Hydraulic Pulse Interference Tests for Site Hydrogeologic Characterization

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ABSTRACT: Hydraulic pulse interference tests involve a cyclic injection of fluid into the source well, and by high precision measurement of the pressure pulse in a neighboring well, detailed hydraulic characterization between wells can be made. The pulse interference test is highly sensitive to hydrogeological properties between the pulse source and receiver wells. The transient nature of the test, involving the time delay and attenuation of the hydraulic pulse, enables the formation's complete hydraulic properties to be computed. The advantages of the pulse interference test are the short duration of the test, the high resolution and directional characterization data obtained, and the lack of any generated contaminated groundwater. The hydraulic pulse interference test is ideal for characterizing a site for groundwater remediation systems such as iron permeable reactive barriers and accelerated bioremediation injection systems. The hydraulic conductivity of the site formation and the hydraulic connectivity between wells are of utmost importance when designing such systems. Hydraulic pulse interference tests are presented for two case histories; one involving a subsurface iron permeable reactive barrier in a sand and gravel deposit, and the second for a accelerated bioremediation injection system in a fractured basalt bedrock overlain by a sand, gravel and clay glacial deposit. The pulse interference data are presented as pressure time histories and interpreted by type curve analyses for both the porous media and fractured bedrock sites. Data from these hydraulic pulse interference tests were utilized directly in the design of both remediation systems, the iron permeable reactive barrier and the accelerated bioremediation injection system.

HYDRAULIC PULSE INTERFERENCE TEST

Hydraulic pulse interference tests have been utilized in the petroleum industry since the mid sixities, Johnson et. al. (1966), Earlougher (1977), Lee (1982), Kamal (1983) and Horne (1995), primarily as full penetrating aquifer tests, but in some cases as vertical pulse interference tests. The test involves a cyclic injection or withdrawal of fluid from the source well followed by a shut in period, and by high precision measurement of the pressure pulse in a neighboring well, detailed hydraulic characterization between wells can be made, see Figure 1. The hydraulic pulse interference test is highly sensitive to hydrogeological properties between the pulse source and receiver wells. The time delay and attenuation of the hydraulic pulse enable the formation hydraulic properties to be computed. Since the test is a transient test, both the formation transmissivity and storativity can be calculated for a full aquifer penetrating test. Type curves are available for interpreting pulse interference tests, either as a fully penetrating wellbore, with and without borehole storage effects, or partially penetrating wellbore system.

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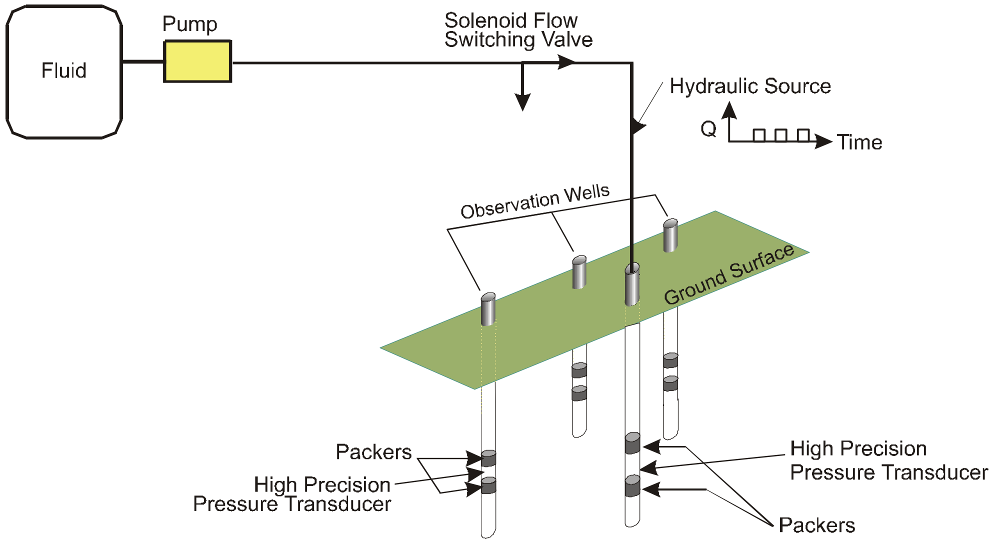

