DELTA RISK MANAGEMENT STRATEGY

INITIAL TECHNICAL FRAMEWORK PAPER

SUBSIDENCE

Prepared by:
URS Corporation/Jack R. Benjamin & Associates, Inc.

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SUBSIDENCE

Steve Deverel (HydroFocus, Inc.)

Foreword

The purpose of the Delta Risk Management Strategy (DRMS) Initial Technical Framework (ITF) is to guide the analysis of specific technical topics as they relate to assessing potential risks to Delta levees and assets resulting from various potential impacts (e.g., floods, earthquakes, subsidence, and climate change). These ITFs are considered “starting points” for the work that is to proceed on each topic. As the work is developed, improvements or modifications to the methodology presented in this ITF may occur.

Subsidence crosses the boundaries of three Delta Risk Management Strategy Working/Topical area groups; levee vulnerability, hydrodynamic modeling and water management, and environmental consequences. Therefore, subsidence merits comprehensive yet separate attention so that the proper information can be provided to the appropriate working groups. Specifically, relative to levee stability, subsidence of organic soils increases hydraulic gradients across levees to drainage ditches which increase seepage through and under levees. Subsidence affects static stability within some temporally and spatially variable zone of influence adjacent to levees and drives the need for upgrades. Levee stability is affected by ongoing subsidence because there is an ongoing need to deepen drainage ditches. Drainage ditches are commonly adjacent to levees on the perimeter of islands.

Relative to hydrodynamics and water-quality, future subsidence will determine the volume of water that will fill an island after levee failure. The location and volume of flooding determines the extent of seawater intrusion which can threaten the drinking water supply for much of California. For example, an average additional foot of subsidence on Sherman Island in about 20 years would create about 10,000 acre feet of additional volume below sea level. Depending on island location, the volume of flooding influences the extent of saline water intrusion into the Delta and subsequent water management decisions about water exports and releases from upstream reservoirs. Also, subsidence increases drainage volumes from Delta islands. This occurs because subsidence necessitates deepening of drainage ditches, thus increasing the hydraulic gradient onto Delta islands. This increases drainage volumes over time and therefore loads of organic carbon and other constituents of concern to Delta channels.

Relative to the environmental consequences working group, subsidence determines the depth of island flooding due to levee failure which influences the resultant habitat. Geomorphologically, the depth of island flooding affects channel flows and therefore influences the extent of scour of adjacent channels and the probability of additional levee failure.

The overall objective of the proposed work is to estimate future depths of subsidence and island surface elevations. Specific objectives are as follows:

- Estimate the spatial distribution of current and future subsidence rates in the area of organic soils in the Sacramento-San Joaquin Delta.
- Estimate current and future depths of organic soils.
- Estimate uncertainty and randomness in subsidence predictions.

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1.0 INTRODUCTION

Subsidence is the primary landscape altering process in the Delta. A visual survey of the Delta today clearly demonstrates this. Stout levees imperfectly protect Delta island surfaces that range from several feet to over 20 feet below sea level. Prior to reclamation, island surfaces were near sea level. Subsidence caused this decrease in island surface elevation and continues to cause the land surface to decrease. Almost all Delta agriculture requires a drained root zone, which results in oxidation of organic soils, which is the primary cause of present-day subsidence. Continual seepage occurs onto farmed Delta islands (almost all Delta islands are farmed) from adjacent channels; the seepage is removed by a network of drainage ditches and discharge pumps. Continued organic-soil oxidation and subsidence causes farmers to continually deepen drainage ditches to maintain a sufficient root zone for crop production.

Subsidence crosses the boundaries of three Delta Risk Management Strategy Working/Topical area groups; levee vulnerability, hydrodynamic modeling and water management, and environmental consequences. Therefore, subsidence merits comprehensive yet separate attention so that the proper information can be provided to the appropriate working groups. Specifically, relative to levee stability, subsidence of organic soils[1] increases hydraulic gradients across levees to drainage ditches which increase seepage through and under levees. Subsidence affects static stability within some temporally and spatially variable zone of influence adjacent to levees and drives the need for upgrades.[2] Levee stability is affected by ongoing subsidence because there is an ongoing need to deepen drainage ditches. Drainage ditches are commonly adjacent to levees on the perimeter of islands.

