REVIEW OF SEISMIC EVENTS IN LAWRENCE COUNTY PENNSYLVANIA

JANUARY 2017

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

Commonwealth of Pennsylvania
Department of Environmental Protection
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I. BACKGROUND OF SEISMIC EVENTS

The following summary is based on both initial and subsequent refined data relating to several low magnitude earthquakes that occurred in Lawrence County just west of New Castle on April 25, 2016. Epicenter locations for the earthquakes vary slightly based on the degree of data refinement, but in general are confined to Mahoning, North Beaver and Union Townships in Pennsylvania. The earthquakes were registered by PASeis (Pennsylvania State Seismic Network), OhioSeis (Ohio Seismic Network) and LCSN (Lamont-Doherty Cooperative Seismic Network). PASeis advised the Pennsylvania Department of Environmental Protection (DEP) of 4 seismic events, OhioSeis notified DEP of 3 seismic events and LCSN noted 5 seismic events on their website (http://aqms.ldeo.columbia.edu/recent.html). The magnitudes for the quakes ranged from 2.0M_L to 2.3 M_L as reported by PASeis, 1.8 M_L to 2.2 M_L as reported by OhioSeis and 1.8 M_L to 2.1 M_L as reported by LCSN. The first registered earthquake was noted at 08:16:54 UTC (Coordinated Universal Time – this is 4 hours ahead of local time: Eastern Daylight Time (EDT)) on Monday, 4/25/2016; with subsequent events occurring at 09:03:02 UTC and 14:54:26 UTC on 4/25/2016, and a final event occurring at 02:10:23 on Tuesday, 4/26/2016. DEP personnel were notified of the seismic events at 08:54 EDT by PASeis. OhioSeis also notified DEP personnel of the events in the morning of April 25. LCSN noted an initial earthquake at 04:05:25 UTC on Monday, 4/25/2016. LCSN does not directly notify DEP of seismic events within the Commonwealth of Pennsylvania. Depth estimates on the seismic events range from 6,600 feet to 22,000 feet.

II. OIL AND GAS ACTIVITY

Upon receiving notification of the seismic events, DEP personnel began investigating local oil and gas activities. DEP noted that Hilcorp had begun fracking and stimulation activities on a well pad within a 5 mile radius of most of the reported epicenters of the seismic events. This well pad was identified as the North Beaver NC Development and included four (4) wells. These wells were the North Beaver NC 7H (Permit Number - 073-20493); 9H (Permit Number - 073-20512); 10H (Permit Number – 073-20520); and 12H (Permit Number - 073-20521). All four wells target the Utica Formation and have an average true vertical depth of 7,900 feet. Fracking and stimulation activities had begun at the Well Pad on March 30, 2016. The fracking and stimulation activities at the wells with laterals drilled to the southeast (7H and 9H) had been completed, but the wells had not yet been flowed back; activities were ongoing at the wells with laterals drilled to the northwest (10H and 12H)(Figure 1). Individual fracture/treatment stages measured approximately 200 feet along the lateral. Hilcorp was using a fracking technique known as “zipper fracturing” to simultaneously treat two adjacent wellbores while holding pressure in the reservoir.

When DEP contacted Hilcorp in the morning of April 25 about the events, they immediately volunteered to stop all ongoing activities and began demobilization at the site at noon. It was later reported that they would be discontinuing all fracking and stimulation operations at the well pad indefinitely. These actions were implemented voluntarily. At the time of the incident, Hilcorp had fracked and stimulated 28 of a planned 35 stages for the wells drilled to the northwest.

