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Solutions for Land and Water Resources

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Dear Mr. Jones,

I herein provide information relevant to the consideration of easements for subsidence mitigation in the Delta. As I see it, key relevant questions relative to this proposed policy are as follows.

1. **What is the nature (causes, rates) of subsidence occurring adjacent to Delta levees? How has subsidence rates been measured? How long will it continue?**
2. **How can subsidence of peat soils be stopped?**
3. **Can stopping of current subsidence adjacent to levees make a difference in long-term levee stability?**
4. **What processes and factors determine where these easements could be implemented?**
5. **What is the long-term prognosis?**
6. **What are suggested practices for implementation?**

Below, I provide answers to these questions.

1. **What is the nature (causes, rates) of subsidence occurring adjacent to Delta levees? How has subsidence rates been measured? How long will it continue?**

Substantial understanding and quantification of Delta subsidence has occurred since the early 1900s. Walter Weir (UC Cooperative Extension) and others (Weir, 1950) measured subsidence along a transect extending across Bacon and Mildred islands and Lower Jones Tract from the early 1920s until the early 1980s. HydroFocus reported subsidence rates from 1978 to 2006 on the same transect (Deverel and Leighton, 2010). Average subsidence rates ranged from over 4 inches per year before 1950 to 0.8 inch per year from 1978 to 2006. Recently, remote sensing has been used to estimate subsidence rates on Sherman Island ranging from 0 to 2 inches per year and averaged

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0.6 inch per year. High precision and long-term measurements are required to measure Delta subsidence because of tillage and the effect of groundwater fluctuations that cause peat soils to rise and fall seasonally. Deverel et al. (2016) estimated subsidence rates throughout the Delta; in the central Delta rates were as high as an inch per year.

Subsidence of organic soils in the Sacramento-San Joaquin Delta is caused primarily by the microbial oxidation of organic matter (Deverel and Rojstaczer, 1996). Percent soil organic matter is therefore a key factor determining the rate of subsidence. Rojstaczer and Deverel (1995) and Deverel and Leighton (2010) demonstrated that spatial variations in soil organic matter content ranged from 4 to 60 % and explained the majority of the variation in average subsidence rates from 1978 to 2006.

During the 6,000–7,000 years prior to the 1850s, about 5 billion cubic meters of tidal marsh sediment accumulated in the Delta (Deverel and Leighton 2010; Mount and Twiss 2005). Since the mid-19th century, half of this volume disappeared (Deverel and Leighton 2010; Mount and Twiss 2005). Present-day soils reflect organic matter accumulation through millennia, spatially variable fluvial deposition and oxidation; thus, soil type and organic matter content vary substantially (Deverel and Leighton 2010). Highly organic mineral surface soils generally predominate in the western and northern Delta and true surface organic soils predominate in the central, eastern and southern-central Delta.

2. **How can subsidence of Delta peat soils be stopped?**

The primary Delta subsidence mitigation tools are rice cultivation and permanently flooded wetlands i.e. saturated soil conditions (Deverel et al. 2016; Miller et al. 2008). Rice has been demonstrated to stop subsidence. Permanently flooded wetlands reverse the effects of subsidence. The depth of the unsaturated zone is the primary determinant of subsidence rates; the shallower the water table, the lower the subsidence rates (Stephens et al. 1986). Deverel and Rojstaczer (1996) demonstrated similar subsidence rates for non-flooded cultivated and uncultivated Delta peat soils.

3. **Can stopping of current subsidence adjacent to levees make a difference in long-term levee stability?**

Seepage under levees onto islands is a primary process that can affect levee stability. Seepage rates onto islands increase with ongoing subsidence (Deverel et al.2007a). This is due to two factors. First, as the island surface declines, hydraulic gradients (the difference in water levels between the channel and the island) increase. This can result in faster rates of subsurface flow onto the island. Second, as the thickness of the peat decreases, rate of upward movement of groundwater from below the peat onto the island speeds up. Levee failure or instability from seepage occurs when hydraulic gradients are large enough to where seepage water can mobilize subsurface materials and destabilize the levee. On Twitchell Island, Deverel et al. (2014) estimated that these critical underflow hydraulic gradients would be reached within a few decades at selected locations with ongoing subsidence.

Bachand et al. (2016) investigated the effect of subsidence on current and future failure risk and the benefit that strategic placement of shallow aquatic systems such as rice and wetlands could have to reduce levee risks in the Delta. Mechanistic models, data for levee geometry and historic failures were used to calculate factors of safety against static and seepage failures. Results from the modeling were used to calculate relative probabilities of failure (RPF) as a function of levee height and marsh deposit thickness.

RPF as a function of levee height and marsh deposit thickness is shown in Figure 1. Failures become more likely as marsh deposits thin to less than 9 to 12 feet. Estimated risk was exacerbated where levees are higher. The increasing probability of failure with thinning peat is caused by increasing seepage forces; the increasing risk with height is primarily due to increasing static loads. The increasing height of levees has been in response to subsidence that has occurred since the late 1800s. A reduction in future RPF was estimated due to the planting of rice adjacent to levees.

