RECLAMATION

Managing Water in the West

Airborne Red, Near-IR, and Thermal-IR Multispectral Remote Sensing for Detecting Canal Embankment and Levee Seepage

Research and Development Office
Science and Technology Program
Final Report ST-2015-5326-1

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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14. ABSTRACT *(Maximum 200 words)*

This document outlines suggested remote sensing and image processing techniques to detect canal embankment and levee seepage. The technique involves using an aircraft to acquire red, near-infrared, and thermal-infrared bands at a 1-2 m spatial resolution to detect areas that are anomalously highly vegetated and wet.

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Peer Reviewer: I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy. I have not reviewed any of the information in the introduction section regarding delays to this project. My signature here does not imply an affirmation of this timeline.

Reviewer ______________ Date reviewed 12/31/2015
(Signature)

Introduction

The original goal of this project was to determine whether remote sensing could be used to narrow down areas of potential canal leakage on which soil resistivity surveys would be performed. However delays in receipt of funding and purchase of software necessary to complete the work prevented completion of the project as proposed.

Because of these delays, the project as originally proposed could not be completed. Instead, the focus of this S&T Project is to recommend remote sensing and image processing procedures to detect seepage along canal embankments and levees.

Background

There are over 100,000 miles of levee embankments on the national inventory list. Many of these structures are nearing or have exceeded their design life. The Homeland Security Presidential Directive (May 7, 2001) identifies levees as one of the 18 most critical infrastructure and key resource sectors (e.g., assets, systems, and networks, whether physical or virtual, so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, public health or safety or any combination thereof). Canal and levee leaks can be confirmed with soil resistivity surveys. Remote sensing may provide a relatively easy, economical way to narrow down which areas along a canal embankment may be leaking. This could save time and money by preventing geophysicists from conducting soil resistivity surveys on areas that are not leaking.

Goals of the Project

The original goal of this research project was to improve specific geophysical tools for rapid and proactive characterization of canal levee and embankment structures and for rapid and economical reconnaissance surveys to be conducted along extensive segments of canal levees and embankments. Due to delays in funding and the inability to acquire the software required to complete the project as proposed, the goal of this S&T Project is to support the FY2016 S&T Project Evaluation and Development of Rapid Geophysical Profiling for Canal Embankment and Levee Health Assessment and Seepage Detection (X9918) by outlining suggested remote sensing and image processing techniques to detect canal embankment and levee seepage.

Proposed Method

The recommended method to detect seepage and leaks in canal embankments and levees is based on two principles:

1. Areas of water seepage will have a denser canopy of active, healthy vegetation due to the increased availability of water (Appendix 1; Jensen, 2006).
2. Areas of water seepage will have a lower temperature.

To support the FY2016 S&T Project Evaluation and Development of Rapid Geophysical Profiling for Canal Embankment and Levee Health Assessment and Seepage Detection (X9918), the following general procedure is recommended.

1. Determine study area from project engineers and/or geophysicists
2. Acquire basic GIS and Remote Sensing data for the study area (Tables 1 and 2).
3. Follow general procedures outlined by Huang et al. (2010) to:
    a. acquire airborne multispectral data of the study area in the red, near-IR, and thermal-IR portions of the electromagnetic spectrum at a spatial resolution of no more than 2 meters.
    b. process and analyze data to detect potential areas of seepage

AIRBORNE MULTISPECTRAL REMOTE SENSING

In order to detect canal and levee leakage remote sensing imagery must have a spatial resolution of no more than a few meters. However, Earth-observing satellite systems are limited in the spatial resolution with which they can make such observations. Low-resolution satellite systems such as NOAA-AVHRR and Terra-MODIS are applicable only to regional-scale studies. Other thermal IR satellite systems, including Terra-ASTER and Landsat 7 ETM, from 30 to 100 meters. High-spatial-resolution satellite imagery is currently available in the visible and near-IR wavelengths (e.g., IKONOS and QuickBird), however, there are no civilian high-spatial-resolution thermal IR data are currently available.

In the absence of space-based systems, aircraft observations will be necessary for studies involving remote sensing (Huang et al., 2010). While several airborne remote sensing systems are commercially available, none contain the combination of sensors (visible, NIR, and thermal) necessary to support a wide variety of water resource studies.

Huang et al. (2010) successfully determined leaks along irrigation canals using airborne multispectral (red, near-IR, and thermal-IR) remote sensing techniques.

They concluded that airborne multispectral imaging is a promising technique for evaluation of canal conditions and leak detection in irrigation distribution networks. They found that the combination of red, near-IR and thermal-IR sensors is effective in determining the leak points and identifying the potential of seepage in irrigation canals.

DATA ACQUISITION SYSTEM

The airborne multispectral remote sensing system was developed by integrating commercially available imaging and computer components.

The system combined high-performance, high-resolution imaging sensors in the visible, near-IR, and thermal IR wavelengths.

