PROPOSAL

Determination of Land Subsidence Rates and Distribution in Hampton Roads, Virginia: Data Program

Date:	January 2012
Prepared By:	U.S. Geological Survey – Virginia Water Science Center (USGS-VWSC)
Cooperator:	Hampton Roads Planning District Commission (HRPDC)
Project Period:	February 2012 to June 2014

Problem

Land subsidence is contributing to problems of rising water in Hampton Roads. Rising water can be caused both by sea-level rise and by land surface elevation declines, which combined make up 'relative sea-level rise.'

The Hampton Roads region has the highest rate of relative sea-level rise on the US Atlantic Coast[1], a rate more than twice the rate of global sea-level rise (4.0 vs. 1.8 mm/yr). Relative sea level has risen 14.5 inches since 1930 in Norfolk[2] and rising water is causing damage in low-lying areas [2, 3, 4]. Hampton Road communities support a growing population of more than 1.6 million people, the nation's 9th busiest port facility, the world's largest naval base, and numerous other military installations. A recent study identified more than $85 billion dollars of infrastructure exposed to rising sea-levels in Hampton Roads, making it the 10th most endangered harbor in the world[5].

Because land subsidence may be causing more than half of the observed relative sea level rise in Hampton Roads, it is important to understand the rate and distribution of land subsidence in the region. This proposal describes a program to collect land subsidence data that will improve understanding of land subsidence in Hampton Roads and assist planners preparing for rising water.

Objectives

The USGS VWSC proposes a 3-year study to collect and analyze land surface elevation data that will provide a detailed view of past and current land subsidence rates in the Hampton Roads region.

1. Compile data to develop a more complete understanding of past land subsidence
2. Determine current rates and distribution of land subsidence
3. Design an ongoing land subsidence monitoring program to serve the needs of regional planners

Background

Measured Land Subsidence Rates in Hampton Roads

Land subsidence rates of the Virginia Coastal Plain have been measured in prior studies. Using traditional geodetic surveying methods, Holdahl and Morrisson (1974)[6] found land surfaces subsiding at rates of 1 to 4 mm/yr in the Hampton Roads area between 1940 and 1971. Pope and Burbey (2004)[7], analyzing data from two extensometer installations, found aquifer compaction rates of 1.5 mm/yr in Franklin, VA, from 1979-1995 and 3.7 mm/yr in Suffolk from 1982-1995.

Causes of Land Subsidence

Most land subsidence in the US is caused by compaction of aquifer systems, drainage and subsequent oxidation of organic soils, or dissolution and collapse of susceptible rock[8]. Other factors, such as crustal flexure or the settling of fill material or natural soils, can also be involved. Based on observed strong spatial and temporal correlation between land surface declines and increased groundwater pumping [6, 7], we expect the majority of land subsidence in the Hampton Roads area to be associated with aquifer compaction caused by groundwater pumping. An ongoing study by the USGS-VWSC looks at this issue.

Measuring Land Subsidence

Land surface elevation data is the basis for determining locations and rates of land subsidence. Types of elevation data available for Hampton Roads are:

Continuous GPS (Global Positioning System) Data –

Eight continuous GPS stations are currently active in the Virginia coastal plain (Figure 1 – CORS station map) and provide highly accurate and detailed land surface positional data at their individual locations. Two of these stations have been operated by federal government agencies in the Hampton Roads area for 5 years or more. The other six stations are operated by cooperating groups and were installed less than five years ago.

Extensometers -

Extensometers record changes in the thickness of an aquifer measured from the land surface down to the bottom of the extensometer borehole. The USGS previously operated two extensometers in the Virginia Coastal Plain; one at Franklin from 1979 through 1995, and a second at Suffolk from 1982 through 1995. Data from these two extensometers describe changes in the thickness of the Virginia Coastal Plain aquifer system during those time periods. Installation of a new extensometer would probably have a relatively high cost ($500K+), but it may be possible to reactivate the two existing extensometers for a much lower cost.

