RELATIONSHIPS AMONG SNOW DEPTH, SNOW WATER EQUIVALENT, STREAMFLOW AND VIRUS ACTIVITY IN TWO COLORADO SUBWATERSHEDS, 2004 TO 2016

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ABSTRACT

Vesicular stomatitis (VS) is the most common vesicular disease affecting livestock (domestic horses, cattle, pigs) throughout the Americas. VS is a vector-borne disease with more than >1500 infected premises in the western US from 2004-2016. The ecology of the host-vector-virus-environment system is the subject of a large, collaborative USDA research effort. Initial findings indicate VS incidents were spatially distributed near the stream network and temporally related to streamflow conditions with all first incidents (n=35) occurring following peak annual streamflow. These spatial and temporal relationships showcase the importance of hydrological contributions to the emergence and distribution of VS and indicate that snow conditions may play an important role in VS emergence. Peters et al. (2017) report that VS infected premises can be evaluated based upon outbreak (2004, 2014) and expansion (2005, 2015) years. Here we evaluate the relationships between monthly snow depth, snow water equivalent, streamflow and the number of VSV infected equine premises in two watersheds (Big Thompson and Saint Vrain) with a high number VS infected premises. The water content of snowpack and snow depth within both watersheds the months prior to a VS outbreak were both lower (2004) and higher (2014) than years with no infected premises. Conversely, outbreak years had higher autumnal and late season monthly streamflow than years with few or no VS infected premises. The complex water management system of reservoirs and irrigation canals along the Front Range of Colorado and VS vectors may buffer the relationship between SWE, snow depth and virus transmission observed in other locations. More detailed analyses of water conveyance associated with VS infection is needed in these watersheds to evaluate the impacts of local water conditions on the vector-host relationship, particularly related to observed elevated autumnal and summer streamflow co-occurring during outbreak years.
(KEYWORDS: vesicular stomatitis, snow water equivalent, host-vector-virus-environment system, water management, virus transmission)

INTRODUCTION

Snowpack and snow water equivalent have previously been linked with vector-borne disease outbreaks. One common vector-borne disease affecting livestock throughout the Americas, Vesicular stomatitis virus (VSV), has periodic outbreaks with high infection rates in Northern Colorado. While considered a foreign animal disease, there has been sporadic infection within the western United States, first documented in the early 1900s and occurring roughly every decade. In an effort to better understand the ecology of the host-vector-environment system, a significant collaborative effort (The VSV Grand Challenge) led by the USDA has gained traction in recent years. Biting flies, direct contact with lesions of affected animals and areas or objects contaminated with virus are the three main routes of transmission attributed to VSV premises (figure 1). This study will focus on the insect vector relative to abiotic factors.

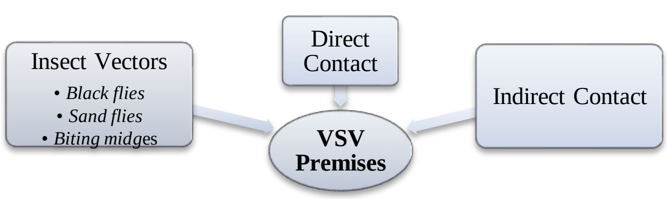

Figure 1. Routes of transmission for VSV premises

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Distribution of VSV premises and the insect vector habitats suggest hydrology is an important factor in VSV outbreaks (table 1). This indicates the value of hydrological contributions to not only vector life cycles but spread of VSV. Of particular interest to this study are the snow pack conditions above infected premises on the Front Range Mountains of Colorado, from 2003 to 2015. Within outbreak (2004, 2014) and expansion (2005, 2015) years we aimed to evaluate the relationship between monthly snow depth, snow water equivalent (SWE), streamflow and the number of VSV infected premises for two subwatersheds (St. Vrain and Big Thompson) within the South Platte Basin.