- Terrestrial thermal IR: 12-bit digital camera capable of resolving the temperature range of the target into 4096 discrete levels, allowing an extremely sensitive analysis of surface temperature variations.
- Imaging in the visible and near-IR wavelengths is accomplished using two 12-bit digital cameras capable of resolving the surface reflectance of the target into 4096 discrete brightness levels, allowing subtle differences in vegetation density to be detected.
- All cameras are fitted with astronomy-grade interference filters to allow them to image targets in the red (0.66 micron) and near-IR (0.8 micron) wavelengths with extreme sharpness.
- Image data from all cameras captured using a PCI-bus computer with two digitizing boards. This computer also runs the software to control image acquisition by the cameras. Cameras and data acquisition commands are displayed on a touch-sensitive, flat-screen monitor.
- Imagery is saved to a hard disk drive within the computer.
- A small camcorder is used to provide a real-time, true-color display of the general area being imaged by the system making it easier for the operator of the system to give directions to the aircraft pilot regarding adjustments to the flight track. (NOTE: Flying at approximately 5000 feet above ground level (AGL) with the above described cameras should result in a surface resolution of 1 to 2 meters and allow detailed imaging of surfaces sufficient to detect seepage from canal embankments and levees).

WORKING PROCEDURE

In general, leak detection of irrigation canals using remote sensing should go through the following procedure as outlined in Huang et al. (2010):

- Canal survey to determine the segments needed to evaluate
- Generate a GIS map to show geographic locations of the selected canal segments for pilot and imager operator
- Flyover to acquire imagery of the canal/levee segments
- Processing of the imaging data, described below
- Image analysis to identify suspicious leak points and potential seepage areas
- Field reconnaissance to verify image analysis

IMAGE PROCESSING METHODS

- Data acquisition occurs simultaneously from the three cameras (Red, NIR and Thermal), generating an image triplet at each scene.
- Image format conversion: Data are imported from a RAW (.raw) format into a format that can be manipulated in an image processing software (e.g., ERDAS Image, ENVI).
- Image registration: In order to compare or integrate data obtained from different measurements, image registration is required to transform the Red, NIR, and Thermal images from each scene into one coordinate system.
- Image stack: A process to stack the three registered images (Red, NIR, and Thermal images) into one composite image.
- Image geo-reference: Establishes a relationship between the coordinates of a planar map (i.e., x,y) to real-world coordinates (i.e., longitude/latitude, UTM, etc.). Stacked images should be geo-referenced to Digital Orthophoto Quarter Quads (DOQQs) using an image processing software to Universal Transverse Mercator (UTM), North American Datum of 1983
- Image AOI generation: Subset or clip the image to an Area of Interest (AOI).
- NDVI image generation: Using the AOI of the composite image, the image of normalized difference vegetation index (NDVI) can be generated as: NDVI=(NIR- Red)/(NIR+Red) NDVI has been widely used for remote sensing of vegetation for many years for different sensors (Appendix 1; Jensen, 2006).

Table 1. Basic GIS and Remote Sensing data to be acquired for all studies

Data Type	Description	Spatial Resolution	Source (ID from Table 2)	Notes
GIS	Reference and infrastructure data	N/A	1	Roads, state and county boundaries, railroads, utilities, etc., to be used as reference data and aid in interpreting site conditions.
	Digital Elevation Model	30 m or higher	1-6	Also search for state and university web sites that may have online GIS data. Obtain highest spatial resolution possible.
	Geologic Data	N/A	7	Also search for state and university web sites that may have online GIS data.
	Soils		8,9	Acquire through ArcGIS Soil Data Viewer
Remote Sensing	NAIP or other recent aerial photography	1-2 m	2,3,4	Acquire most recent imagery available at highest spatial resolution available
	Landsat	30 m	3,4,10,11	-----

Table 2. Data Sources for Basic GIS and Remote Sensing Data to be acquired for all projects.

Source ID	Data Source	Uniform Resource Locator (URL)
1	DataSpace, U.S. Bureau of Reclamation	N/A
2	Geospatial Data Gateway	https://gdg.sc.egov.usda.gov/
3	USGS GloVis: The Global Visualization Viewer	http://glovis.usgs.gov/
4	USGS Earth Explorer	http://earthexplorer.usgs.gov/
5	The National Map	http://viewer.nationalmap.gov/launch/
6	NOAA Digital Elevation Model (DEM) Discovery Portal	https://www.ngdc.noaa.gov/mgg/dem/
7	The National Geologic Map Database	http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
8	SSURGO Data Downloader	http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/
9	STATSGO2 Database	http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053629
10	LandsatLook Viewer	http://landsatlook.usgs.gov/
11	Free Web Enabled Landsat Data (WELD)	http://globalmonitoring.sdstate.edu/projects/weld/

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APPENDIX 1

Normalized Difference Vegetation Index (NDVI)
Jensen (2006)

Chlorophyll and photosynthesis in healthy vegetation cause vegetation to absorb light in the red portion of the visible spectrum. The internal cellular structure of vegetation produces a strong reflectance in the near-infra red (NIR) region. Conversely, when vegetation is not healthy, it has less NIR reflectance and more red reflectance.

NDVI combines the information in the red and near-infrared bands into a single value by dividing the difference between the NIR and Red bands by their sum:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The negative sign on the numerator ensures that, regardless of the red and NIR values, the NDVI will always calculate to a value between -1 and 1. Healthy vegetation will tend values close to one; less healthy vegetation will have lower values but will still remain positive.
Water has a distinctive NDVI because almost all NIR light is absorbed by water, the red reflectance becomes higher than the NIR. This results in a negative numerator and a negative NDVI value.

Therefore, NDVI could be used two detect seepage in two ways: (1) in arid areas with little vegetation, high NDVI values may indicate vegetation that is receiving water from seepage and (2) negative or near zero NDVI values outside the boundaries of a water body may indicate the presence of seepage.