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

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November 22, 2022

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_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 known 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 seismic activity (Brodsky et al., 2003, Binda et al., 2020, Manga and Wang, 2015), however understanding the mechanisms driving these groundwater responses, and the specific ties 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 earthquakes, but to also develop an understanding of the changes in groundwater in proximity to a seismic sequence. To do so, we discuss a sequence beginning with a M 6.5 earthquake which occurred on May 15th, 2020 within the Monte Cristo Range followed by thousands of aftershocks and several >M 5.0 events that occurred in late June, November, and December 2020. This sequence occurred within the Central Walker Lane, within the Mina Deflection, in Esmeralda County. 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 they are located in various settings spanning 3 hydrographic basins and occurring on both the hanging wall and footwall of the Candelaria fault.

The Columbus Salt Marsh

- Closed hydrographic basin with recharge via subsurface flow from Fish Lake Valley
- 16m deep high capacity (350gpm) saline well
- Located within 1km of Columbus Marsh range front fault activated during series
- Experienced VIII-XII shake intensity during main shock

The Mina Dump Road spring

- Within an alluvial aquifer recharged from Pilot Mtns. and subsurface flow from Garland Flat
- Artesian flow from pipe purposed for cattle
- Located on Benton Springs Fault, NE of Mina deflection

Fish Lake Valley hot well

- Thermal water source
- Artesian flow ~50gpm from a 163m deep exploration well drilled in the 1970's

Willow Ranch well

- Residential well within an alluvial aquifer above thermal aquifer tapped by Fish Lake Valley hot well
- Cooler temperature and lower SpC compared to Fish Lake Valley hot well

Monitoring Groundwater

A groundwater monitoring program was established the day after the main shock in 2020 to measure physiochemical parameters of the water, and to sample for elemental chemistry. Physiochemical analysis was conducted in the field using a YSI 556 Multiprobe and Hach Alkalinity kit. Initially sampling was weekly, then monthly as aftershocks decreased and will continue through summer 2021. Monitoring initially began with 2 sites, at Mina and Fish Lake Valley, adding Columbus Marsh 1 week later, and the Willow residential well 1 month later.

Field Parameters measured:

- flow rate (springs only)
- Alkalinity
- Specific conductance (SpC)
- pH
- Temperature

A series of samples were taken in the field to analyze several groundwater parameters.

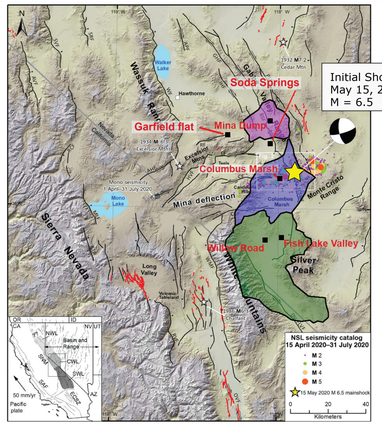
- Three bottles for hydrogeochemical analysis.
- A dram to be used for isotopic analysis (water δD and $\delta^{18}O$)
- Lastly, a sample used for alkalinity testing (100 ml)

All samples except for the alkalinity sample are filtered on site using a .45 µm size filter. Elemental chemistry was analyzed by the Pozzi lab in Como Italy by collaborators Pozzi and Binda.

Mina Dump

Columbus

Fish Lake Vly hot well



Location map, Modified from Koehler et al. (2021)
The colored sections of the map represent separate Hydrographic Basins.

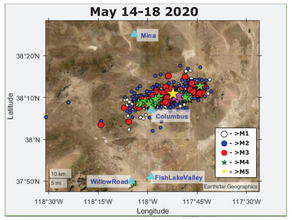
Garfield Flat ephemeral spring, June 1 2020

Results - Strain Analysis

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

Using both InSAR data and the surrounding the MAGNET GPS network, coseismic offsets due to the main shock event were modeled with slip on fault planes and predictions were generated on a regular grid of nodes with a ~1km spacing. With these offsets a strain analysis was conducted for the initial M 6.5 shock at each sampling location.