Table 1. Suspected insect vectors of VSV. Known taxonomic level of vectors. Hydrologic conditions related to habitat of varying stages for insect vector. Distance traveled is what adults will travel for either mating or from hosts to egg sites. All vectors have complete metamorphosis (holometabolous). Their feeding strategies are all similar where the adult male and females are herbivorous (nectar feeders) prior to breeding then the adult female feeds on blood (Connelly, 2005; Mann, et Al., 2012; McMillan, 2013).

Common Name	*Taxonomy*	*Hydrologic Conditions*	*Travel*
Black Flies	Family: Simuliidae	Eggs laid in/on/near water; Larva and pupa stages occur in water; larvae have been known to overwinter	10-40km
Sand Flies	Genus: *Lutzomyia*	Terrestrial for all stages; Adults have shown daytime preference for dark, humid microhabitats	~1km
Biting Midges	Genus: *Culicoides*	Larval stage is not strictly aquatic or terrestrial, but cannot develop without moisture or further than 100mm below water surface	1-2km

STUDY AREA

Between 2004 and 2016, the South Platte Basin had at least 512 premises infected with VSV. With an area of 62,936 km^2 (24,300 mi^2), the majority within the state of Colorado (49,261 km^2; 19,020 mi^2; CWRRI, 1990), this basin serves multiple users and purposes, including the Denver metropolitan area and its increasing municipal water demands as well as five other metropolitan areas. We chose to explore these relationships within the St. Vrain and Big Thompson subwatersheds (Figure 2), because they not only had the greatest number of VSV-infected premises, but their physical geography is characteristic of snow fed systems. Their western portions are dominated by the Front Range Mountains and their eastern portions by the plains. Collectively, they accounted for 45% of VSV premises for all years, within the South Platte Basin. Of the total infected premises, the St. Vrain had 27% and the Big Thompson had 17%. Table 2 shows the amount of VSV premises by year for the subwatersheds in our study area.

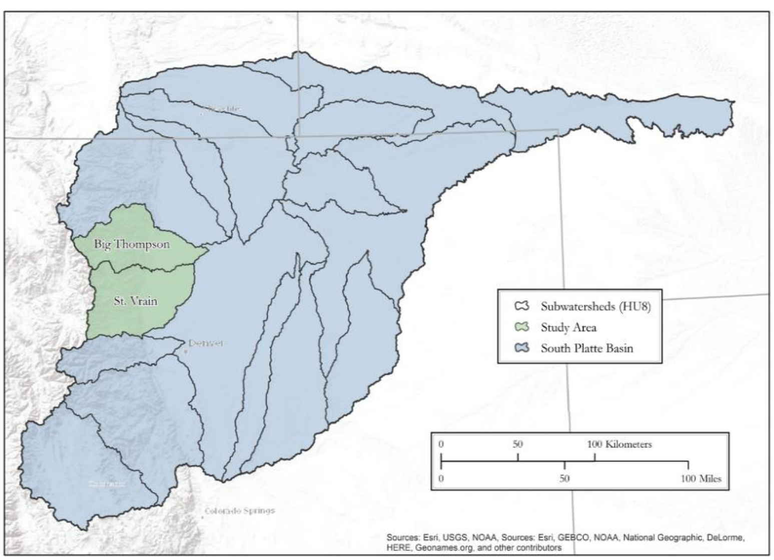

Figure 2. This shows the extent of the South Platte Basin and highlights our study area; the Big Thompson (HU 10190006) and St. Vrain (10190005) subwatersheds.