FIGURE 1. Point Source Hydraulic Pulse Interference Test

Pulse interference testing has not been used extensively in the groundwater or environmental fields. However, considering the advantages of the test; namely, it's short duration, high resolution and directional characterization data obtained, and the lack of any generated contaminated groundwater, the test has considerable merit for both groundwater and environmental applications. To obtain maximum hydraulic property resolution (Hocking and Wells, 1997), the pulse interference test can be constructed as a point source utilizing straddle packers in the injector well. The flow rate into the source injector well is rate controlled and set at a constant flow rate, which will depend on the site hydrogeological conditions. The pulse source and receivers can be located at differing depth locations in their respective wells yielding a detailed quantification of the site's hydrogeological properties.

The mathematical solution of the point source pulse interference test has been presented earlier, Hocking (2001), along with a generated type curve for a point source pulse test in a finite confined aquifer system. A site's hydrogeological parameters idealized as either porous or fractured media can be quantified by the pulse interference test using the appropriate type curves or non-linear regression analysis. The source well injection system consists of inflatable straddle packers to isolate the injection horizon, and a pressure transducer is placed in the source well to monitor injection pressures. The receiver well system also consists of straddle packers isolating the high precision pressure transducer from wellbore storage effects. The injection flow rate is controlled by a constant flow rate direct drive pump with solenoid adjustable time interval switching values to modulate the periodic timed injection and shut in of the source well. A typical hydraulic pulse interference test system and receiver well test response data are shown on Figure 2.

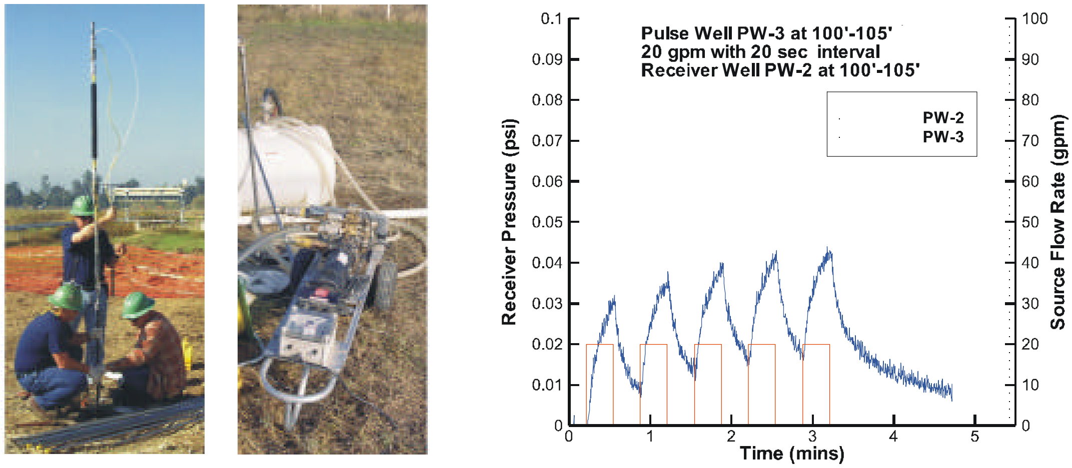

FIGURE 2. Typical Hydraulic Pulse Interference Test Setup & Response Data

During the pulse interference test, the source well's flow rate and pressure are monitored along with all of the receiver pressure transducers. It is essential that the pressure transducers are of high precision and that the flow rates and pressures are all continuously monitored and recorded at high data acquisition rates. To ensure the tests are repeatable, the pulse switching mechanism needs to be automatically controlled and recorded on the data acquisition system. To optimize the resolution of the test, the injection/shut in time interval and/or injection flow rate will need to be varied depending on site conditions and the distances between source and receiver wells.

PERMEABLE REACTIVE BARRIER SITE

A deep iron permeable reactive barrier (PRB) was constructed in a sand and gravel deposit by the azimuth controlled vertical hydraulic fracturing technology, as shown in plan and section on Figure 3. Prior to construction of the PRB the site's hydrogeological properties were quantified by hydraulic pulse interference tests conducted perpendicular and diagonally across the PRB alignment. The source pulse well (PW-3) and the receiver wells (PW-1, PW-2 and PW-4) are shown in plan on Figure 3. The hydrogeological system consists of a confined aquifer overlain by an upper confining layer from ground surface down to 35 feet below ground surface and underlain by a lower confining layer at a depth of 110 feet bgs, as shown on Figure 3.

