Applications of Remote Sensing to Hydraulic Fracturing in Larimer and Weld Counties

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Background

This study is concerned with the environmental impact of hydraulic fracturing, or “fracking,” in communities with large numbers of fracking wells, as well as the impact of fracking water use on agriculture in regions with current or anticipated water scarcity. Using a time series with earth imagery, two band indices (Normalized Difference Vegetation Index (NDVI) and Soil Adjusted and atmospherically Resistant Vegetation Index (SARVI)) are used to determine if there have been significant reductions in productive acreage in Larimer and Weld County, Colorado. A third band index (the Normalized Difference Water Index (NDWI)) is used to determine if the composition of water bodies has changed significantly of the time period of the study.

A significant portion of the land in Larimer and Weld County has traditionally been used for agricultural purposes. According to the 2007 United States Census of Agriculture, Larimer County had 1,757 total farms and used 489,819 acres of land for farming. Furthermore, Larimer County had 799 farms used with irrigated land and 63,405 total acres of irrigated land. According to the same census, Weld County had 3,921 total farms using 2,088,715 acres, and 327,836 acres of that land were irrigated. These numbers suggest that both counties used significant areas of land for agriculture as of the year 2007.

Beginning in 2008, hydraulic fracturing took off in many counties in Northern Colorado. From the period between 2008 and 2011, six counties (including Larimer and Weld) saw leasing activity for fracking companies increase substantially. The likely reason for this increase was the discovery of oil in the Niobrara (which is a rock formation underneath the Front Range of Colorado. The increase in wells presents some issues for the region; on top of the already-present fears regarding groundwater contamination and the currently unknown effects of many of the chemicals used for fracking, the recent increase in wells presents new issues regarding water use.

According to a recent study, fracking wells require 22,100 to 39,500 acre-feet of water per year. Used fracking water is injected into geologic formations after a well is fracked, and since fracking water is contaminated with chemicals it is not economic to cleanse. Therefore, once water is used for fracking, it cannot be re-used for agricultural purposes. Unlike agricultural or municipal waste water, frack water is thus removed from the “Water Cycle” forever. As of 2012, fracking water use in Weld County had used enough water for 66,400 to 118,400 homes or enough water for a city of 166,000 to 296,000 people.

Given the tremendous economic benefits of fracking, oil and gas companies can afford to pay more than other potential users of this water, in particular agricultural users. Thus, hydraulic fracturing companies take potential water use away from agricultural production in counties where both fracking and agricultural are significant industries. This suggests that the increase of fracking wells beginning in 2008 in Larimer and Weld County could have noticeable effects on agricultural vegetation health; as the number of wells increases, the health of agricultural vegetation should decrease due to the lack of water.

Research Question & Hypothesis

Questions:

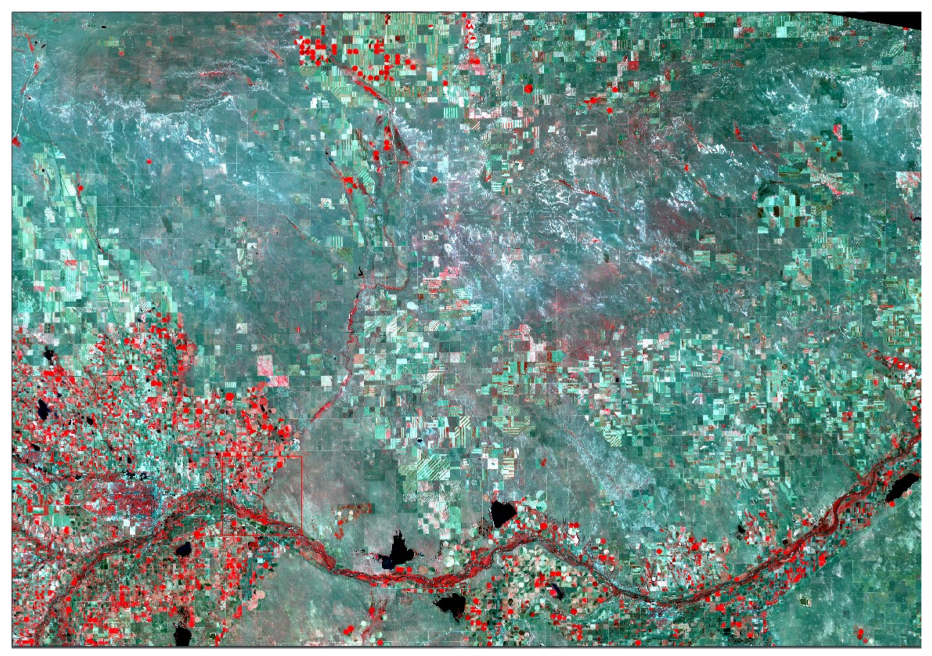
Does earth imaging analysis indicate that there has been a decline in vegetation health in Weld County and Larimer County since the fracking boom began? Furthermore, has the increase in the number of fracking wells had a significant impact on the health of the vegetation in the area directly surrounding the wells? Are there any other detectable environmental effects on the region that can be traced back to the increase in hydraulic fracturing, such as changes in water reflectance due to changed water composition?

Hypothesis & Objectives:

In this study I will focus on the effects of significant water resources being used for hydraulic fracturing and the consequences this water use has on agricultural production in Larimer and Weld County. I will also examine impacts on water bodies in the Larimer and Weld County from chemicals in wastewater pits near the fracking wells, and subsurface migration of fracking chemicals to the surface.

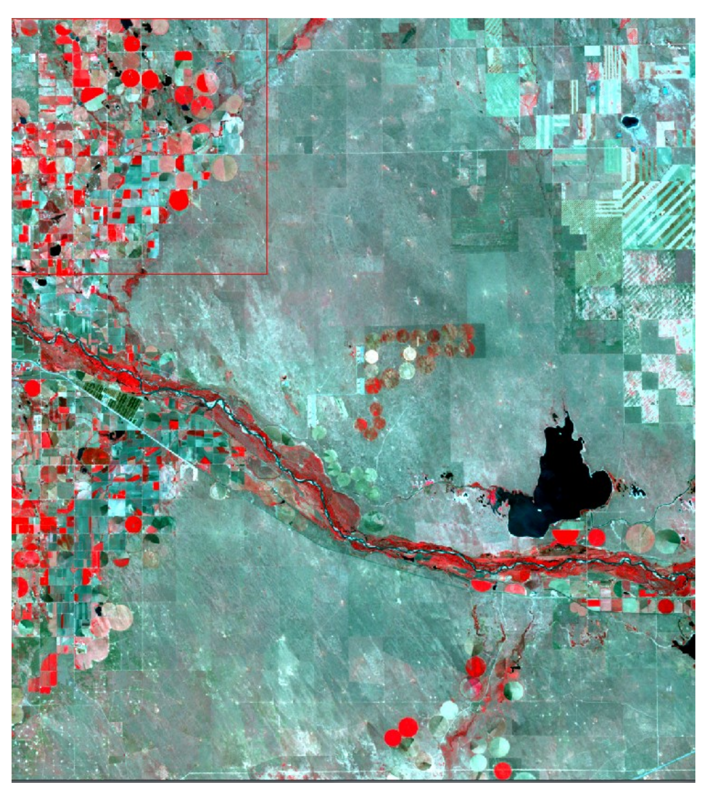
I hypothesize that: if there has been an increase in water use for hydraulic fracturing in Larimer and Weld County, then there will be a statistically significant decrease in vegetation health (both in irrigated and non-irrigated vegetation) from the year 2000 to 2013.