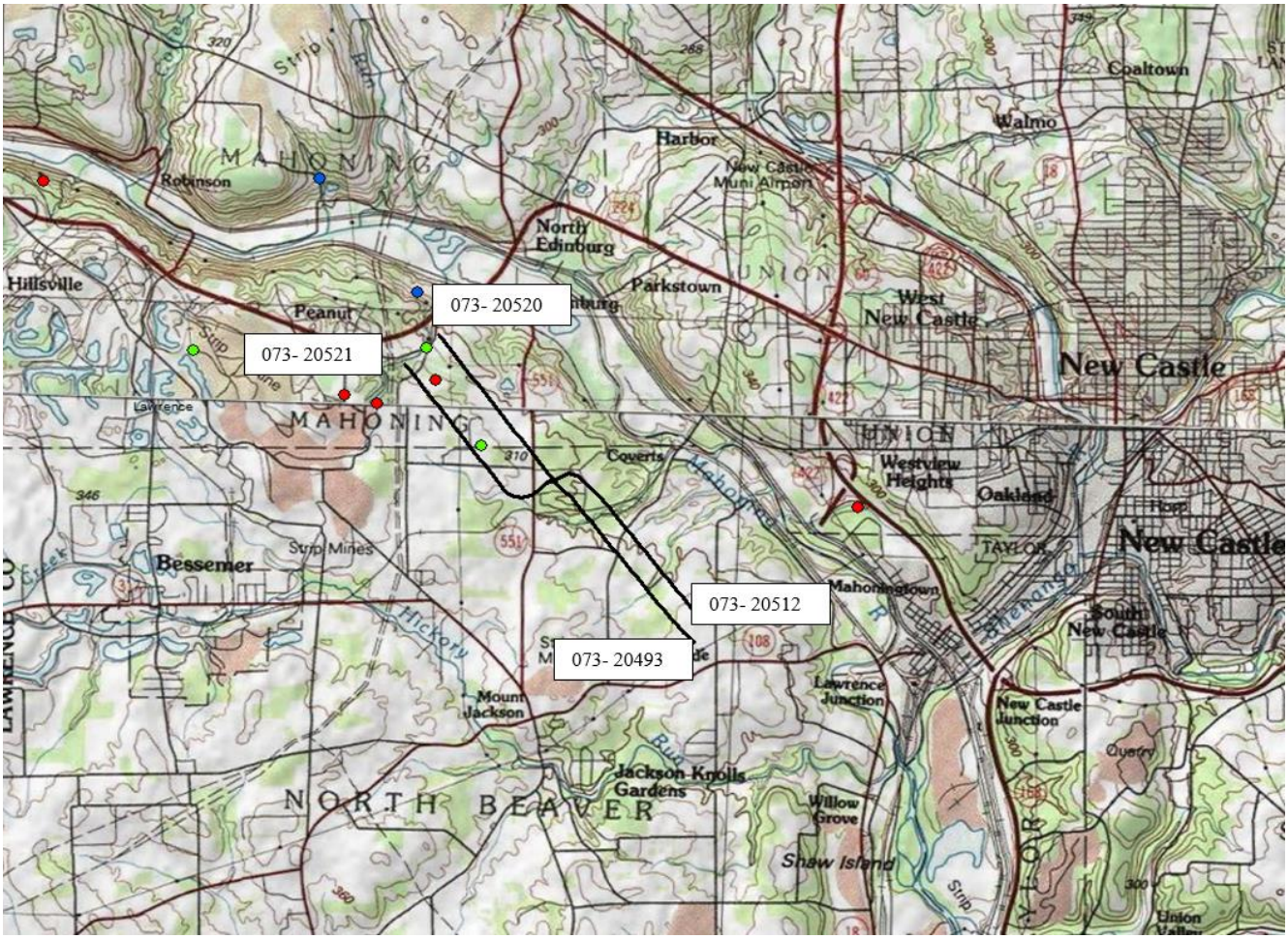

Figure 1. Location of well laterals and reported earthquake epicenters (PASeis – blue dots, OhioSeis - green dots, LCSN - red dots) in Mahoning, North Beaver and Union Townships.

III. GEOLOGIC SETTING

Most of Lawrence County, with the exception of the very southeastern portion, is located within the Northwestern Glaciated Plateau Section of the Appalachian Plateau Physiographic Province of Pennsylvania. This province is defined by broad, rounded to flat uplands having deep, angular valleys generally underlain by shale, siltstone and sandstone (DCNR, Map 13).

The area of the well pad is underlain by Pennsylvanian-age rocks of the Allegheny and Pottsville Groups. Outcrops of the Mississippian-age rocks of the Shenango Formation are noted in the region as well (Figure 2). The Allegheny Group is described as cyclic sequences of shale, sandstone, limestone, clay and coal; while the Pottsville Group is described as predominately gray sandstone and conglomerate with thin beds of shale, claystone, limestone and coal. The Shenango Formation is characterized as light-gray sandstone with some beds of medium-gray shale and siltstone (DCNR, Map 1).