Both the source and receiver wells were straddled packed in a screened well section of 2" diameter from a depth of 100 feet down to 105 feet. The receiver well (PW-2) was located 50 feet from the source well (PW-3). The injection flow rate into the packed off section of the source well was 20 gpm with a pulsed injected time interval of 20 seconds and a shut in time interval also of 20 seconds. The receiver well response is shown on Figure 2 for a series of five (5) pulsed intervals. The maximum receiver pressure response during the first pulsed period is approximately 0.03 psi, with an extremely small time delay between the receiver well response from the source well flow rate change. The injection pressure in the source well was typically less than 5 psi throughout the test. It is imperative in such a test to fully develop the source well after construction, so as to enable high injection flow rates and thus maximize the pulse test resolution.

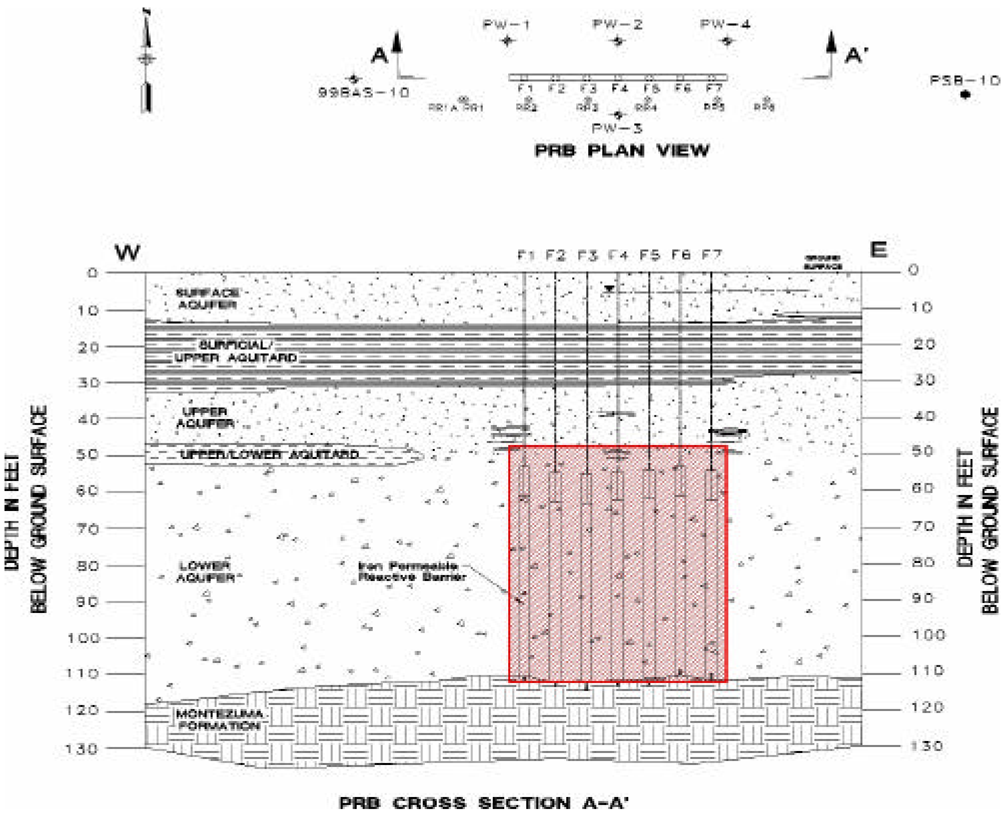

FIGURE 3. Plan and Sectional View of Pulse Test Wells at the PRB Site.