Relative to hydrodynamics and water-quality, future subsidence will determine the volume of water that will fill an island after levee failure. The location and volume of flooding determines the extent of seawater intrusion which can threaten the drinking water supply for much of California. For example, an average additional foot of subsidence on Sherman Island in about 20 years would create about 10,000 acre feet of additional volume below sea level. Depending on island location, the volume of flooding influences the extent of saline water intrusion into the Delta and subsequent water management decisions about water exports and releases from upstream reservoirs. Also, subsidence increases drainage volumes from Delta islands. This occurs because subsidence necessitates deepening of drainage ditches, thus increasing the hydraulic gradient onto Delta islands. This increases drainage volumes over time and therefore loads of organic carbon and other constituents of concern to Delta channels.

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[1] Subsidence is the downward movement of land surface. In this ITF paper, we discuss and propose work relative to subsidence of island surfaces.

[2] Available data indicates the subsidence rate near the tow of the levee is substantially less than the island interiors. Recent data for an extensometer on Twitchell Island which is within 500 feet of the levee toe indicated subsidence rates ranging from 0.5 to 0.6 inches per year. These rates are generally consistent with rates measured and reported by Deverel and Rojstaczer (1996) and Rojstaczer and Deverel (1995) for soils with organic matter contents ranging from 5 to 15%. These organic matter percentages are characteristic of soils near the levee toe.

Relative to the environmental consequences working group, subsidence determines the depth of island flooding due to levee failure which influences the resultant habitat. Geomorphologically, the depth of island flooding affects channel flows and therefore influences the extent of scour of adjacent channels and the probability of additional levee failure.

2.0 OBJECTIVE

The overall objective of the proposed work is to estimate future depths of subsidence and island surface elevations. Specific objectives are as follows:

- Estimate the spatial distribution of current and future subsidence rates in the area of organic soils in the Sacramento-San Joaquin Delta.
- Estimate current and future depths of organic soils.
- Estimate uncertainty and randomness in subsidence predictions.

3.0 PHYSICAL SYSTEM AND PROBLEM

Subsidence of Delta organic soils is caused primarily by microbial oxidation of organic carbon. Ongoing oxidation daily removes tens of thousands of cubic yards of soil and creates an equivalent volume below sea level. Subsidence has resulted from draining of over 250,000 acres of organic soils on 60 islands in the late 1800’s and early 1900’s and has lowered land surfaces to as much as 30 feet below sea level.[3] During the previous 6,000 to 7,000 years, about 5.1 billion cubic meters of tidal marsh sediment accumulated in the Delta. During the past 150 years, half of this volume disappeared. This has created an accommodation space of over 2 billion cubic meters below sea level that can be filled by flood waters (Mount and Twiss 2005).

4.0 SCIENTIFIC MODELS

We propose to estimate spatially variable future subsidence rates by projecting recent subsidence rates using a statistical approach and by using the correlation of soil percent organic matter and subsidence rates. However, current data for subsidence rates are sorely lacking throughout the Delta and Suisun Marsh. The most recently published rates (Deverel et al. 1998; Deverel and Rojstazcer 1996; Rojstazcer and Deverel 1995) range from 0.6 to 4 centimeters per year and are limited to 6 islands. Other limited data are available for some islands based on leveling surveys related to water management and levee upgrades and repair. Rates vary spatially (between and on islands) and correlate with soil organic matter content (Rojstazcer and Deverel 1995). Deverel (1998) estimated historic Delta-wide subsidence rates using topographic maps from the early 1900’s and mid-1970s. He estimated errors in these rates that ranged from about 30 to over 150% (Figure 1) associated with mapping error.

[3] Data provided by DWR for Sherman Island indicate island elevations of -30 feet.