Structurally, Lawrence County is located north and west of the mapped lateral extent of the Rome Trough (Figure 3). This structural feature accommodates a deepening of Precambrian crystalline basement rocks within its extent. It should also be noted that some geologic literature proposes that the Blairsville-Broadtop Lineament extends through Lawrence County and may connect to the Mahoning River Lineament, but currently the mapped extent ends in Butler County (Figure 4). The depth to Precambrian crystalline basement rock in the area of the well pad is approximately 9,500 to 10,000 feet.

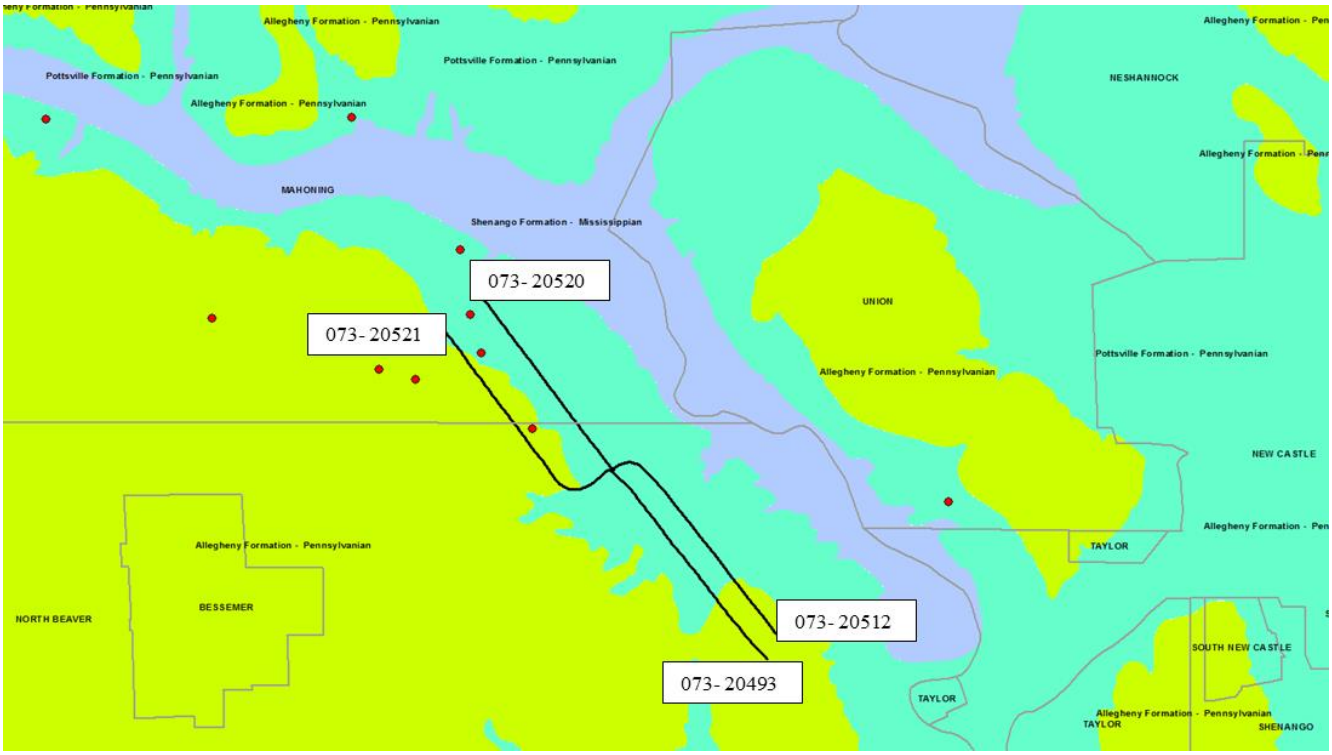

Figure 2. Geologic setting of well pad and epicenters of earthquake events.