2000 Larimer & Weld County (RGB: 4, 3, 2)

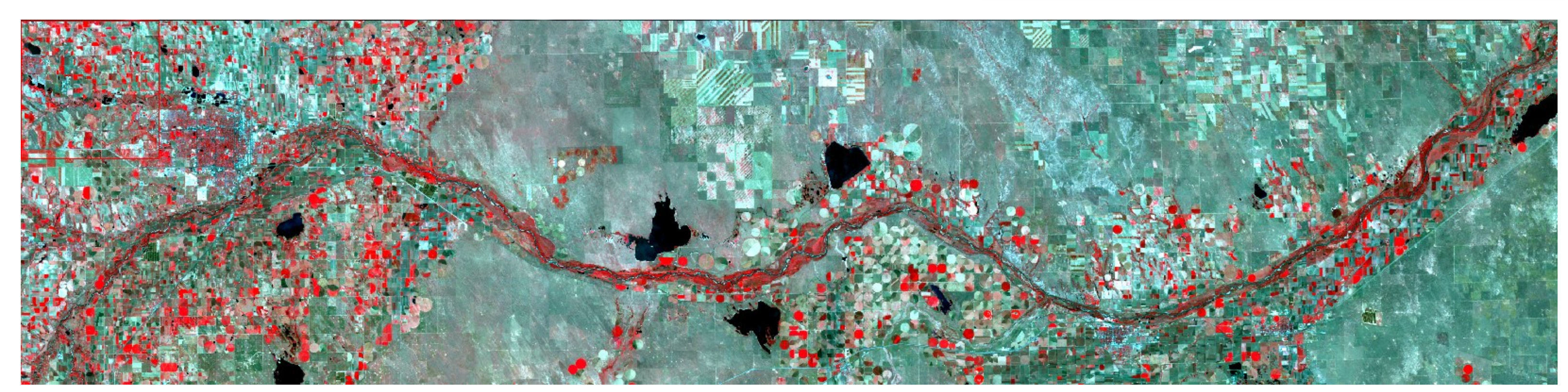


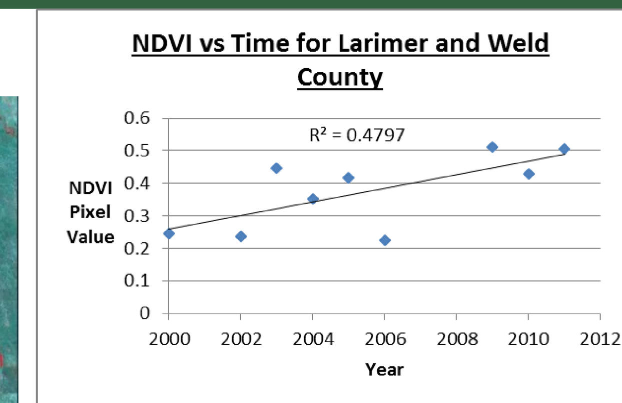
2000 Irrigated Land (RGB: 4, 3, 2)

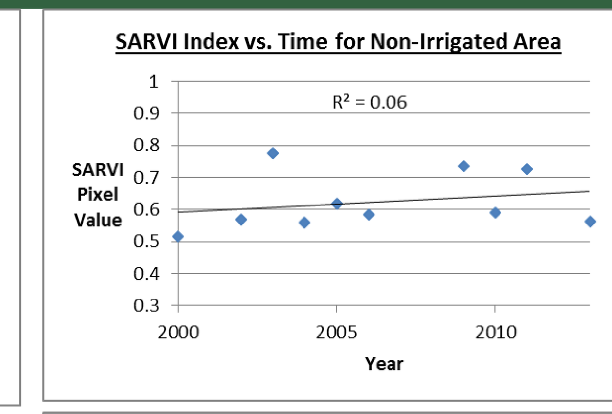
2000 Non-Irrigated Land (RGB: 4, 3, 2)

