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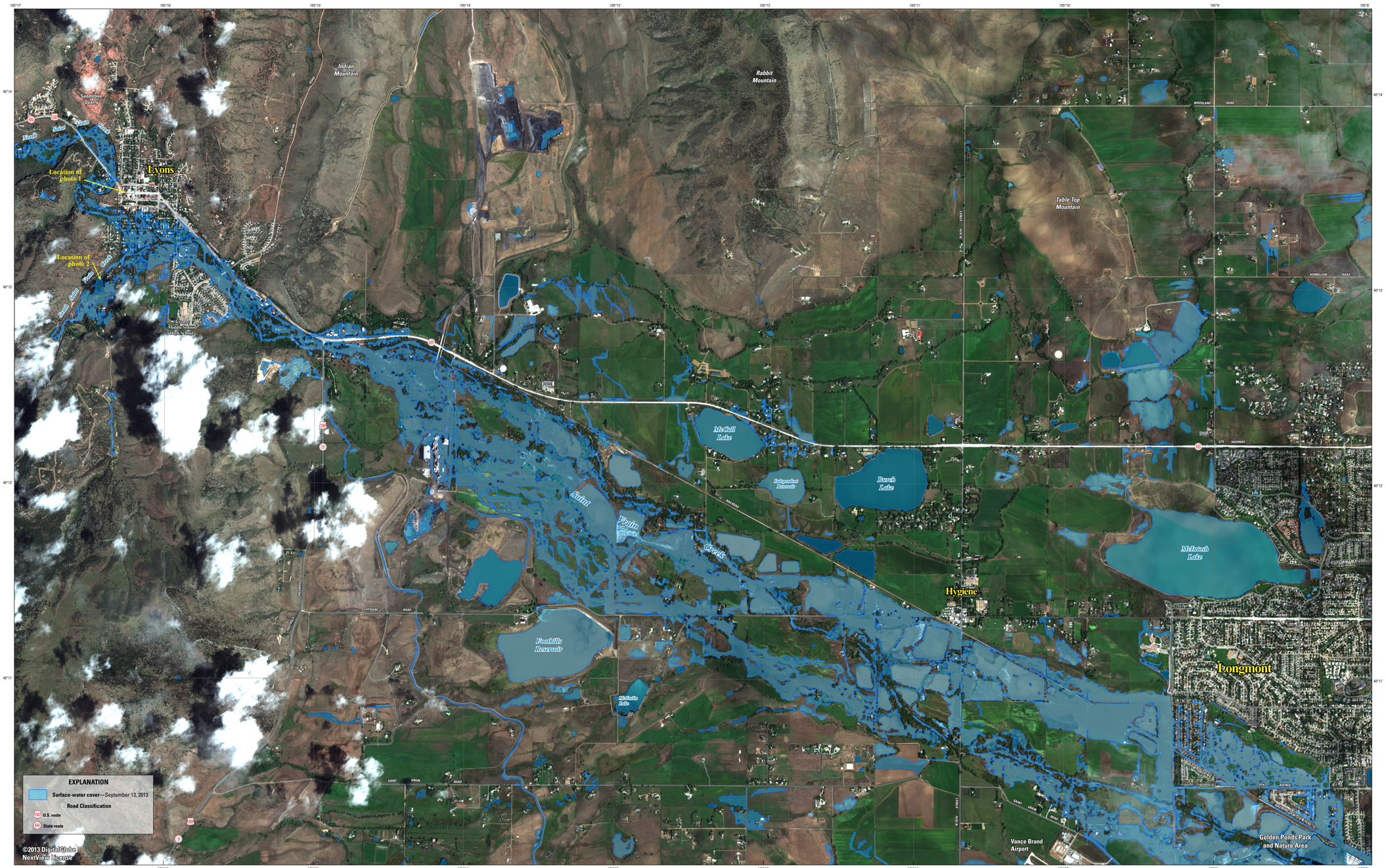
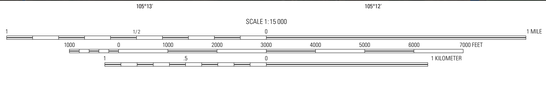


Image base mosaics produced from DigitalGlobe WorldView-2 data, accessed Sept. 13, 2013
Water and place names derived from 1:1,000,000-scale U.S. Geological Survey National Map digital data, accessed in 2014 at http://viewer.nationalmap.gov/viewer/.