The interpretation of the point source hydraulic pulse interference test follows similar procedures to line source interpretation procedures such as type curves and non-linear regression analysis. The type curve for the confined aquifer test described above was generated using complimentary error function solution modified to account for the periodic nature of the injections and also the confined nature and finite thickness of the aquifer system. The type curve generated is shown on Figure 4 as a plot of dimensionless pressure versus dimensionless time. The dimensionless pulsed time interval is labeled on the type curves for the respective shut in time periods as seen on the pressure descending portion of the curve. The receiver well pressure response in the pulse interference test is overlain on the type curve and matched in response as shown on Figure 4. The receiver well pressure is plotted as pressure in psi versus time in minutes. The match point in pressure from Figure 4 is pressure=$1x10^{-2}$ psi with dimensionless pressure=$7.6x10^{-4}$, yielding a formation hydraulic conductivity of 105 feet per day. The match point in time from Figure 4 is time=1 min with dimensionless time=$2.04x10^{6}$, yielding a formation specific storage of $5.2x10^{-6}$ 1/foot.

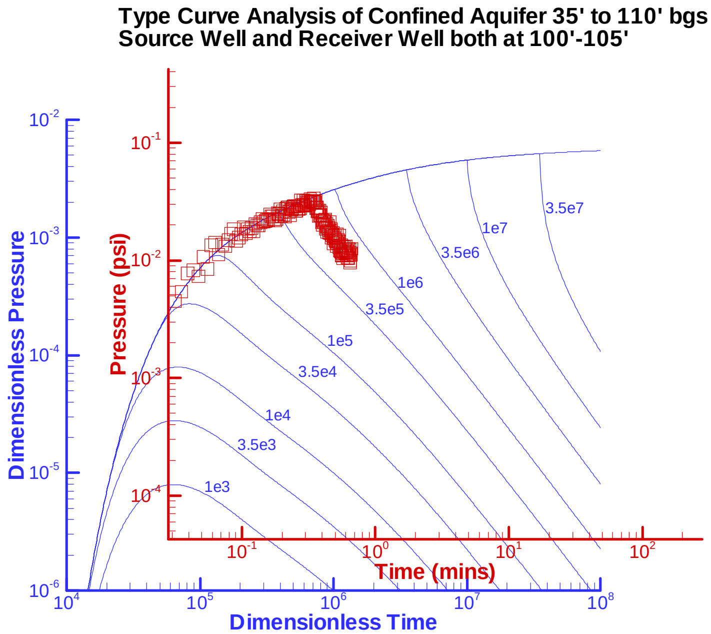

FIGURE 4. Type Curve Match for Hydraulic Pulse Interference Test.

Non-linear regression analysis of the pulse test data yielded similar hydrogeological properties for the formation as quantified by the type curve analysis. The type curve analysis though is significantly less sensitive to noise in the receiver well response compared to the non-linear regression analysis method. The above pulse interference test for quantifying formation hydrogeological properties highlights the advantages of the method; namely, its short duration, a single pulse plus shut in period of 40 seconds, and the injection of only seven (7) gallons of water into the formation.

ACCELERATED BIOREMEDIATION SITE

The accelerated bioremediation site consists of a fractured basaltic bedrock over lain with glacial deposits consisting of gravel, sands and clay layers as shown on Figure 5. The area was investigated for a accelerated bioaugmentation pilot test, in which electron donors augmented with microcosms are to be injected into the subsurface for accelerating the dechlorination of chlorinated solvent contaminants below the groundwater table. Potential injection and monitoring wells were installed in the fractured bedrock, denoted as the C Zone, and in the overlying sediments, denoted as the B Zone. In order to determine hydraulic connectivity, hydrogeological properties and natural groundwater flow velocities, a series of hydraulic pulse interference tests were conducted initially followed by bromide tracer tests. The hydraulic pulse interference tests were conducted in both the B and C Zones. The source pulse injection wells were the B Zone well MW-B19 and the C Zone MW-C19, as shown in plan and section on Figure 5.