Figure 1 – Continuous GPS stations, Hampton Roads, 2011

InSAR

Interferometric synthetic aperture radar (InSAR) uses reflected radar waves to determine changes in land surface elevations over wide areas[9]. Multiple passes of a satellite are required to measure surface deformation. InSAR data for Hampton Roads are available for various time periods after 1992 and can be used to develop a detailed and accurate picture of land surface elevation changes over the entire region for 1992-2000 or for 2002-2010. An InSAR study could be performed in cooperation with scientists from the USGS National Research Program and would involve purchasing data from international satellite operators. The data would then be processed and interpreted with persistent scatter analysis methods. InSAR work could be phased to reduce annual costs and test results, with the initial phase covering the southern half of the Hampton Roads area.

Traditional Surveying

The geodetic network last surveyed in 1971 offers an opportunity to determine land subsidence rates from 1971 to present. Subject to an evaluation of the network during year 1, we propose resurveying the historical benchmarks in cooperation with the National Geodetic Survey in Year 2 of the study. The new survey would provide valuable data for calibration of predictive land subsidence models.

Work Plan

The work plan is designed to produce land subsidence data with the most use and value to HRPDC in its planning efforts.

Year 1 Compile and analyze historic data and document findings in a draft journal article and fact sheet. Determine costs and benefits of long-term subsidence data collections activities including use of satellite data. With HRPDC, develop a plan for ongoing subsidence monitoring.

Years 2-3 Start subsidence data collection efforts planned in Year 1. Publish fact sheet.

Year 1 Tasks

Task 1 - Compile historic and readily available land surface elevation and subsidence data
Task 2 - Analyze data to determine rates and spatial distribution of land surface subsidence
Task 3 - Assess options for ongoing data collection
Task 4 - Develop a plan for ongoing subsidence data collection
Task 5 - Write a report that documents finding and establishes baseline conditions

Task 1: Compile Existing Data

1.1 Compile existing publications on relative sea-level rise in Hampton Roads
1.2 Develop databases of existing extensometer and continuous GPS data

Task 2: Review and analyze data

2.1 Perform time series statistical analysis of continuous GPS data from the eight CORS stations for the full period of record.
2.2 Review extensometer data collected 1979-1995 in context of more recent satellite-based data.
2.3 Produce contour maps of subsidence rates over time in Hampton Roads
2.4 Determine relative contribution of land subsidence to overall relative sea-level rise
2.5 Assess likely processes contributing to land subsidence
2.6 Quantify relative contributions from all potential causes of regional land subsidence.
2.7 Determine elastic and inelastic specific storage and vertical permeability parameter values

Task 3: Assess data collection options for Year 2-3 activities

3.1 Inspect two historic extensometer stations to determine potential for reactivation

3.2 Determine costs and benefits of resurveying the 1971 geodetic network
3.3 Determine costs and benefits of undertaking an InSAR data program

Task 4: Develop monitoring and data-collection plan in cooperation with HRPDC
4.1 Determine goals of an ongoing subsidence data collection program
4.2 Develop a ranked list of data collection activities with associated costs
4.3 Hold quarterly meetings with HRPDC and USGS
4.4 Complete plan for land subsidence monitoring and data collection

Task 5: Write report
5.1 Prepare summary document at end of Year 1 containing ongoing monitoring plan
5.2 Prepare scientific journal article
5.3 Prepare draft USGS fact sheet

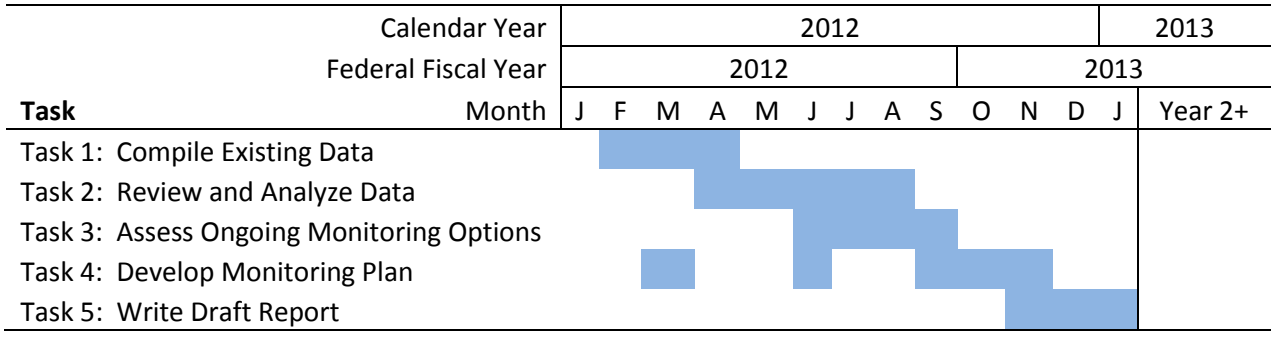
Years 2-3 Tasks

Data collection activities in Years 2 and 3 will be determined during Year 1

Monitoring activity options for Years 2-3 include:

