etc. etc.

Waterfracs “A Perspective”

- Why the added emphasis now? (cont.)

3. Tremendous acceleration in learning curve of how to complete in unconventional rock.
4. A tremendous number of reservoirs which were uneconomic to produce when stimulated with viscous fracturing fluids.

Waterfracs "A Perspective"

- What's different in completion techniques?

1. Everything!
2. Typically, but not certainly not universally, because of the dominance of fractured permeability, the wells must be completed horizontally.
3. The type of isolation mechanism depends upon the nature of the rock. Isolation of separate intervals is an absolute necessity to optimize stimulation and production.

Waterfracs "A Perspective"

- What's different (cont)

4. Fracture design (They can be modeled)

   Everything that is sacrosanct in conventional design is open game in design of these treatments.

   a. Large pad volumes with thin fluids.
   b. Sweeps and over flushing are not only good but necessary.
   c. Perforating "Geophysically"

Waterfracs "A Perspective"

- What's different (cont.)
  d. Perforating not based on lithology, porosity, crossover, etc etc.
  e. Proppant selection not based on proppant pack conductivity.
  f. Surfactants, as is the case in microdarcy rock, have been found to not be beneficial and in some cases detrimental.

Waterfracs "A Perspective"

- Where terrain or other logistical circumstances exist, non stabilized foams have proved to be an effective substitute.
- It is our belief and experience that "Hybrid" treatments are not beneficial and can be detrimental to successful stimulation in naturally fractured rock.

Waterfracs "A Perspective"

- Complications of Waterfrac Designs

1. Conventional completion mindset.
2. Perforations should be picked from FMI or other source of identifying natural fractures. Perforating using conventional procedures will result in pain and misery.
3. Tortuosity is really defined by perforating in the wrong place, in this case, in the matrix of the shale.

Waterfracs "A Perspective"

- Complications of Waterfrac Completions

4. The use of acid even in non reactive rock has been found to be extremely advantageous.
5. Diagnostics in the classic sense have been found to be potentially very non-productive.
6. Not unlike Coal Seam Stimulation, once you have started pumping you do not want to shut down.

Waterfracs “A Perspective”

- Complications of Waterfrac Completions

7. Too aggressive pump-ins can doom the frac to failure.
8. Conventional monitoring of net pressure plots is counterproductive.
9. Building net pressure or not over flushing are not positive in the treatment of naturally fractured reservoirs.

Waterfracs “A Perspective”

- Understanding the mechanism of stimulation of rocks which do not have a dominate stress

1. Obtaining a dominate fracture is counterproductive.
2. Proppant packs are also counterproductive.
3. Stimulation is achieved by bridging and diverting in a maze of fractures and the natural fractures are held open by the proppant yielding infinite conductivity.

Waterfracs "A Perspective"

- Understanding the mechanism of stimulation of rocks which do not have a dominate stress (cont.)

4. The use of large proppants and even tailing in with large proppants has been counterproductive. For most areas the use of 30/50-40/70 proppant has been dominate but fairly recently large volumes of 100 mesh (70/140) has found success in the Barnett. In other areas 100 mesh has not functioned well as a proppant/bridging/diverting agent.
5. One very interesting finding is that where there appears to not be a dominate stress, the expected closure on proppant based upon fracture closure is not seen.

Waterfracs “A Perspective”

- Selecting Waterfrac Candidates

1. Naturally fractured reservoirs or fracturable rock---(evidence of drilling induced fractures).
2. Stacked sand shale sequences. The differential width allows for bridging of proppant and created open fractures.
3. Formations where high viscosity fracs have failed.

Waterfracs "A Perspective"

- Selecting Waterfrac Candidates

4. Sub cutoff porosity conventional reservoirs with good gas shows—indications of natural fractures.
5. Formations with indications of pressure dominated leak off. Don't slow down-increase rate and dilate the fracture.

Waterfracs "A Perspective"

- On Waterfrac Design

1. High rate is a necessity
2. Large volumes are required
3. We feel very strongly that proppant is required
4. The use of polymer at low concentration is essential when using high density proppant
5. Keep the fluid simple---very little magic required.
6. Be prepared for tortuosity-slugs acid etc.