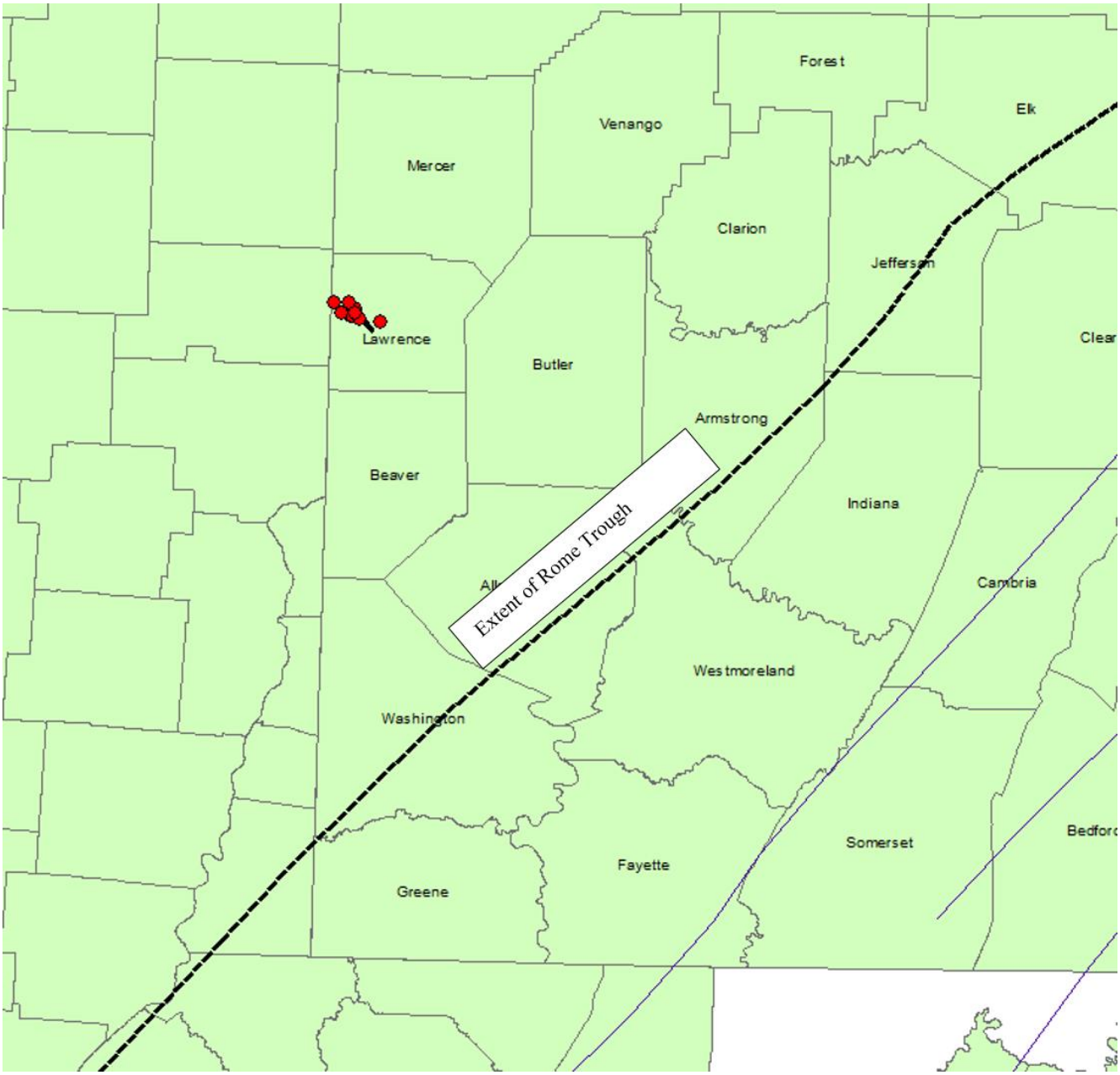

Figure 3. Proposed extent of the Rome Trough structural feature.