Table 2. VSV premises by year for the subwatersheds and the basin related to this study

Total VSV Premises by Year

	2004	*2005*	*2014*	*2015*
Big Thompson	35	0	52	2
St. Vrain	39	0	94	7
S. Platte Basin	122	1	322	67

METHODS

We used a GIS to initially evaluate the locations of VSV infected premises relative to the subwatershed boundaries, SNOTEL site locations and USGS gages. Snow water equivalent (SWE) and snow depth from the SNOTEL network and streamflow from selected USGS gages within the St. Vrain and Big Thompson subwatersheds were used in relation to VSV incidents on a monthly time-step. Each set of data was downloaded from either the NRCS report generator for the SNOTEL stations or from the USGS surface water records, water year summaries by sites. Once downloaded, the data were aggregated according to subwatersheds and organized by month, beginning with October 2002 through December 2015. This enabled us to look at calendar and water years 2003 through 2015. Within the St. Vrain we used five SNOTEL sites and one USGS gage. One gage and two SNOTEL sites were examined for the Big Thompson (Figure 3); SNOTEL sites at this subwatershed are operated seasonally (January through June). Since VSV outbreaks occur sporadically, a statistical test of significance is not useful due to the limited amount of VSV outbreak years. Instead we evaluate differences between years with and without VSV infection emergence. Thus, we compare outbreak years (2004 and 2014) with no or low VSV years (2015).