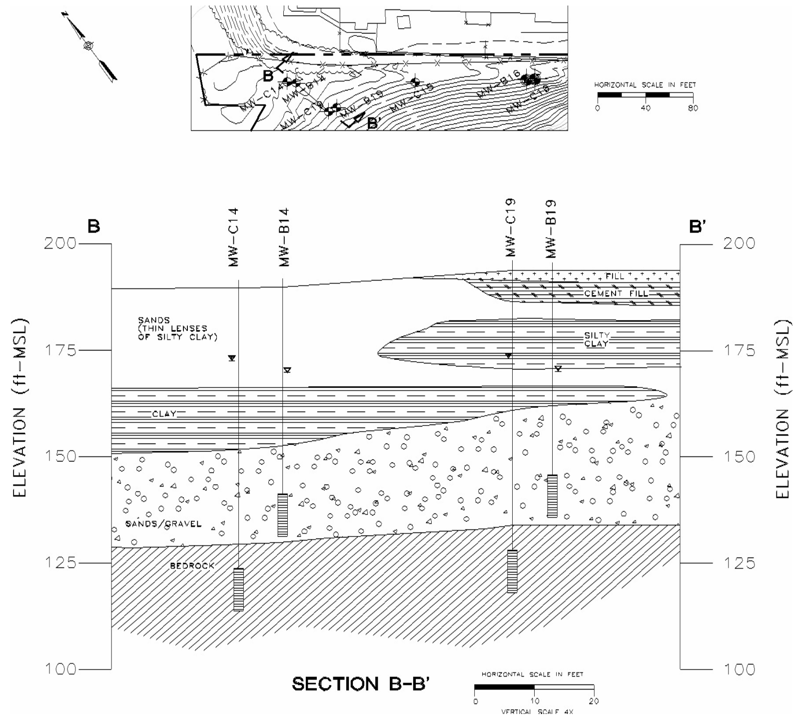

FIGURE 5. Plan and Cross-sectional View of Accelerated Bioremediation Site

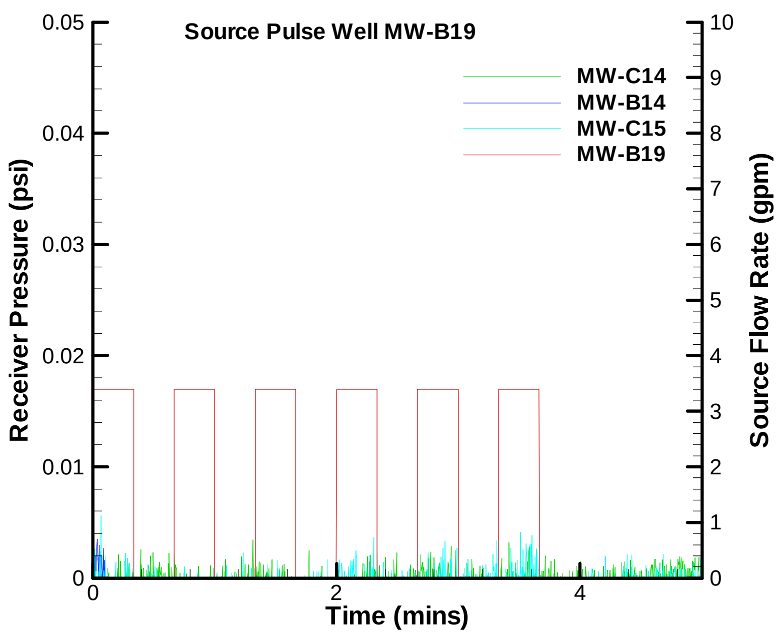

FIGURE 6. Hydraulic Pulse Interference Test Data for Source Well MW-B19

The hydraulic pulse interference test data with MW-B19 as the source well are shown on Figure 6, for the three receiver wells, MW-B14, MW-C14 and MW-C15. The source pulse well was injected at a constant flow rate of 3.4 gpm for a 20 second interval followed by shut in period of 20 seconds for a total of six (6) injection pulses as shown on Figure 6. It is clear from this figure that the B and C Zones are not hydraulically connected in this area. The B Zone wells, MW-B14 and MW-B19 are well connected hydraulically and thus were utilized as injection and monitoring wells for the bioremediation pilot test. The hydraulic conductivity and specific storage of the B Zone formation in this area was quantified from the hydraulic pulse interference data from type curve interpretation as described earlier for the iron PRB site. A bromide tracer was conducted under approximately natural groundwater gradients with MW-B19 as the source well and MW-B14 as the monitoring well. From continuous recording of bromide concentrations in the monitoring well MW-B14, the mean groundwater residence time between the two wells was quantified.