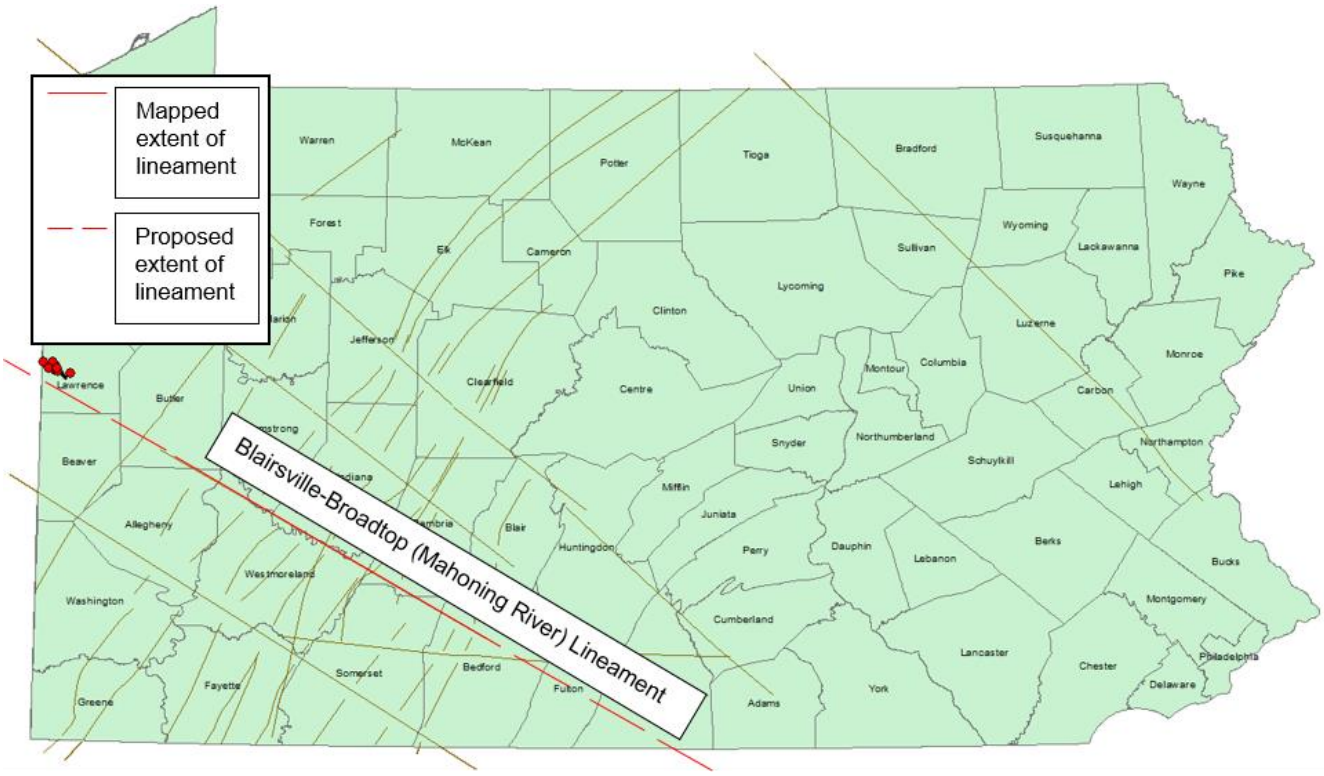

Figure 4. Proposed and mapped extent of the Blairsville-Broadtop Lineament.

IV. DISCUSSION OF FINDINGS

DEP personnel held a teleconference meeting with members of Ohio Department of Natural Resources (Ohio DNR) to compare the seismic events that occurred in Lawrence County and those that had taken place in association with fracking and stimulation at a Hilcorp well pad located in Poland Township, Mahoning County, Ohio in March of 2014. The well pad in Mahoning County is between approximately1.4 and 7.7 miles from the epicenter locations of the seismic events in Lawrence County. Similarities between the events in Ohio and Pennsylvania include temporal and spatial relationships with active fracking/stimulation activities at a nearby well pad, fracking/stimulation activities associated with Utica Shale Formation wellbores and seismic activities for both events located vertically within or near the Utica Shale Formation to a shallow depth within the crystalline basement rock. Studies of the March 2014 events (*Earthquakes Induced by Hydraulic Fracturing in Poland Township, Ohio*; Skoumal, Brudzinki and Currie, 2015) indicate that the earthquake epicenters occurred along a fault plane near the top of the Precambrian crystalline basement rock. Additionally, proprietary seismic data presented by Hilcorp suggest a correlation between the Ohio seismic events and an existing fault plane at or near the top of the Precambrian crystalline basement. Review of other proprietary seismic datum relating to the Pennsylvania seismic events do not indicate a fault at or near the Precambrian crystalline basement. However, due to the resolution and coverage area associated with available data, questions remain regarding the potential for the existence of other small-scale faults in the stratigraphic column between the Utica Shale Formation and the Precambrian crystalline basement.