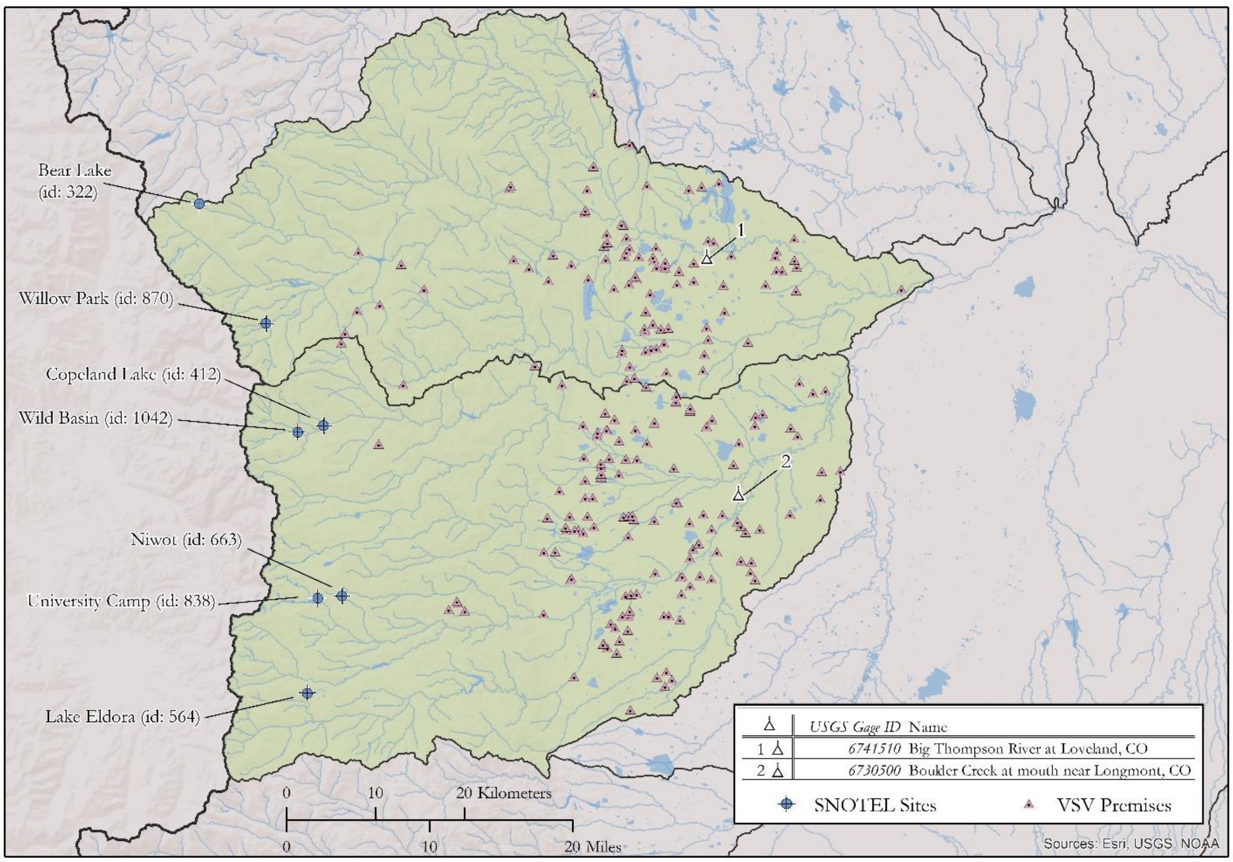

Figure 3. Study area detail

RESULTS

Big Thompson

In the two outbreak years (2004 and 2014), spring SWE and snowpack were both above and below the median representing years with no VSV infection (Figure 4 and Figure 5). In contrast, autumnal (October and November) and spring (March, April and May) monthly streamflow volume near VSV outbreak locations was higher during outbreak years than years without VSV infection (Figure 6).

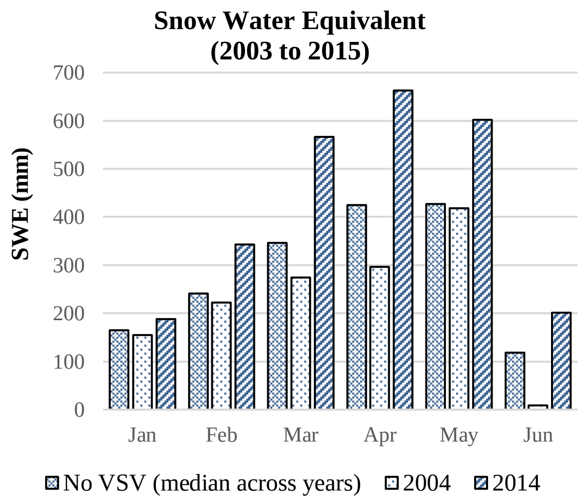

Figure 4. Snow water equivalent (mm) from two SNOTEL stations in the Big Thompson subwatershed for January through June, from 2003 to 2015

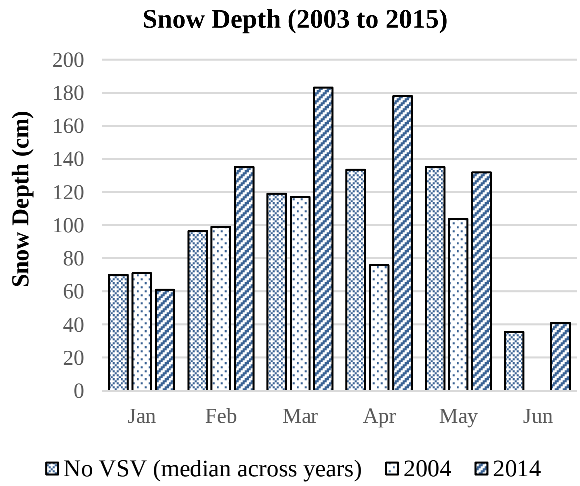

Figure 5. Snow depth (cm) from two SNOTEL stations, Big Thompson subwatershed for January through June, from 2003 to 2015