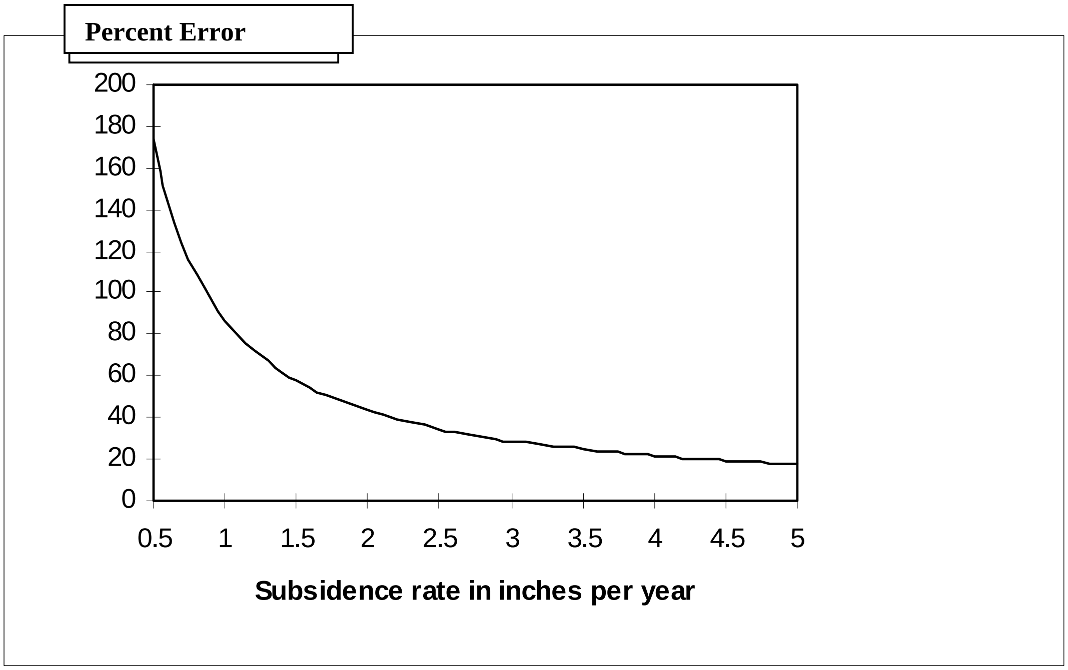

Figure 1: Variation in Percent Error Relative to Delta Subsidence Rate (Source: Deverel 1998)

Using long-term historic rates will overestimate future subsidence. To estimate elevation changes to 2050, Mount and Twiss (2005) used 1950 to 1980 elevation changes for three islands to adjust elevation changes from Shuttle Radar Tomography Mission (SRTM) data and historic USGS maps for 1900 to 2000.[4] The SRTM data are reported as vertically accurate to about +/- 10 meters (USGS 2006). However, Mount and Twiss (2005) compared SRTM land-surface elevations with those determined with LIDAR and GPS and estimated elevation error to be about +0.24 m for average island elevations. The error is certainly larger at the smaller spatial resolution of individual islands.

To reduce the error associated with lack of data for recent subsidence rates, we propose to collect additional elevation data to assess recent elevation changes as described below. Using recently collected elevation data in places where subsidence rates have been measured previously, we propose to estimate spatially variable current and future rates throughout the Delta. Similar to Mount and Twiss (2005), we propose to adjust long-term elevation changes (1900 to 2005) using the best available topographic data and recent subsidence rates. We propose to use a grid for each island to estimate elevation changes.[5]

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[4] Deverel et al. (1998) and Rojstaczer et al. (1991) evaluated the results of elevation data collected on Lower Jones Tract, Bacon Island, and Mildred Island from 1924 to 1981. Mount and Twiss (2005) used these data and estimated the change in subsidence rates from 1950 to 1981 relative to those from 1925 to 1981. The 1950–1980 rates were 20 to 40% less than the 1925–1981 rates. Conservatively, Mount and Twiss (2005) reduced the 1900–2000 elevation changes by 40% and used the reduced rates to predict subsidence rates to 2050.