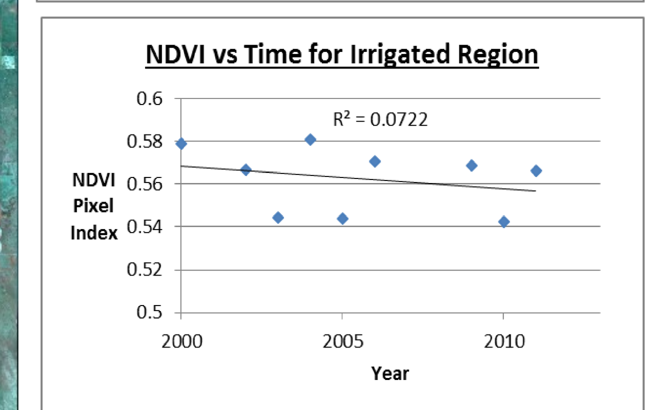


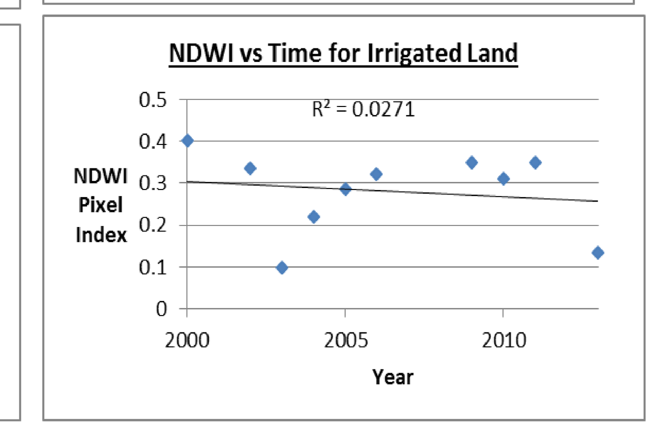
2000 River Region (RGB: 4, 3, 2)