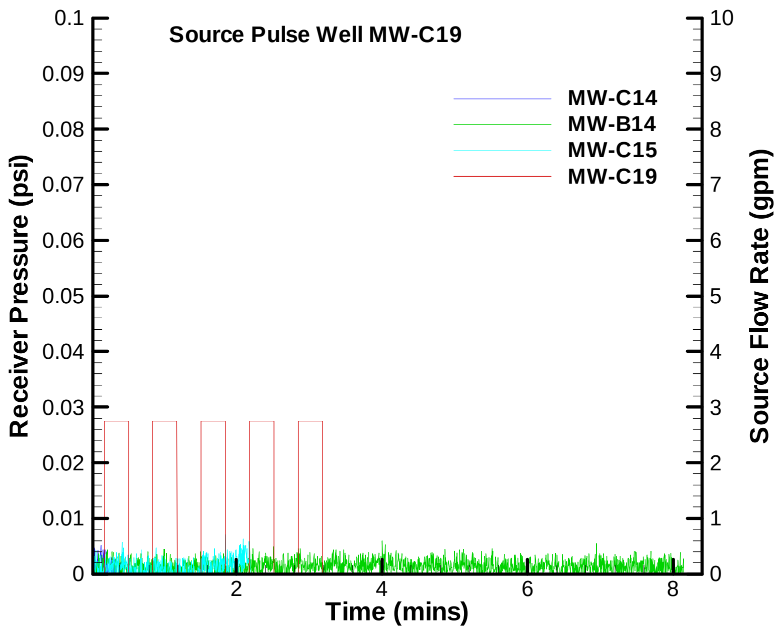

FIGURE 7. Hydraulic Pulse Interference Test Data for Source Well MW-C19

The hydraulic pulse interference test data with MW-C19 as the source well are shown on Figure 7, for the three receiver wells, MW-B14, MW-C14 and MW-C15. The source pulse well was injected at a constant flow rate of 2.75 gpm for a 20 second interval followed by shut in period of 20 seconds for a total of five (5) injection pulses as shown on Figure 7. It is also clear from the data in this figure that the B and C Zones are not hydraulically connected in this area. The C Zone wells, MW-C14 and MW-C19 are moderately well connected hydraulically, while the C Zone well MW-C15 is poorly connected to the source pulse well MW-C19. Since the C Zone wells MW-C14 and MW-C19 were moderately connected, these wells were utilized as injection and monitoring wells for the bioremediation pilot test. The hydraulic conductivity and specific storage of the C Zone formation in this area was quantified assuming an equivalent porous medium from the hydraulic pulse interference data using type curve interpretation as described earlier for the iron PRB site. However, further interpretation utilizing discrete fracture type curves is currently underway to better characterize the fractured basalt bedrock. A bromide tracer was conducted under approximately natural groundwater gradients with MW-C19 as the source well and MW-C14 as the monitoring well. From continuous recording of bromide concentrations in the monitoring well MW-C14, the mean groundwater residence time between the two wells was quantified.

CONCLUSIONS

The hydraulic pulse interference test is an ideal test for the quantification of a site's hydrogeological properties. The pulse interference test is highly sensitive to hydrogeological properties between the pulse source and receiver wells. The transient nature of the test, involving the time delay and attenuation of the hydraulic pulse, enables the formation's complete hydraulic properties to be computed. The method is equally applicable to porous media and fractured bedrock systems. The advantages of the pulse interference test are the short duration of the test, the high resolution and directional characterization data obtained, and the lack of any generated contaminated groundwater during the test.

1.1.1.1 REFERENCES

Earlougher, R.C. (1977). Advances in Well Test Analysis, AIME, NY.

Hocking, G., and S. L. Wells. (1997). Orientated Vertical Hydraulic Fracture Iron Reactive Walls, presented at the ASCE Environmental Group Meeting, Atlanta, GA, March.

Hocking, G. (2001) Hydraulic Pulse Interference Tests for Integrity Testing of Containment and Reactive Barrier Systems, 2001 Int. Containment & Remediation Conf, Orlando, FL, June 10-13.

Horne, R. N. (1995). Modern Well Test Analysis - A Computer-Aided Approach, Petroway, Palo Alto, 2nd. Ed.

Johnson, C. R., R. A. Greenhorn and E. G. Woods (1966). Pulse-Testing: A New Method for Describing Reservoir Flow Properties Between Wells. *JPT*, Vol. 237, pp1599-1604, Trans., AIME.

Kamal, M. M. (1983). Interference and Pulse Testing - A Review. *JPT*, pp2257-2270.

Lee, J. (1982). Well Testing, AIME, NY.