Modeled Strain by Well Location
Mina
-3.2967E-5
Willow Road
5.1692E-5
Columbus
0.0016267
Fish Lake Valley
5.065E-5



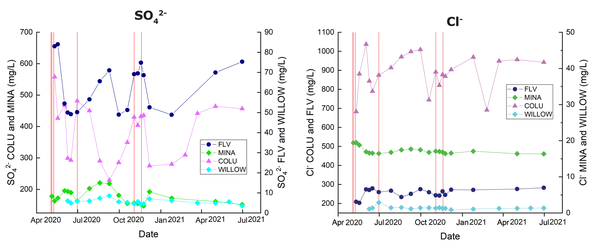
(left) Table of modeled cosiesmic strain at the surface experienced by each well location. Units are represented in strain, where 1e-3 is one millistrain and 1e-6 is one microstrain. Columbus experienced the largest strain as well as the greatest swings in SpC (right) Map of siesmic events from May 14-18th, 2020. The purple star represents the M6.5 epicenter from the main shock.

Results - Elemental Chemistry

Varying elemental responses were observed at each sample location throught the time series. The results of Ca^{2+} and SO_4^{2-} are plotted below with red lines representing the initial shock and several aftershocks.

Columbus showed different types of responses to seismicity, with changes in major ion compositions. A decrease in Na^+ and Cl^-, with a concomitant increase is K^+, Ca^{2+} and SO_4^{2-} was observed. A similar trend in major ions was reported for Fish Lake Valley, while Mina dump showed some changes in concomitance with May, November, and December, 2020 shocks. All these results are well in accordance with the registered conductivity values.

While Columbus showed some responses in trace elements (namely the increase in Ni, Cr and Fe and contemporary decrease in Sr and Li, data not shown), other springs do not show specific anomalies in minor and trace components. Willow road, instead, showed no trend in major and minor element composition.



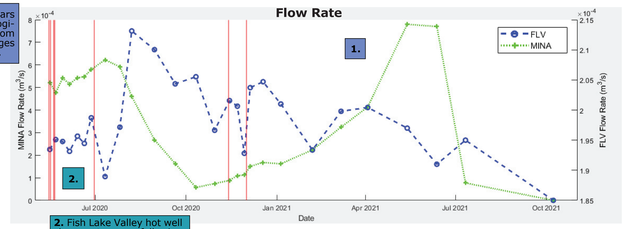
Timeseries of elemental changes in SO_4^{2-} (left) and Cl^- (right) at all sample locations

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 >M 5. Dashed vertical lines represent pumping taking place at the Columbus well. Alkalinity and pH not shown here as data appear to have elevated noise.

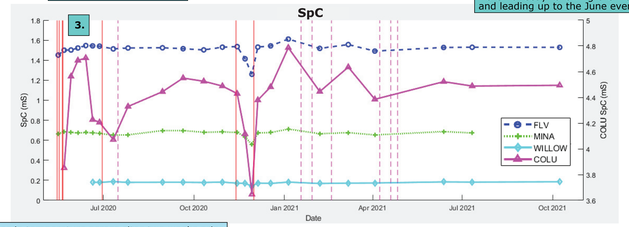
In addition, Soda Springs (not monitored) experienced increased flow rates after the initial M 6.5 event, and an ephemeral spring occurred in Garfield Flat, lasting 5 weeks from early June through mid July.

1. Mina appears to be meteorologically driven from seasonal changes in precipitation.

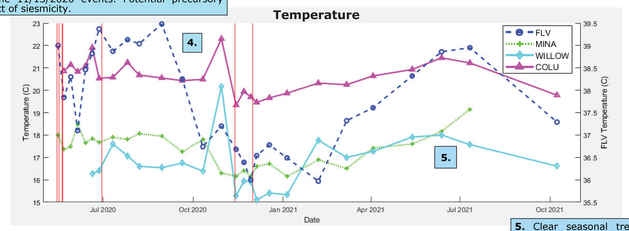


2. Fish Lake Valley hot well shows strucure following July, November and December >M 5 events.

3. Large changes in SpC at Columbus March directly following the May shocks and leading up to the June event.



4. Rise in temperature across sites two weeks prior to the 11/13/2020 events. Potential precursory effect of siesmicity.



5. Clear seasonal trends in temperature across 2021. Seismic induced noise in 2020?

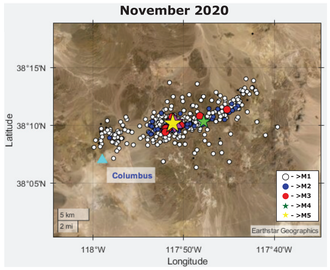
November and December Events

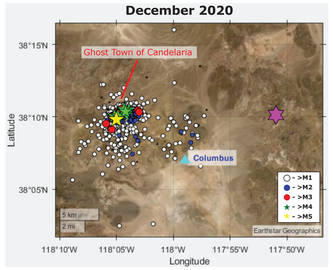
Although large changes were observed in SpC at Columbus Marsh following the initial May 2020 shocks, they are difficult to interpret without pre event baseline measurements.