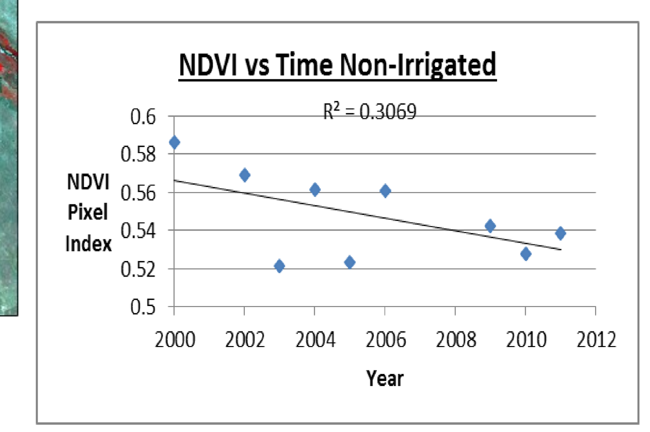


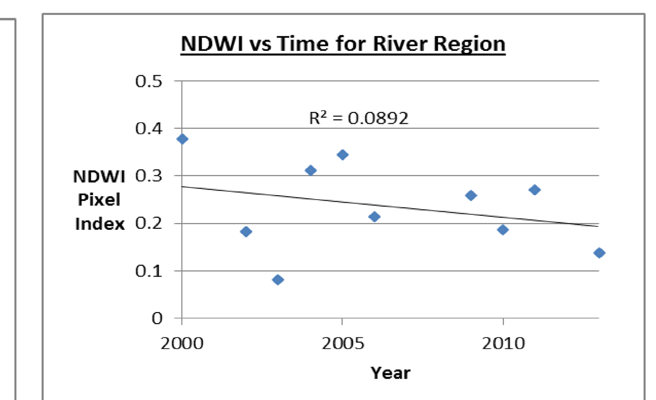


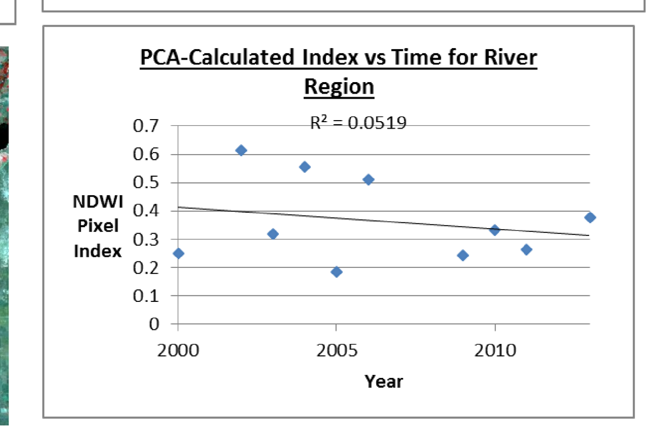












Additionally, since there has been an increase in hydraulic fracturing in these two counties, there will be a statistically significant change in water composition as represented by a change in the NDWI band index from the year 2000 to 2013. This change in water composition could be due to migration of subsurface fracking chemicals to surface water, or from migration of chemicals directly from the surface locations of the fracking wells.

In order to answer the questions I have posed, I will use three band indices that will highlight characteristics such as vegetation health and reflectance of surface water. I first plan on using the NDVI band index to determine amount of green vegetation in the region. In order to examine the effects on vegetation health, I will apply the NDVI index to three separate regions. I will apply the index to a region of irrigated vegetation surrounding a city in the southern area of Larimer County, a region of non-irrigated vegetation located in a region that saw a large increase in the number of wells from 2000 to 2013, and finally, the entire area of both counties. I am interested in applying the NDVI calculation to an irrigated area on my image because an increase in water usage for fracking will likely have its biggest impact on irrigated vegetation. I am also applying the NDVI band index to a non-irrigated region surrounding the new fracking wells because I am interested to determine if there is an impact on natural vegetation surrounding the wells.

The next band index I will apply is SARVI (Soil Adjusted and Atmospherically Resistant Index). This index measures amount of green vegetation in a similar way to NDVI. However, the purpose of SARVI is to correct for both atmospheric and soil variations in the image; therefore, I believe this index will give me a better idea of the effects on healthy vegetation in areas that have significant amounts of soil. Hence, I plan to apply this band index to the non-irrigated region surrounding the fracking wells, because this area has significantly more soil features than the irrigated region. These soil regions could affect the NDVI calculation in the region, but these errors should be corrected to some extent by the SARVI index.

Finally, I will apply the NDWI band index to two regions in my image: the irrigated region of my image and the area surrounding the river in the southern area of my image. The NDWI band index is derived in a similar to the NDVI index, except that it has the opposite effect – it highlights the green band from the data to maximize reflectance in this region while simultaneously minimizing reflectance in the near-Infrared region. The effect of this index is that it highlights water bodies and gives them a positive pixel value, while values of all other land features are either zero or negative. I am interested in using this index to determine if there is a change in reflectance of water bodies of the time period of my study. Therefore, I am including a region along the river located near the fracking wells to see if the development of fracking has caused a change in water composition of the river.

Band Equations:

NDVI = (Band 4 – Band 3)/(Band 4 + Band 3)

SARVI = (1.5)(Band 4 – Band 3)/(Band 4 + Band 3 + 0.5)

NDWI = (Band 2 – Band 4)/(Band 2 + Band 4)

Results and Analysis

The results that I obtained from my band index calculations were somewhat inconclusive. Because of the time constraints on my project, I was not able to gather enough data in order to find statistically-significant patterns for the values of my band indices. Keeping in mind that I did not get useable image from 2001, 2007, 2008, and 2012, this meant that I only had 10 data points to use for each of my indices. However, the data I gathered was able to produce some trends that I might be able to examine further if I continue my study.

An important outcome of my research was the differences between the indices that I used. When I calculated the NDVI for the non-irrigated region I found a decreasing trend in the average pixel values per year. However, when I calculated the SARVI values for the pixels in the same non-irrigated area, I found an increasing trend over the time period of my study. As a continuation of my study, it would be interesting to further compare the indices I used in order to determine which one best represents the levels of healthy vegetation. I could also compare additional indices as well in order to find the most accurate index for measuring vegetation health in the Larimer and Weld County region. I could carry out similar processes to determine the proper band index to use for water composition as well.