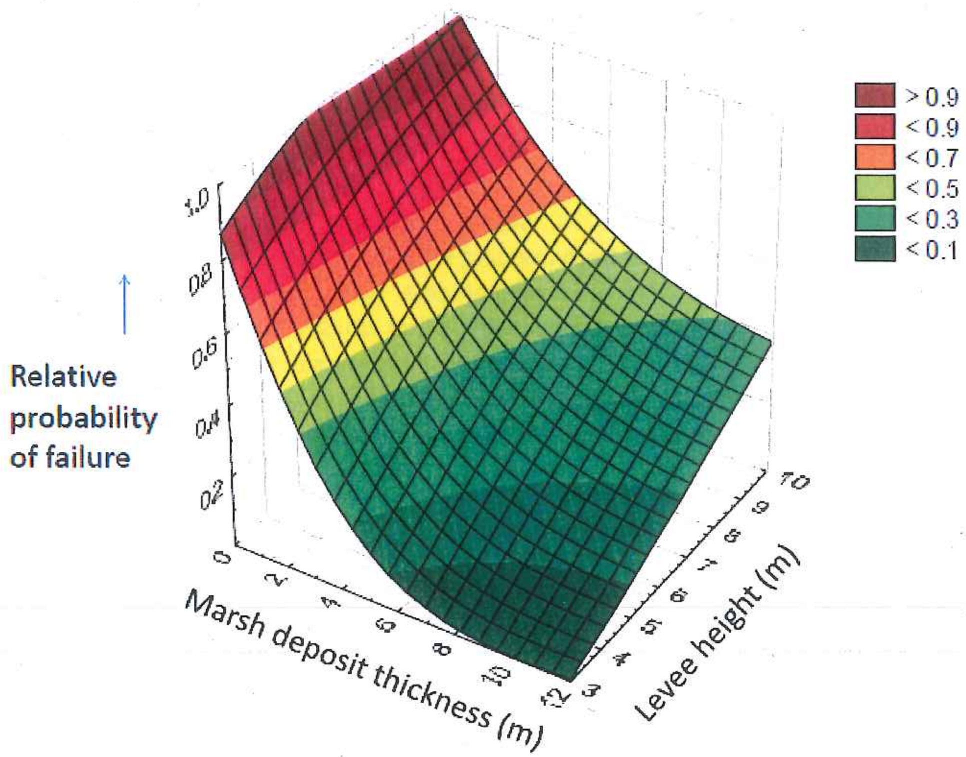

Figure 1. Relative Probability of Failure (RPF) as a function of marsh deposit thickness (T) and levee height (H).

4. **What processes and factors determine where these easements could be implemented?**

Bachand et al. (2016) results indicate that high subsidence rates and peats thinner than 9 to 12 feet present the greatest risk for increasing RPF. Maps of peat thickness and estimated or measured subsidence rates could be used to determine where easements make the most sense in the short term; areas of thin peat (less than 9 feet) and higher subsidence rates (greater than about 0.5 inches per year) would seem to be priority areas. Using data presented in Atwater (1982) and boring logs, Deverel and Leighton (2010) and Deverel et al. (2015) presented maps of peat thickness. The thickest peat resides in the western and northwestern Delta where thicknesses range to over 20 feet on Sherman Island. For most of the central, eastern and southern-central Delta, less than about 8 feet of peat remains. Delta subsidence will continue until management practices are adopted that stop subsidence or the organic deposits disappear. Rates of subsidence are highest in areas of high soil organic matter content.

The largest uncertainty for estimating determining where to prioritize areas for easement would is the spatial distribution of subsidence rates. Deverel et al. (2016) estimates rely heavily on data for soil organic matter content. Greater certainty in these data will lead better estimates. Remotely sensed data (e.g. Sharma et al. 2016) will rely on ground truthing for more certainty. However, current estimates of subsidence can serve as a framework for prioritizing areas for easements.

5. What is the long-term prognosis?

As demonstrated by the work of Bachand et al, (2016), stopping subsidence adjacent to levees will help to reduce the probability of failure resultant from ongoing subsidence. However, ongoing subsidence in the interior of islands where there are no easements will continue to steepen hydraulic gradients, increase seepage rates and cause peats to thin which can contribute to the potential for seepage failure over the longer term. Ongoing oxidative subsidence also contributes to increasing dissolved organic carbon loads to Delta channels (Deverel et al. 2007a,b),,greenhouse gas emissions (Knox et al. 2015), reduced arability (Deverel et al. 2015) and increased volume below sea level (Deverel and Leighton, 2010).

6. What are suggested practices for implementation?

The current proposed language states that "*the width of the easement shall be determined by the local maintaining agency's engineer, considering depth of peat, other site conditions, levee geometry and foundation conditions, and engineering judgement*". I suggest that the width and location of the easement should include input from an independent professional geologist, engineer or other quantified professional familiar with Delta subsidence and soils.

The current proposed language states that "*The easement shall (1) restrict the use of the land to open-space uses, nontillable crops, the propagation of wildlife habitat, and other compatible uses*". I suggest limiting the use of the land to practices that greatly reduce, stop or reverse the effects of subsidence as cited above.

Thank you for the opportunity to contribute.

Sincerely,

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Principal Hydrologist

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