Waterfracs "A Perspective"

- On Waterfrac Design

7. Perforation placement and absolute control of fluid and proppant is essential. Concentrating energy into natural fracture systems is a key to success.
8. Pseudo Limited Entry is beneficial in most reservoirs.
9. Sufficient pad should be pumped to put formation in a situation of stasis.

Waterfracs "A Perspective"

- On Waterfrac Design

10. The use of spacers or "sweeps" is tremendously beneficial in achieving proper distribution of proppant as far as possible from the well bore.
11. We have not found a reservoir where surfactant was required---we feel that surfactants for the most part are detrimental in low permeability rock.

Waterfracs "A Perspective" Recommendations & Comments Concerning "Water Fracs"

1. Use Large volumes and extend sand / sweep stages to no greater than 2 pounds per gallon.---Volume and surface area is the desire not conductivity.
2. Utilize 3D Frac models for design. The input data is correct!
3. Keep the fluids simple—water and proppant are the only truly necessary items.
4. Utilize capillary suction tests to identify what fluid should be used---Specify fluids to be tested –never use distilled water.

Waterfracs "A Perspective" Recommendations & Comments Concerning "Water Fracs"

5. The Water Frac technique properly applied has opened up huge areas of heretofore non economic reservoirs. Combined with Horizontal Drilling there is the potential for tremendous increases in recoverable reserves.
6. "Water Fracs" containing breaker and some proppant provide excellent refrac opportunities for applicable formations.

WELL / LOCATION: Michigan
FORMATION: Stacked Shale Sand sequence
Perforations 5,010-14, 5,034-38, 5,050-54, 5,062-66, 5,073-77
5,123-27, 5,133-37, 5,172-76 1 spf 32 .43" holes

Stage	Fluid Type	Fluid Volume (gals)	Proppant Concentration (ppg)	Stage Proppant (lbs)	Injection Rate (bpm)
1.	15 % HCL	2,000	-	-	10-70
2.	KCL Water + F.R.	85,000	-	-	70
3.	"	5,000	1 #/gal 100 mesh	5,000	70
4.	"	90,000	-	-	70
5.	"	5,500	.1	550	70
6.	"	5,500	-	-	70
7.	"	5,500	.2	1,100	70
8.	"	5,500	-	-	70
9.	"	5,500	.4	2,200	70
10.	"	5,500	-	-	70
11.	"	5,500	.6	3,300	70
12.	"	5,500	-	-	70
13.	"	5,500	.8	4,400	70
14.	"	5,500	-	-	70
15.	"	5,500	1	5,500	70
16.	"	5,500	-		70
17.	"	5,500	1	5,500	70
18.	"	5,500	-		70
19.	"	5,500	1	5,500	70
20.	"	5,500	-		70
21.	"	5,500	1.25	6,875	70
22.	"	5,500	-		70

23.	"	5,500	1.25	6,875	70
24.	"	5,500	-	-	70
25.	"	5,500	1.25	6,875	70
26.	"	5,500	-	-	70
27.	"	5,500	1.5	8,250	70
28.	"	5,500	-	-	70
29.	"	5,500	1.5	8,250	70
30.	"	5,500	-	-	70
31.	"	5,500	1.5	8,250	70
32.	"	5,500	-	-	70
33.	"	5,500	1.75	9,625	70
34.	"	5,500	-	-	70
35.	"	5,500	1.75	9,625	70
36.	"	5,500	-	-	70
37.	"	5,500	1.75	9,625	70
38.	"	5,500	-	-	70
39.	"	5,500	2	11,000	70
40.	"	5,500	-	-	70
41.	"	5,500	2	11,000	70
42.	"	5,500	-	-	70
43.	"	5,500	2	11,000	70
44.	"	5,500	-	-	70
45.	"	5,500	2.25	12,375	70
46.	"	5,500	-	-	70
47.	"	5,500	2.25	12,375	70
48.	"	5,500	-	-	70
49.	"	5,500	2.25	12,375	70
50.	"	5,500	-	-	70
51.	"	5,500	2.5	13,750	70
52.	"	5,500	-	-	70
53.	"	5,500	2.5	13,750	70
54.	"	8,200	-	-	70

TOTALS: Fresh water - 500,000 gals. Plus tank bottoms*
40/70 Ottawa Sand - 199,925 lbs

- The additional water is for extending flush stages where we are seeing banking and or excess pressure.