This dataset has been orthorectified and pan-sharpened to enhance mapping accuracy and spatial resolution. Multispectral red (band 3), green (band 2), and blue (band 1) image composite shown.

UTM projection, zone 13N, World Geodetic System of 1984 (WGS84)



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Use of Satellite Images to Determine Surface-Water Cover During the Flood Event of September 13, 2013, in Lyons and Western Longmont, Colorado

By

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Abstract

The flooding that occurred in north-central Colorado in 2013 was some of the most destructive in the state's history. Following a summer of drought and wildfires, a wet weather system stalled over the Front Range area from Fort Collins in the north to Colorado Springs in the south, including the cities of Lyons and Longmont. This weather system produced rainfall amounts that greatly exceeded historical highs. The Colorado Office of Emergency Management reported at least eight deaths. More than 11,000 people were evacuated from their homes, and the flooding caused an estimated $2 billion dollars in damages. On September 14, 2013, President Barack Obama issued a major disaster declaration for 15 Colorado counties affected by the severe weather and related damage.

To support local, State, and Federal disaster response coordination efforts in Colorado, the U.S. Geological Survey (USGS) developed a geospatial product to identify surface-water cover from Lyons to western Longmont. This information was derived from September 13, 2013 WorldView-2 multispectral imagery at a spatial resolution of 3 meters (m). These data were orthocorrected and pan-sharpened. Three spectral indices (NDVI, NDWI, and NDTI) that were computed from this processed imagery were used to help determine the extent of the surface-water cover. The result was converted to a vector format.

This surface-water cover dataset was created as a timely representation of post-flood ground conditions to support response efforts. This dataset and all processed imagery and derived products were uploaded to the USGS Hazards Data Distribution System (HDDS) website (http://hddsexplorer.usgs.gov/uplift/hdds/) for distribution to those responding to the flood event.

Introduction

The flooding that occurred in north-central Colorado in 2013 was some of the most destructive in the state's history. Following a summer of drought and extreme wildfires, a wet weather system stalled over the Front Range area from Fort Collins south to Colorado Springs and produced rainfall amounts that greatly exceeded historical highs (Boulder Creek Critical Zone Observatory, 2013). Boulder County has an average annual precipitation of 20.7 inches, and it was one of the worst hit areas with 9.08 inches of precipitation on September 12, 2013, and up to 17 inches of rain on September 15 (Current Results, 2013; Freedman, 2013; Henson, 2013; Paulson, 2013; Smith and Hennen, 2013). At least eight deaths were reported by the Colorado Office of Emergency Management (Henson, 2013; Shiff, 2013), more than 11,000 people were evacuated from their homes (Boulder Creek Critical Zone Observatory, 2013; Garrison, 2013), and the flooding caused an estimated $2 billion dollars in damages (Shiff, 2013). President Barack Obama declared a state of disaster for 15 counties in Colorado (Balluck, 2013).

Purpose

The U.S. Geological Survey (USGS) developed a 1:15,000-scale geospatial product to identify surface-water cover to support local, State, and Federal disaster response coordination efforts in Colorado. This product, presented here as a map, depicted the water-surface cover that resulted from the flooding that occurred from Lyons to western Longmont on September 13, 2013.