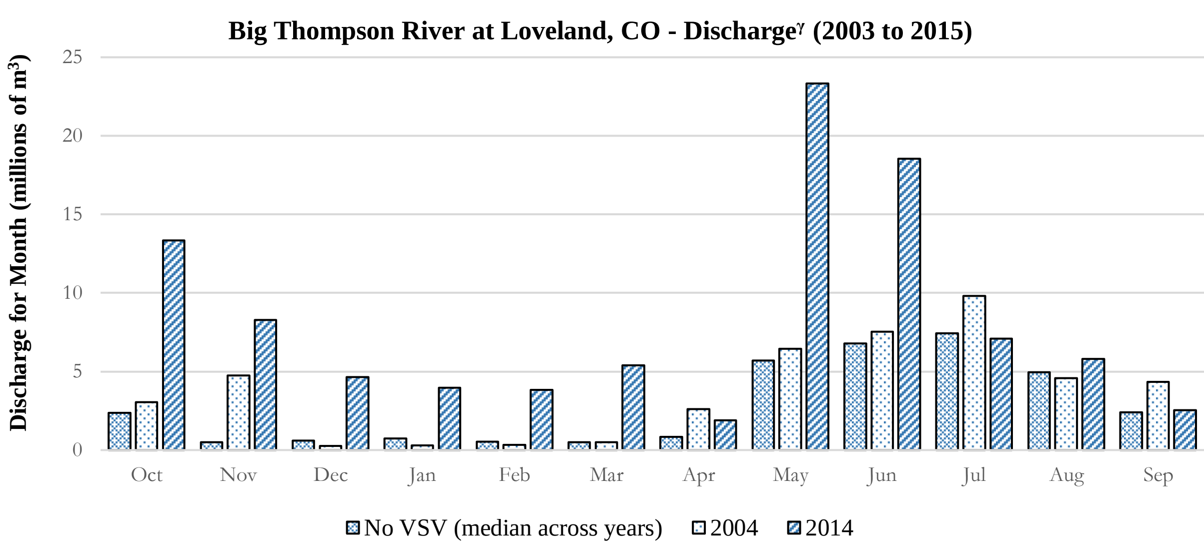

Figure 6. Monthly discharge in millions of cubic meters, as measured by the USGS gage (06741510), Big Thompson River at Loveland, CO

[γ] *Natural flow of stream affected by transmountain diversions, storage reservoirs, power developments, diversions for irrigation, and return flow from irrigated areas.*

St. Vrain

In the St. Vrain subwatershed, the water content of snowpack and snow depth the months prior to a VS outbreak were both lower (2004) and higher (2014) than years with no infected premises (figures 7 and 8). Conversely, outbreak years had higher autumnal and late season monthly streamflow than years with few or no VS infected premises. March and April discharge was greater for outbreak years, compared to no/low VSV years (Figure 9).

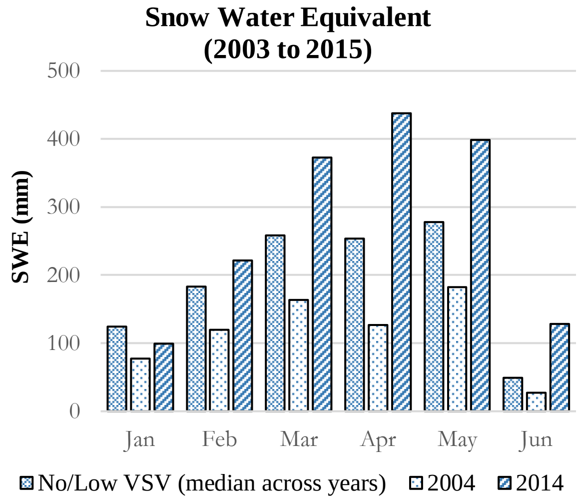

Figure 7. Snow water equivalent (mm) from five SNOTEL stations in the St. Vrain subwatershed for January through June, from 2003 to 2015.

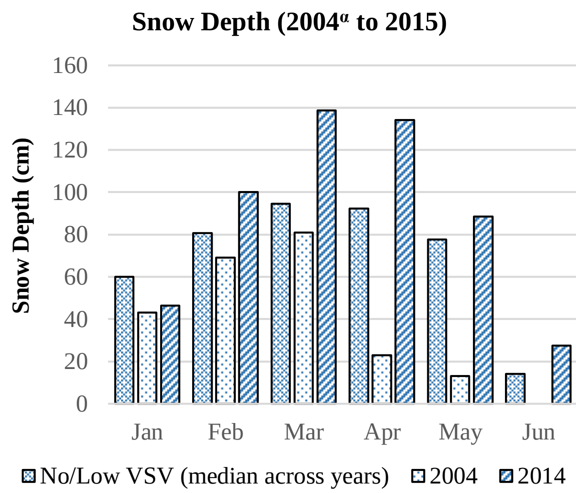

Figure 8. Snow depth (cm) from five SNOTEL stations in the St. Vrain subwatershed for January through June, from 2004 to 2015.
[α]Snow depth data for water year 2003 was incomplete