However, renewed seismicity in November and December, although not exceeding M 5.3, provides a useful time series to evaluate effects of seismicity.

A significant amount of the events that occurred on and in the days leading up to 11/13 were positioned on the eastern side of Veterans Memorial Highway. A sequence of 1-3 M earthquakes shook this area in the days prior to this event. The main shock on 11/13 was closer to the epicenter of the 5/15 M 6.5 earthquake, occurring at a depth of 4.8 km.

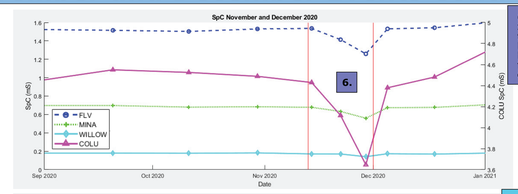
The events that occurred on 12/1 can be described as a series of M 4.3-5.1 shocks at around 4-5km depth. These events occurred much further west of the initial 5/15 shock, and the 11/13 events. The epicenters were also notably north of many of the prior events, almost in the center of the ghost town of Candelaria



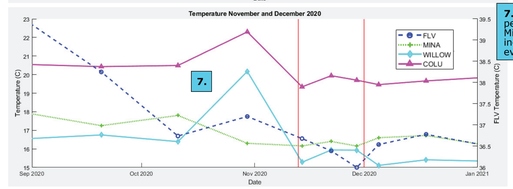


Maps showing the localized seismic uptick in November and December 2020. Purple star represents the M6.5 epicenter from the main shock.

November and December Events Cont.



6. A systematic decrease in SpC across all sites between the November and December events followed by a rebound of values in the days following the December event.



7. An increase in temperature at all sites but Mina in the weeks leading up to the November event.

SpC and temperature data plotted above with red bars representing the aftershocks that took place in November and December of 2020.

Discussion

Despite the lack of pre-event data prior to the initial shock, the 16 month dataset shows large variations are present in parameters such as SpC at the Columbus site between May and July 2020. This align with the large amounts of strain the site experienced. The initial decrease in SpC values and changes in elemental chemistry at Columbus following the first shocks may be in part by the large amount of dilation the site experienced, introducing fresh water to the well. These oscillations in data are not related to well withdrawal.

There is a distinct difference in the effects of the 11/13/20 and 12/1-2/20 events. In the weeks following the 11/13/20 events and approaching 12/1/20, the SpC across all of the sites dropped. Following the 12/1/20 event, an abrupt increase was observed, and SpC returned to the values observed prior to 11/13/20.

Temperature anomalies +3°C to +4°C occurred on 10/30/20 at the Willow and Columbus site, and the day after 11/13/20, temperatures returned to values prior to the event.

Initial observations suggest differential strain between 11/13/20 and 12/1/20 events and suggests that the differential response of groundwater between sites is a result of these variations. Hydrochemical and flow rate changes at the Mina site, while small, are interesting because of its location on the Benton Springs fault. Koehler et al. (2021) showed a series of surface ruptures along this fault associated with the initial event. The Benton Springs Fault is right lateral shear, and thought to accommodate ~1mm/yr dextral slip, which is roughly half of the deformation in that region (Angster et al 2019).

The elemental results confirm geochemical responses to seismicity. The drop in Cl^- after the initial shock is consistant with observations of SpC, however we also see a distinct increase in SO_4^{2-}. This suggests a complex relationship between seismicity and elemental chemistry. Similar relasionships are also observed after the 11/13/20 and 12/1/20 seismicity.

Future Work

- Ongoing chemical analysis, coupled with strain analyses for aftershock sequences are planned to further evaluate observed responses and to clarify groundwater relationships between sites, and 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 slower groundwater flow paths. These can be testing by analyzing dilation and/or aquifer mixing.
- Sampling of several depths within the Columbus well to better understand any chemical stratification present with respect to SpC and elemental data.
- Calculating the coseismic strain across the events of November and December is underway and may lead to a better understanding of the causes for a differential hydrochemical reaction between events.
- A comparison of climate indices to physiochemical parameters is also underway to better understand what other factors may be affecting data throughout this study.

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Support for this project comes from NSF RAPID grant 2038474. Thanks go to Forrest and Nadine Fasig, Gary McGaughey for help scouting and sampling wells, Adam Chiparro for access to his Willow Ranch, the staff at Ireland Minerals for access to Columbus Marsh well.