DESIGN/FLUID CRITERIA:

1. Design Pump rate - 70 bpm.
2. Maximum Pump rate - 80 bpm.
3. Maximum treating pressure –3,800 psi.
4. HHP required 5,000 HHP plus 50% standby.
5. Fluid – Fresh water with friction reducer.
6. Based on pumping down 5,010' of of 5 1/2" 15.5 # J-155 casing.
7. We will conduct a pump in to ascertain the number of perforations open.

ADDITIVES:
1. Fresh water only.
2. Water based friction reducer.
3. Check for emusion problems run NE if required.

ADDITIONAL EQUIPMENT:
1. 2 in-line densiometer(s).
2. Equipment to perform immediate flowback to closure while monitoring flowback rate and pressure.
3. Sand sieves, and associated equipment to perform QC on location. Sand sieves on all compartments and water analysis on all tanks.
4. 50 % Standby horsepower.
5. Pressure relief valve on the casing and kickouts or popoff required on downhole pumps.
6. Have ball gun on site and 48 low temperature bioballs for ballout if perforations are not all open.

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WELL / LOCATION: Nacogdoches County Texas
FORMATION: Upper Travis Peak
2 spf 30 .37” holes 60 degree phasing

Stage	Fluid Type	Fluid Volume (gals)	Proppant Concentration (ppg)	Stage Proppant (lbs)	Injection Rate (bpm)
	15 % HCl	2,000	-	-	5-20
	Fresh water + FR	120,000	-	-	65
	“	10,000	1 # 100 Mesh	10,000	65
	“	120,000	-	-	65
	“	10,000	1 # 100 Mesh	10,000	65
	“	110,000	-	-	65
	“	7,000	.1 40/70	700	65
	“	7,000	-	-	65
	“	7,000	.25 40/70	1,750	65
	“	7,000	-	-	65
	“	7,000	.5 40/70	3,500	65
	“	7,000	-	-	65
	“	7,000	.75 40/70	5,250	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65

	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65

	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1 40/70	7,000	65
	“	7,000	-	-	65
	“	7,000	1.25 40/70	8,750	65
	“	7,000	-	-	65
	“	7,000	1.25 40/70	8,750	65
	“	7,000	-	-	65
	“	7,000	1.25 40/70	8,750	65
	“	7,000	-	-	65
	“	7,000	1.25 40/70	8,750	65
	“	7,000	-	-	65
	“	7,000	1.25 40/70	8,750	65
	“	7,000	-	-	65
	“	7,000	1.25 40/70	8,750	65
	“	7,000	-	-	65
	“	7,000	1.5 40/70	10,500	65
	“	7,000	-	-	65
	“	7,000	1.5 40/70	10,500	65
	“	7,000	-	-	65
	“	7,000	1.75 40/70	12,250	65
	“	7,000	-	-	65
	“	7,000	1.75 40/70	12,250	65
	“	7,000	-	-	65
	“	7,000	2.0 40/70	14,000	65
	“	7,000	-	-	65
	“	7,000	2.0 40/70	14,000	65
	“	9,000	-	-	65

TOTALS:	15 % HCL	-	2,000 gals Plus tank bottoms
	Fresh water + FR	-	1,020,000 gals. plus tank bottoms*
	100 mesh Sand	-	20,000 lbs.
	40/70 Tempered LC**	-	326,200

DESIGN/FLUID CRITERIA:

- Design Pump rate – 65 bpm.
- Maximum Pump rate- 75 bpm.
- Maximum treating pressure – 6,200 psi.
- HHP required 9,000 HHP plus 50% standby.
- All fluids should be Continuous mixed. Based on pumping down 8,343’ of 4 ½” 11.6 # N-80 casing.