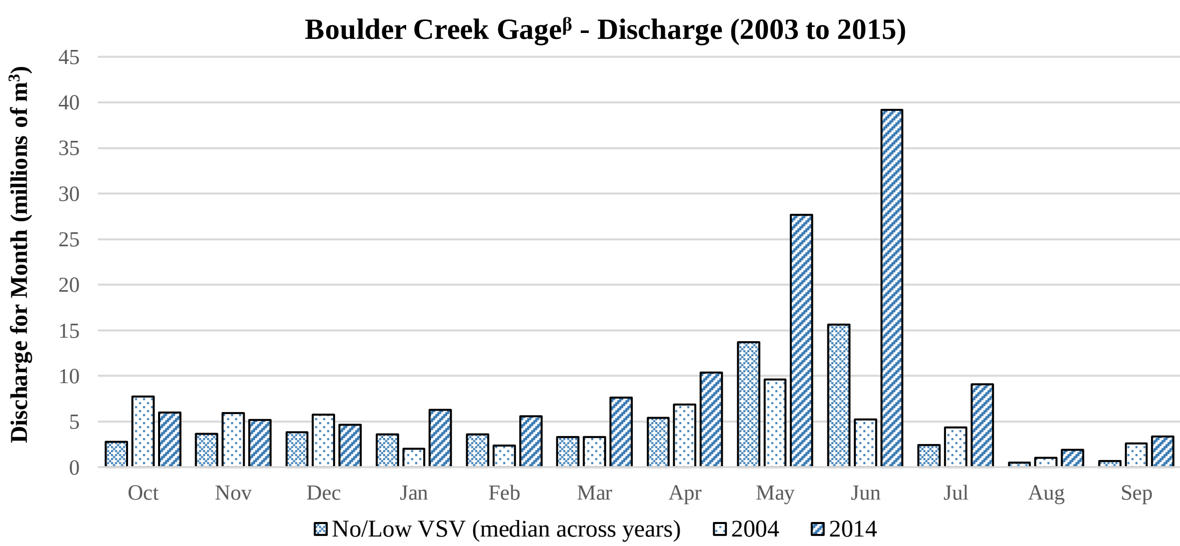

Figure 9. Monthly discharge in millions of cubic meters. As measured at the Boulder Creek at mouth near Longmont, CO (USGS Gage 06730500).

[β]Natural flow of stream affected by transmountain, transbasin, and storage diversions, diversions for irrigation, water-treatment plants, and return flows from irrigated areas.

CONCLUSION

Although snow depth and snow water equivalent have been related to vector-borne disease outbreaks in the past, this research provides little support that VSV infection has a clearly identifiable relationship with snow depth and the water content of snowpack in two subwatersheds along the Colorado Front Range. However, outbreak years had higher autumnal and late season monthly streamflow near the outbreak locations than years with few or no VS infected premises.

The complex water management system of reservoirs and irrigation canals along the Front Range of Colorado may buffer the relationship between SWE, snow depth and virus transmission observed in other locations. Streamflow observed in this study are affected by:

- transmountain diversions
- transbasin diversions
- storage diversions
- diversions for irrigation
- storage reservoirs
- power developments
- return flow from irrigated areas
- sewage treatment plants
- water treatment plants

More detailed analyses of water conveyance associated with VS infected premises is needed in these watersheds to evaluate the impacts of local water conditions on the vector-host relationship, particularly related to observed elevated autumnal and summer streamflow co-occurring during outbreak years. Other abiotic factors likely play an important role in the host-vector-environment system. The next steps in the broader VSV Grand Challenge project include localized analysis of streamflow and management factors affecting VSV spread, genetic sequencing and modeling of VSV spread from South America to the U.S. related to climatic and environmental factors.

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