Preliminary Seepage Analysis
Prospect Island, California

Prepared for:
U.S. Department of Justice

May 1998

Todd Engineers

Technical Memorandum
May 26, 1998

TECHNICAL MEMORANDUM

To: Kristin S. Door  
Assistant U. S. Attorney, U. S. Department of Justice

From: Phyllis Stanin and David Todd

Re: Preliminary Seepage Analysis, Prospect Island, California

Todd Engineers was requested by the Department of Justice (DOJ) to evaluate potential hydrologic impacts of flooding on Prospect Island, an island in the northwestern Sacramento-San Joaquin Delta of California. This request was in response to a complaint filed by a landowner on adjacent Ryer Island asserting that flooded conditions on Prospect Island beginning in March 1995 had resulted in the flooding of Ryer Island, preventing farming activities (Sam Sakata Farms v. United States of America, 1996). A portion of Prospect Island is owned by the U. S. Department of the Interior, Bureau of Reclamation (BOR). This memorandum describes the evaluation conducted by Todd Engineers and presents our preliminary findings.

BACKGROUND

Prospect Island and Ryer Island are located in the Sacramento River Delta in Solano County, California (Figure 1). Prospect Island consists of approximately 1,692 acres bounded by the Port of Sacramento Deep Water Ship Channel on the west and Miner Slough on the east (Figure 2). The Port of Sacramento (Port) owns approximately 309 acres in the southern portion of the island. Approximately 1,228 acres in the northern portion were purchased by the BOR in 1995 for fish and wildlife habitat restoration (Corps, 1997). The remaining acres on Prospect Island are privately owned. Ryer Island consists of more than 7,000 acres and is located east of Prospect Island on the east side of Miner Slough (Figure 2).

In March, 1995, a levee break on Miner Slough along the Port’s property flooded the southern portion of Prospect Island. Rising flood waters undermined the cross levee separating the Port’s property from BOR property and subsequently flooded the northern portion of
Prospect Island. Flood waters rose to an elevation approximately equal to sea level, and thus, the sea level contour on the U.S.G.S. topographic base map can be used to approximate the edge of the flood water (Figure 2).

Repair work on the cross levee was completed approximately one year later in March 1996. Flood waters were pumped from Prospect Island into Miner Slough in May 1996. Final repairs to the Miner Slough levee break on the Port's property was accomplished in November 1996. However, the same areas of the Miner Slough levee and the cross levee failed again during heavy rains in January 1997 along with several other areas on the levees.

The island has remained flooded since 1997 and was observed to be flooded by Todd Engineers during a January 1998 site visit. Future plans involve stabilizing the existing levees and intentionally breaching them at two locations (one at Miner Slough and one at the Ship Channel) to allow surface water to circulate over the island, leaving it in a flooded condition (Corps, 1997).

On August 26, 1996, Sam Sakata Farms filed a complaint for damages alleging that "hydrologic pressure" from flooded conditions on Prospect Island had resulted in flooding on Ryer Island. The Sam Sakata Farms property involved in the complaint is shown on Figure 2. Although the purpose of this study is to evaluate the technical details asserted in the complaint, the analysis is also relevant to the potential for future impacts from the permanent flooding of Prospect Island as proposed by the U. S. Army Corps of Engineers (Corps).

DATA SOURCES

Todd Engineers’ review was based on published documents and site-specific field data collected by others. General site information, monthly precipitation and soil types were gathered from public sources. The remaining data were provided to Todd Engineers for compilation and analysis by the California Department of Water Resources (DWR), the Bureau of Reclamation (BOR), and the U.S. Army Corps of Engineers (Corps) as summarized below.

Groundwater monitoring data were available from a field program conducted in 1996 and 1997 by DWR to evaluate groundwater conditions on Ryer Island. DWR also compiled and provided 1996 groundwater data collected by the BOR on Prospect Island. The BOR provided aerial photographs of Prospect Island and Miner Slough flown in March 1995. The Corps furnished detailed topographic data on Prospect Island, Miner Slough levee profiles, and soundings in Miner Slough.

PHYSICAL SETTING

Prospect and Ryer Islands are located in the northwestern portion of the Sacramento Delta in Solano County surrounded by sloughs and channels of the Sacramento River system (Figure 1).
Because portions of both islands are below sea level, the land is poorly drained. The lowest area of Prospect Island is on the southern portion, approximately five feet below national geodetic vertical datum (-5 feet NGVD). Elevations on Ryer Island are even lower with the majority of the island below -5 feet NGVD and the southern portion below -10 feet NGVD. Both islands are rimmed by levees to prevent flooding by surrounding surface water which is at or above sea level (USGS, 1993).

The predominant land uses in the area are agriculture and flood control. Both Prospect Island and Ryer Island have been farmed in the past; however, currently farming occurs only on Ryer Island. Prospect Island has remained flooded since 1997 under an average of 5 feet of flood water with lower portions containing up to 9 feet of water during high tides and higher portions drying out during low tides. Prospect Island typically floods first and more frequently than neighboring islands because of the relatively low height of its surrounding levees (Corps, 1997).