- Resurveying the 1971 geodetic network and interpreting results
- InSAR surveying of the southern half of the Hampton Roads area
- InSAR survey of the entire Hampton Roads area
- Rehabilitating existing extensometers
- Installing a new extensometer(s)
- Installing a new continuous GPS station (CORS)

Schedule



Benefits and Products – Year 1

This study will provide benefits and results that the HRPDC can directly use in its sea-level rise planning efforts. The study will provide the first analysis of regional subsidence rates since 1971. Detailed maps of past subsidence rates and projections of future subsidence will be constructed to show local variability in subsidence rates.

Causes of land subsidence in the region will be analyzed, providing quantitative benchmarks and necessary understanding of subsidence in Hampton Roads. As a recent study (Snay and others - VIMS, 2010)[10] concludes, land subsidence likely causes more than half of relative-sea-level rise in Hampton Roads. This study will quantify possible causes of subsidence: groundwater extraction, impact crater settling, glacial rebound, and tectonic movement. The relation between groundwater pumping and subsidence will be analyzed in detail.

The study will produce a plan for ongoing subsidence monitoring. The plan will be developed in concert during quarterly meetings/teleconferences between the USGS and HRPDC. A summary document containing the monitoring plan will be prepared at the end of Year 1.

Products

- Public presentations of study results can be made biannually to the HRPDC and to other groups as requested.
- A summary document that includes a plan for ongoing subsidence monitoring will be developed in cooperation with HRPDC.
- A draft journal article and fact sheet will be prepared documenting results of the land subsidence data study. The final fact sheet will be published in Year 2 of the study.

Budget

Year 1 Budget

The budget for Year 1 is $130,000, with HRPDC providing $78,000 and USGS $52,000. The majority of the budget pays for the time of a hydrogeologist and the remainder pays for travel and field work costs.

Personnel	$	108,500
Supplies, Travel, and Other	$	21,500
TOTAL	$	130,000

Years 2-3 Budget

The budgets for Years 2 and 3 will depend on the monitoring activities chosen during Year 1.

References Cited

1) Thieler, ER, and Hammar-Klose, ES, 1999, National assessment of coastal vulnerability to sea-level rise; U.S. Atlantic Coast, USGS Open-File Report 99-593.
2) HRPDC (Hampton Roads Planning District Commission), 2010, Climate Change in Hampton Roads, February 2010, 43 p.
3) Erwin RM, Brinker DF, Watts BD, Costanzo GR, and Morton DD, 2010. Islands at bay: rising seas, eroding islands, and waterbird habitat loss in Chesapeake Bay (USA). J Coast Conserv, 15(1): 51-60.
4) Kaufman L, 2010, Front-Line City in Virginia Tackles Rise in Sea, New York Times, Nov., 2010, p A1.
5) OECD (Nicholls, R., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, J. Chateau, and R. Muir-Wood), 2008. Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates. OECD Environment Working Paper 1, OECD Publishing.
6) Holdahl, SR, and Morrison, NL, 1974, Regional investigations of vertical crustal movements in the U.S., using precise relevelings and mareograph data. Tectonophysics, 23, 373-390.
7) Pope, JP, and Burbey, TJ, 2004, Multiple-aquifer characterization from single borehole extensometer records. Ground Water, 42, 45– 58.
8) Galloway DL, Jones DR, Ingebritsen SE, 2001, Land Subsidence in the United St. USGS Circular 1182.
9) Pritchard, ME, 2006, InSAR, a tool for measuring Earth's surface deformation. Phys Today, Jul 68-69.
10) Snay R, Cline M, Dillinger W, Foote R, Hilla S, Kass W, Ray J, Rohde J, Sella G, and Soler T, 2007. Using global positioning system-derived crustal velocities to estimate rates of absolute sea level change from North American tide gauge records. J. Geophys. Research, 112: B04409.