[5] Deverel (1998) used a 500-meter grid for estimating subsidence rates and peat elevations. We propose to use the same grid as a starting point.

We will also examine the soil-organic matter-subsidence rate spatial correlation for long-term subsidence rates and recent subsidence rates. Rojstazcer and Deverel (1995) showed that subsidence from 1910 to 1987 on Sherman Island was significantly correlated with soil organic matter content ($r^2 = 0.62$). Soil organic matter content is available for soils throughout the Delta from the Natural Resources Conservation Service. We propose to develop one or more spatial correlations for historic and current subsidence rates and soil organic matter to improve our estimates of the spatial distribution of future subsidence rates. For example, additional data collection as described below will provide recent subsidence data for selected locations in the central and western Delta. For areas where recent subsidence data is not available, the soil-organic matter-subsidence rate correlation may be used to obtain spatial estimates of current subsidence rates based on the current knowledge of soil types and organic matter content.

Future subsidence rates will be estimated by examining the time historical variation of subsidence rates. For example, Deverel et al. (1998) estimated a logarithmic decline in elevations for Lower Jones Tract, Bacon, and Mildred islands. Additional data for these and other islands will provide more complete information about how subsidence rates have changed with time. We may also assess the temporal rate changes using the model developed in Deverel (1998).[6] This physically and chemically based model may be used test and modify the validity of the statistically based model for specific locations. For example, the Deverel (1998) model could be used on islands where there is good information about soil organic matter and oxidation rates and can be compared to the statistically based model for the same islands. This will allow modification of the statistically based model to better estimate future subsidence.

In Suisun Marsh, subsidence is more limited in areal extent and magnitude than in the Delta and there is limited elevation data. We intend to work with the Department of Water Resources to develop estimates of future subsidence based on historic elevation changes that vary by land use and soil type.

5.0 PROBABILISTIC APPROACH

There are three primary sources of uncertainty for estimating subsidence. First, there is uncertainty associated with comparing mapped elevation data to calculate elevation differences. A portion of this uncertainty can be attributed to changing datum and uncertainty in mean sea level measurement. Some of the uncertainty is attributed to mapping uncertainty and the inability to determine elevations exactly at any given point. We will estimate this uncertainty based available data for the data for the individual surveys from individual islands. As an example, Deverel (1998) estimated the uncertainty associated with mapped elevations to be plus or minus one-half the contour interval based on discussions with the U.S. Geological Survey. Additional investigation should yield a more precise uncertainty estimator.

The uncertainty for subsidence estimates using mapped data increases with decreasing cumulative elevation change. This systematic uncertainty can generally be quantified because we know the uncertainty associated with historical mapping of elevations. Also,

[6] Deverel (1998) modeled historical subsidence rates based primarily on Michealis-Menton kinetics for carbon oxidation. Model results agreed well with historical data. Extended use of the model is limited by lack of knowledge about parameters for the Michealis-Menton equation.

we will compare mapped elevation data with measured elevations. (Mapped elevation differences will be used to project future elevations based on knowledge of recent and historic subsidence rates.)

Second, there is uncertainty associated with lack of knowledge of present-day elevation changes. For the most part, this uncertainty is currently generally unquantifiable because of a general lack of subsidence data since the 1980's. We propose to reduce and quantify this uncertainty by collecting recent elevation data and estimating recent subsidence rates. We will also collect soil samples where we determine elevations and determine soil organic matter content to better quantify the relation of subsidence to soil organic-matter content. Once we collect data for recent subsidence rates, we will estimate the uncertainty associated with estimating historic subsidence rates with different statistical models.

We will quantify the uncertainty in this estimate using standard statistical methods for estimating error in regression equations. We will also use professional judgment and experts to evaluate the validity of future subsidence estimates. We will provide a probability distribution of subsidence rates based upon estimation of uncertainty.