NDVI results

When I calculated the NDVI on my three regions of interest (Larimer and Weld County, irrigated region, non-irrigated region), the data for the irrigated and non-irrigated regions showed a generally downward trend. This suggests that the amount of healthy vegetation in those locations decreased from the beginning of the time period of my study to the end. But, the overall trend for the entire region of Larimer and Weld County was an increase in vegetation health.

The NDVI values for the entire region of Larimer and Weld County suggest that there has actually been an increase in healthy vegetation from the beginning of my study to the end. It is difficult to use the result for the entire area of Larimer and Weld County as a measurement of overall vegetation health because the area contains a diverse range of vegetation features. However, the values for both the irrigated and non-irrigated regions which I examined showed decreasing trends in healthy vegetation. When segmenting the image into smaller subsections representing specific land surface types, I was able to get a better idea of the effects of fracking.

SARVI results

Interestingly, in contrast to the NDVI calculations for the non-irrigated region, when I calculated the vegetation health values using SARVI for the non-irrigated region I found a generally increasing trend in the data values. This index takes into account soil variations, and the fact that I found a generally increasing trend from the beginning of my study to the end suggests that the changes in healthy vegetation that I found using the NDVI calculation could have been driven by soil changes from year to year. Therefore, this index may be more useful than NDVI when determining levels of healthy vegetation surrounding fracking wells, and it could show a more accurate representation of the effects of the wells in areas with more sparse vegetation. As stated in the introduction to the analysis and results subsection, an interesting continuation of my study would be to do a deeper study comparing the accuracy of NDVI to SARVI (as well as other band indices) in measuring vegetation health surrounding fracking wells.

Results Continued

NDWI results

Both of the regions that I analyzed using NDWI (and the PCA-calculated index that I created) showed generally decreasing trends in water reflectance from the beginning of my study to the end. The trends in the data using the NDWI calculations were likely driven by the calculated value for the first year; the NDWI value for both the irrigated and river region was much higher in 2000 than in any of the subsequent years. In contrast, the trend that I found for the PCA-calculated index did not find as high a value for the first year, and it still found a downward trend in the data. Similarly to the comparison of the SARVI and NDVI calculations, it would be interesting to continue investigating the differences between the NDWI values and the values for the index I created.

Conclusion & Limitations

Although my results did not show statistically-significant trends for any of the bands that I calculated, the results that I found did show some trends that would be interesting to examine further. Additionally, the processes that I used in order to analyze the changes in Larimer and Weld County due to fracking showed that further analysis using remote sensing techniques could show meaningful information about the effects of fracking.

The limitations of my study were largely due to the time constraints; therefore, if I continue my research I will likely be able to understand better the effects on the band indices that I calculated. I only gathered images from ten years, so if I included another ten years in my study it might help show more meaningful trends in the data. Another possibility in order to expand the data collection for my study would be to include data from images in different months. However, this might present problems due to the fact that there will be seasonal changes in healthy vegetation that will not necessarily be accounted for by atmospheric or temporal corrections of the data.

Further remote sensing analysis could provide meaningful results regarding the impact of fracking on Larimer and Weld County. Analysis of vegetation health is an important indicator of the effects of fracking on these counties because agriculture is such an important part of the economy. Additionally, analysis of water composition in the region could provide insight into the quantity of chemicals being released by the fracking process into the water supply. Both of these issues are at the forefront of the current debate regarding hydraulic fracturing in Colorado, and this study indicates that questions regarding these issues can be answered using remote sensing techniques.

Data Sources

Data Source: Earth Explorer.gov (United States Geological Survey)

Satellites: Landsat 5, Landsat 8 (June 10, 2000; June 24 2002; June 11; 2003; June 29, 2004; June 16, 2005; June 19, 2006; June 27, 2009; June 30, 2010; June 27, 2011; June 6, 2013)