V. RECOMMENDATIONS

Although there is no definitive geologic association of events at this time, there is a marked temporal/spatial relationship between fracking/stimulation activities at the North Beaver NC Development well site and the seismic events on April 25, 2016. Due to this relationship and pursuant to Hilcorp's permit, DEP approved the following plan for Hilcorp to monitor and respond to seismic activity associated with Utica Shale Formation gas wells within North Beaver, Mahoning and Union Townships in Pennsylvania and recommends other operators in this area follow similar plans:

1. Hilcorp shall continue to operate and maintain their own seismic network to monitor within the area of the aforementioned Townships. Hilcorp shall not terminate the use of their seismic network in the referenced Townships without written permission of DEP.
2. For purposes of this plan, an "Event" shall mean circumstances which reflect tectonic seismic activity above the thresholds and within the distances set forth in numbers 5 through 7 below.
3. In connection with seismic activity that may be an "Event", as defined above, Hilcorp will submit the seismic activity data received from the aforementioned seismic network during stimulation of any well to the DEP, Bureau of Oil and Gas Planning and Program Management (BOGPPM), electronically via email within ten minutes of the recording of any such seismic activity that may be an "Event".
4. In connection with an "Event", Hilcorp will call the DEP's statewide toll free number as soon as reasonably practicable, but no later than one (1) hour after a determination is made that the seismic activity is an "Event".
5. In accordance with the requirements of numbers 3 and 4 above, Hilcorp will notify the DEP of an "Event" above a $1.0M_L$ and within a 6-mile radius of a wellbore path.
6. In accordance with the requirements of numbers 3 and 4 above, Hilcorp will notify the DEP of any succession of three (3) "Events" occur within a three consecutive day period between $1.5M_L$ and $1.9M_L$ within a 3-mile radius of a wellbore path. In this case, Hilcorp shall take the additional steps stated below:
    a. Hilcorp will suspend stimulation operations on the well.
    b. Hilcorp will submit to DEP the "Event" data and location analysis that is prepared by the independent consultant that maintains Hilcorp's seismic network.
    c. If the "Events" are linked to stimulation activity at the well, Hilcorp will promptly submit a plan, in writing (including email), to modify the stimulation activities at the well. A plan to proceed could include:
        i. Skipping or eliminating stimulation stages;
        ii. Modification of stimulation pressures and volumes; and/or
        iii. Reduction or modification of volumes being used.
    d. Hilcorp will proceed with implementation of the modified stimulation plan, and Hilcorp may resume operations at a well unless specifically directed by DEP to make adjustments to the plan within 24 hours of submittal of the plan. DEP will submit suggested revisions to the plan, if any, within 24 hours of the "Events" described above. Hilcorp may re-commence stimulation activities within 24 hours of the most recent "Event" described above taking into account

its modified plan, as such plan may be adjusted after consultation with the DEP.

7. In accordance with the requirements of numbers 3 and 4 above, Hilcorp will notify the DEP of an "Event" equal to or above a 2.0M_L and within a 3-mile radius of a wellbore path. Should an "Event" be detected at or above this threshold, Hilcorp shall implement the procedures set forth in step 3 above, and take the following additional steps:
    a. Hilcorp will safely shut down stimulation operations on the well in accordance with generally accepted industry procedures.
    b. Hilcorp may proceed with production operations of any remaining wells on the pad.
    c. At Hilcorp's discretion, Hilcorp may proceed to flow back the well in question per standard operating procedure and place the well into production.
    d. Hilcorp will be allowed to resume stimulation operations on well in question if Hilcorp demonstrates to the DEP that the "Event" was not related to Hilcorp's stimulation operations. DEP shall make a determination regarding whether the "Event" was or was not related to Hilcorp's stimulation as soon as reasonably practicable.
    e. Hilcorp will be allowed to resume stimulation operations on the well if Hilcorp presents an approved plan to modify its operations and DEP determines, based on available data, such modifications allow for the safe resumption of stimulation operations.
8. Hilcorp will not use "zipper fracturing" on a well.
    a. Zipper fracturing is defined as fracture stimulating two wells simultaneously that are:
        i. Oriented in the same direction;
        ii. Stimulated or fractured at the same time; and
        iii. Adjacent to each other with less than ¼ mile between lateral portions of the wellbore.
9. These terms will apply to any new permits requested by Hilcorp within the referenced townships.