Hydrochemical response of groundwater following the 2020 Monte Cristo Range Earthquake sequence within Mineral and Esmeralda counties, NV

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Abstract

The 2020 Monte Cristo Earthquake sequence in western Nevada began with a M6.5 shock on 5/15/20, and was the largest to occur in Nevada since 1954. The event exhibited left-lateral slip along an eastward extension of the Candelaria fault and extensive distributed surface faulting in the epicentral area. Groundwater monitoring and strain analysis were conducted to evaluate hydrochemical effects on the regional groundwater systems following the initial event. Physio-chemical monitoring, (started on 5/16 and still ongoing) includes measurements of temperature (temp), pH, specific conductance (SpC), flow rate, alkalinity and collection of samples for major ions and trace element analysis. Since sites had not been monitored prior to the initial shock, measurements were evaluated against a year of post-event data to gauge response to seismicity. Four sites were monitored: a well from Columbus Marsh (CM) located 5 km from the epicenter; an artesian thermal well from Fish Lake Valley (FL); a well at Willow Ranch (WR) tapping cool water above the FL waters; and a spring along Mina Dump Road (MD) located 15 km north of the Candelaria fault on the Benton Springs Fault. GPS and InSAR measurements were used to create a model of the slip from which we estimated coseismic strain at each sampling location. All but one sample site, MD, experienced positive dilation and CM experienced the greatest amount of strain (15-17 microstrains). Hydrologic and chemical changes were observed following the initial shock, varying between sites. CM had significantly lower SpC values in the week following the event, as well as changes in major ion composition. Other sites showed minor changes; MD showed fluctuations in pH values and FL experienced a slight drop in temp. These waters showed minimal changes in major ions and trace elemental composition. Clear responses were observed throughout three >M5 aftershocks (6/30/20, 11/13/20, and 12/1/20), especially in SpC and alkalinity. A remarkable change in elemental concentration (an increase in Ca, K, SO\textsubscript{4}, Fe, and decrease in Na, Cl, Li, and Ba) was observed in CM. WR experienced a transient increase in temp measured two weeks prior to the 11/13/20 earthquake. Strain analyses of the smaller (>M5) events are planned to further evaluate observed responses and to clarify factors affecting groundwater response.
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Introduction

It has been shown that seismic activity has a direct impact on the surrounding groundwater systems. Changes in water level, discharge, groundwater contours, and chemistry have been previously observed in response to different seismicity (Brody et al., 2013; Binda et al., 2020; Manga and Wang, 2015), however understanding the mechanisms driving these groundwater responses, and the specific tie to tectonic forces is a subject needing further study. Here, we couple a series of physiochemical field measurements as well as elemental data gathered throughout the Monte Cristo earthquake sequence with strain analysis to help explain changes in groundwater associated with seismicity. The importance of this study is not only to help locate safe drinking water for local communities following a potential event but also to develop an understanding of the change in groundwater chemistry in general during or after a seismic event. To do so, we describe a sequence beginning with a main shock which occurred on May 15th, 2020 within the Monte Cristo Range, and its aftershocks throughout May and December 2020. By examining data from Fish Lake Valley and Willow Road, this study provides a temporal and spatial range of the extent of the seismicity. The initial event was the largest seismic event in the state of Nevada since 1954.

Sites Monitored

These sites can provide some interesting comparisons of differential responses between sites because Columbus is a groundwater-fed Lake, while Willow Road is a spring fed Lake, with similar geographic basins and occurring on both the hanging wall and fault of the Candelaria fault.

The Columbus Salt Marsh

- Located hanging wall with recharge via subsurface
- Median high capacity (>930gal) saline well
- Highest recorded major ion concentration in the hanging wall fault activated during series
- Experimental closed hydrographic basin
- Produced hydrochemical and temperature data

The Mina Dump Road spring

- Thirteen inch pipe discharged from Hot Mtn, and subsurface flow from Garland Flat
- Arsenic flow from pipe pumped for physiochemical analysis
- Located on Benton Spring Fault, NE of Mina deflection

Fish Lake Valley hot well

- Thermal water source
- Thermal water >140°C from a 163m deep exploration well drilled in the 1970’s
- Within a broad hydrographic basin
- Produced hydrochemical and temperature data

Willow Road well

- Residential well with an alluvial aquifer above
- Thermal water heated by Fish Lake Valley hot well
- Cool temperature and lower SpC compared to Fish Lake Valley hot well

Results - Flow Rates, SpC, and Temperature

Physiochemical data are plotted below with red bars representing the main shock on 5/15/2020 and all aftershocks are shown. Vertical dashed lines represent pumping taking place at the Willow Road, California. At plot is shown here as data appear to have elevated noise.

In addition, Soda Springs (not monitored) experienced increased flow rates after the initial M6.5 event, and an ephemeral spring occurred in Garfield Flat, lasting 5 weeks from early June through mid July.

November and December Events Cont’d.

Results - Strain Analysis

Modeling of the 5/15 event (Hammond et al., 2021) show movement along the fault from east to west. The western end of the fault shows a significant amount of dip slip relative to the eastern side, which is predominantly strike-slip.

Using both InSAR data and the surrounding MAGNET GPS network, coseismic offsets due to the main shock were modeled with dip on fault plane and these offsets reach up to 10 cm. Using these strain analysis we conducted for the initial 4.5 shock at each sampling location.

Results - Elemental Chemistry

Although large changes were observed in SpC at Columbus Marsh following the initial May 2020 shocks, they are difficult to interpret without an event baseline measurements. However, renewed seismicity in November and December, although not exceeding M 5.3, provides a useful suite of tests to evaluate effects of seismicity.

A significant amount of the events occurred on and in the leading up to 11/13 were positioned on the eastern side of Veterans Memorial Highway. A sequence of M 3.9 earthquakes shook the area in the days prior to this event. The main shock on 11/13 was closer to the epicenter of the 1/3/20/6.5 earthquake, resulting at a depth of 4.8 km.

The events that occurred on 12/1 can be described as a series of M 4.3-5.1 shocks at around 4.5 am. These events occur in groups of 1-4 shocks, with the largest event on 12/1/20 even. An abrupt increase was observed, and SpC returned to the values observed prior to the event.

November and December Events

A systematic decrease in temperature anomalies +3°C to +4°C occurred on 12/20 at the Willow and Columbus site, and the day after 11/13/20, temperatures returned to values prior to the event.

Discussion

Initial observations suggest differential strain between 11/12-1/20 and 11/12-1/20 events and suggests that the initial events are responsible for the extensive and coseismic offsets detected at Fish Lake Valley. Results from this project are also underway and may lead to a better understanding of the causes for a different hydrochemical reaction between events.

A comparison of climate indices to physiochemical parameters is also underway to better understand the mechanisms responsible for various responses. These mechanisms may include; upwelling and/or leaking of deep fluids, increased permeability along flow paths within the aquifers, and the flushing of solutes from the aquifers. This provides a complex relationship between seismicity and elemental chemistry. Similar relationships are also observed in the 1/12/20 and 12/10/20 activity.

Future Work

- Ongoing chemical analysis, coupled with strain analysis for aftershock sequences are planned to further evaluate observed responses and to clarify groundwater relationships between events in the future.
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