6.0 ASSUMPTIONS, CONSTRAINTS, LIMITATIONS

The primary constraint on future subsidence is the current thickness of the organic soils. As organic carbon disappears, subsidence rates will slow significantly. Therefore, the depth of peat needs to be estimated with some estimated uncertainty based on available data. We will partially rely on present-day peat depth estimates from the Levee Stability Group.

7.0 INFORMATION REQUIREMENTS

Without more knowledge of current rates of subsidence in the Delta, there is potentially substantial unquantifiable uncertainty in predicting future subsidence rates. Deverel et al. (1998) predicted a logarithmic land-surface elevation decline based on elevation data collected on Bacon and Mildred islands and Lower Jones Tract from 1924 to 1981, implying a temporal decrease in subsidence rates. However, Mount and Twiss (2005) estimated a linear decline using more recent data (1950–1981). Since soil organic carbon is continually lost due to oxidative subsidence under current conditions, soil carbon contents are declining. This decline will eventually lead to declining subsidence rates. The nature and timing of this decline is geographically unique and dependent on climatic and hydrologic conditions such that data from other regions are impossible to apply. Data for current elevations where there is long-term elevation data will provide some information about temporally changing subsidence rates. Some islands and parts of island have little organic soil remaining and our effort will included identification of these areas.

There are 4 drained islands in the Delta where there are historic land-surface elevation data; Jersey, Sherman, Lower Jones Tract and Bacon Island. The University of California measured land surface elevations from 1922 to 1981 on Lower Jones Tract and Mildred and Bacon islands. Measuring current elevations at the same locations on Bacon and Lower Jones will provide information about how subsidence rates have changed since 1981. Similarly, revisiting locations where elevations were previously measured on Sherman and Jersey islands (Rojstazcer et al. 1991) will provide information about how elevations have changed since 1987. Therefore, we propose to determine elevations at these locations using GPS technology. This can be done relatively quickly and should not impede project progress.

8.0 ANTICIPATED OUTPUTS/PRODUCTS

We anticipate the following products for downstream users.

1. Estimated subsidence rates and associated uncertainty for at 50, 100 and 200 years in the future.
2. Island surface elevations and associated uncertainty at 50, 100 and 200 years in the future.
3. Changes in peat thickness and associated uncertainty at 50, 100 and 200 years in the future.

9.0 RESOURCE REQUIREMENTS

We anticipate the use of experts Jeff Mount, Professor, University of California at Davis and Stuart Rojstazcer, Professor Emeritus at Duke University.[7] These experts can provide guidance and review of methods and results. We will require the use of Arc View Spatial Analyst software (HydroFocus has this software and expertise in house).

10.0 PROJECT TASKS

Project tasks are as follows:

1. Collect, process and analyze new land-surface elevation data. We propose to collect additional land-surface elevation in the Delta where subsidence rates have been measured previously.
2. Gather and analyze existing land-surface elevation data. We will gather to the extent possible all available land-surface elevation data that can be used for estimating current land-surface elevations and subsidence rates. Sources of information included Reclamation Districts and their engineers, Department of Water Resources and US Geological Survey.
3. Develop subsidence estimation methodology. This includes development and analysis of available elevation, soils and land use data, grid development for estimating the areal distribution of subsidence rates.
4. Spatially analyze elevation data and estimate elevation changes. This includes determination of the areal distribution of historic elevation changes and uncertainty analysis of the elevation changes using GIS.
5. Estimate current and future subsidence rates and uncertainty. Using methodology developed in task 3 and collected and gathered data, we will estimate future land-surface elevation changes. Future subsidence will be constrained by the changes in peat thickness determined in task 6.
6. Estimate peat thickness changes. Using estimated land-surface elevation changes, we will adjust initial peat thickness based on subsidence for 50, 100 and 200 year scenarios.

[7] Dr. Rojstazcer has been contacted and has tentatively agreed to serve as advisor.

7. Coordinate with end users, advisors, and other stakeholders. We intend to maintain a dialog with advisors and end users of subsidence estimates to ensure timely and useful information.
8. Document results. Our report will include methodology, estimated future subsidence rates, elevations, peat thickness, and uncertainty.

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