Methodology

Water cover was derived from DigitalGlobe's WorldView-2 multispectral imagery dated September 13, 2013, at a spatial resolution of 3 meters (m) (DigitalGlobe, 2013). The WorldView-2 data were orthocorrected using a 10-m USGS Digital Elevation Model (DEM) to enhance mapping accuracy (Gesch and others, 2002; see The National Elevation Dataset, NED, at http://ned.usgs.gov/). A 0.50-m resolution pan-sharpened multispectral image was produced to support National Guard flood relief efforts in Lyons, Colorado, and vicinity, and was used for water-cover mapping verification of the extent of the flooding (Cole and others, 2013).

Three spectral indices were computed from the processed 3-m imagery. Spectral indices are commonly used by remote sensing scientists to identify a particular surface-cover type based upon its absorption or reflection of incident solar energy in different regions of the electromagnetic spectrum. The Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Turbidity Index (NDTI) used for this study are defined below:

- **Normalized Difference Vegetation Index (NDVI)**=(Near infrared−red)/(near infrared+red). The NDVI is used to discriminate vegetation health and to differentiate this cover from non-vegetated surfaces (Rouse and others, 1973).
- **Normalized Difference Water Index (NDWI)**=(Green−near infrared)/(green+near infrared). The NDWI is useful for delineating clear water cover (McFeeters, 1996).
- **Normalized Difference Turbidity Index (NDTI)**=(Red−green)/(red+green). The Normalized Difference Turbidity Index (NDTI) allows the detection of high turbidity (low clarity) water cover (Lacaux and others, 2007). Turbid water contains a high volume of suspended materials and is common following flood events.

The use of these indices enabled us to determine the extent of the surface-water cover. Vector polygons identifying all surface-cover features were derived from the processed 3-m data using eCognition Developer image-segmentation software (Definiens, 2012). This software allows us to group similar image pixels and convert them into vector objects based on their spatial and spectral characteristics. Water was then delineated from other surface cover using classification rules based on pixel-value thresholds of the processed imagery, the derived spectral indices, and terrain slope calculated from 10-m DEM information. For instance, surface water holds a very low pixel value in the NDVI, and higher levels in the NDWI and the NDTI than other cover types. The use of slope information from the DEMs reduced the incidence of misclassification of non-vegetated background soils as distinguished from water in high-relief areas. Minor editing was used to refine the extent of the surface-water cover data, and included merging and smoothing the vector polygons as well as revising some of them based on visual interpretation.

Summary

The data displayed on this map were created to support flood-response efforts, specifically for use in determining damage assessment and informing mitigation decisions. Water cover was derived from multispectral imagery at a spatial resolution of 3 m. The data were orthocorrected and pan-sharpened to produce a multispectral image. The extent of the surface-water cover was determined and converted to a vector format. The processed data were then placed onto a base image. All processed imagery and derived products were uploaded to the USGS Hazards Data Distribution System (HDDS) website (http://hddsexplorer.usgs.gov-/uplift/hdds/) for distribution to those responding to the flood event. These data were intended to provide a timely representation of post-flood ground conditions to aid in flood-response efforts by decisionmakers and the general public, and could also be used to support future water-science studies, such as historical inundation trends.

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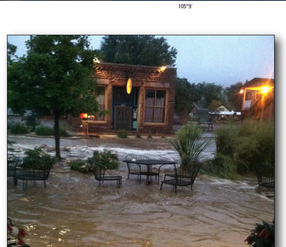

Photo 1. Main Street in downtown Lyons is inundated during the September 13, 2013, flood event. Photograph by Lauren Simms. Used with permission.

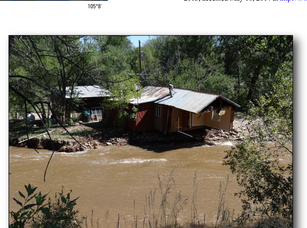

Photo 2. Flooded house on the South Saint Vrain Creek, Southwest of Lyons, Colorado, September 13, 2013. Photograph by Bill Benzel (USGS).

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