*Extra water required for extending stage if pressure increase noted.
** Or equivalent.

Additives:

- Water based friction reducer
- Biocide if required. Common bleach will suffice
- Scale inhibitor if required.

ADDITIONAL EQUIPMENT:

- 2 in-line densiometer(s).
- pH measurement, sand sieves, and associated equipment to perform QC on location. Sand sieves on all compartments and water analysis on all tanks.
- 50% Standby horsepower.
- Pressure relief valve on the casing and kick-outs or pop-off required on down hole pumps.

WELL / LOCATION: North Texas
FORMATION: Bend Conglomerate Vertical
PERFS: 6,360-70, 6,402-10, 6,416-24 4 spf 104 .43” holes

Stage	Fluid Type	Fluid Volume (gals)	Proppant Concentration (ppg)	Stage Proppant (lbs)	Injection Rate (bpm)
	Water + F.R.	120,000	-	-	150
	“	10,000	1 # 100 Mesh	10,000	150
	“	120,000	-	-	150
	“	10,000	1 # 100 Mesh	10,000	150
	“	120,000	-	-	150
	“	10,000	1 # 100 Mesh	10,000	150
	“	110,000	-	-	150
	“	12,000	.1 40/70	1,200	150
	“	12,000	-	-	150
	“	12,000	.1 40/70	1,200	150
	“	12,000	-	-	150
	“	12,000	.25 40/70	3,000	150
	“	12,000	-	-	150
	“	12,000	.25 40/70	3,000	150
	“	12,000	-	-	150
	“	12,000	.5 40/70	6,000	150
	“	12,000	-	-	150
	“	12,000	.5 40/70	6,000	150
	“	12,000	-	-	150
	“	12,000	.75 40/70	9,000	150
	“	12,000	-	-	150
	“	12,000	.75 40/70	9,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150

	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1 40/70	12,000	150
	“	12,000	-	-	150
	“	12,000	1.25 40/70	15,000	150
	“	12,000	-	-	150
	“	12,000	1.5 40/70	18,000	150
	“	12,000	-	-	150
	“	12,000	1.5 40/70	18,000	150
	“	12,000	-	-	150
	“	12,000	1.5 40/70	18,000	150

	“	12,000	-	-	150
	“	12,000	1.5 40/70	18,000	150
	“	12,000	-	-	150
	“	12,000	1.5 40/70	18,000	150
	“	12,000	-	-	150
	“	12,000	1.75 40/70	21,000	150
	“	12,000	-	-	150
	“	12,000	2.0 40/70	24,000	150
	“	14,000	-	-	150

TOTALS:	Fresh water	-	1,360,000 gals. Plus pit bottoms*
	40/70 Ottawa	-	404,400 lbs
	100 Mesh	-	30,000 lbs

The additional water is for extending flush stages where we are seeing banking and or excess pressure.

DESIGN/FLUID CRITERIA:

•Design Pump rate - 150 bpm.
•Maximum Pump rate - 175 bpm.
•Maximum treating pressure –6,200 psi.
•HHP required 13,500 HHP plus 50% standby.
•Fluid – Fresh water with friction reducer
•Based on pumping down 6,360 of 5 1/2 “ 17 # N-80 casing.

ADDITIVES:

•Water based friction reducer.
•Biocide –common bleach will suffice.
•Scale Inhibitor as needed.

ADDITIONAL EQUIPMENT:

•2 in-line densiometer(s).
•Equipment to perform immediate flowback to closure while monitoring flowback rate and pressure.
•Sand sieves, and associated equipment to perform QC on location. Sand sieves on all compartments and water analysis on pit water.
•50% Standby horsepower.
•Pressure relief valve on the casing and kickouts or popoff required on downhole pumps.

Waterfracs "A Perspective" Conclusions

- "Water Fracs", which have been in existence for a very long time have found a resurgence particularly in Source Rock and low permeability stacked pays.
- "Water Fracs", properly designed have allowed us to economically stimulate and produce formations which heretofore were not economic even with ten dollar gas.
- There is a great deal of confusion in relation to proper design and implementation. We have made significant strides in this direction but a great deal remains to be learned.