According to profiles provided by the Corps, the centerline of the Prospect Island levee along the west side of Miner Slough averages approximately 12 feet NGVD (MBK, 1989). The levee along the east side of Miner Slough is approximately 22 feet NGVD (USGS, 1993). Soundings of Miner Slough indicate average bottom elevations of approximately -20 feet NGVD.

In general, the islands are overlain by poorly drained organic soils containing varying amounts of peat. Agricultural soil types on Prospect Island and adjacent parcels of Ryer Island include Columbia fine sandy loam and Valdez silt loam along Miner Slough, and Sacramento silty clay loam underlying the central portions of the islands. On the southern portion of the BOR property, as well as the southern portion of Ryer Island, the predominant soil type is Ryde clay loam (Soil Conservation Service, 1977). Soil borings along the western edge of Prospect Island indicate thicknesses of peat from 2 feet in the north increasing to 21 feet in the south, with an average thickness of 10 feet (Corps, 1997).

Geologic units underlying the surficial soils include a clay layer underlain by a sand layer. Thicknesses of these units have been recorded in boring logs along the Deep Water Ship Channel and reported by the Corps (1977). The clay unit varies in thickness from 4 feet to 29 feet and averages 12 feet thick. Below the clay, borings penetrated up to 10 feet into the sand layer with an average penetration thicknesses of 8 feet (Corps, 1997).

The area receives approximately 17 inches of rainfall annually, with more than 80 percent occurring during the winter months. Monthly rainfall for 1995 through May 1997 is shown on Figure 3 along with normal monthly rainfall amounts for the Sacramento area. Note that the flooding of Prospect Island in March 1995 and January 1997 coincided with high monthly rainfall amounts that were 316 percent above normal and 242 percent above normal, respectively. If precipitation rates exceed the capacity of an island’s surface drainage system, flooded conditions are a likely result.

In addition to precipitation events and levee failures, other factors that may contribute to
island flooding include high tides, releases from upstream dams, or a combination of any of these factors. Observations from the Corps indicate that flooded conditions on Prospect Island do not correlate to flooded conditions on Ryer Island (Corps, 1997). On 1995 and 1997 aerial photographs, Prospect Island is under standing water while Ryer Island does not appear to be flooded (BOR, 1995, 1997). Consistent with the Corps, Todd Engineers observed flooded conditions on Prospect Island and non-flooded conditions on Ryer Island during a January 1998 site visit.

GROUNDWATER AND SURFACE WATER DATA

To evaluate the potential for high groundwater levels on portions of Ryer Island, DWR staff observed the installation and conducted monitoring of six groundwater wells, R-1 through R-6 during the summer of 1996 (Figure 2). The monitoring wells consisted of two-inch diameter casing installed approximately ten feet deep. Installation and monitoring activities were summarized in a DWR office memorandum dated August 6, 1996 (DWR, 1996). Data from subsequent monitoring activities have also been provided to Todd Engineers by DWR (DWR, 1998a).

Since April 1996, DWR has measured water levels generally on a weekly basis in wells R-1 and R-3 through R-6 except for a three-month period in the summer of 1996 when the monitoring program was temporarily suspended (DWR, 1998b). Data are unavailable from well R-2 which was destroyed inadvertently. An electronic data recorder was installed on well R-1 which recorded water levels at one-hour to four-hour intervals to examine changes in water levels with tidal fluctuations in Miner Slough. These detailed levels from the data recorder supplement the manually measured water levels in R-1 and are generally available from April 1996 to June 1996 except during a one-week interval when data were lost during an electronic transfer (DWR, 1996). Water level data in Ryer Island wells from April 1996 through January 1998 were used in this evaluation.

In May 1996, the BOR installed four similar monitoring wells on Prospect Island, P-1A, P-1B, P-2, and P-3 (Figure 2). Water levels were monitored in these wells until the island flooded in January 1997 and the wells were inaccessible. These data were summarized by DWR and were available for this evaluation (1998a). All water level data available from the Prospect Island wells and the Ryer Island wells are presented together in Figure 4.

DWR also installed a tidal recorder at Five Points Marina on Miner Slough at the northern ends of Ryer and Prospect Islands (Figure 2). Stage measurements in Miner Slough are available from April 1996 through December 1996 and July 1997 through December 1998. These elevations have been corrected to the proper vertical datum by DWR and are slightly higher than presented in the 1996 DWR memorandum (DWR, 1998b). These data cover the period of detailed groundwater levels in nearby R-1 as measured by the data recorder in April, May, and the first few days of June, 1996 (DWR, 1998a). Detailed stage data and R-1 groundwater data for
this two-month period are presented in Figure 5.

GROUNDWATER ANALYSIS

Water levels in Ryer Island and Prospect Island wells can be used to approximate local and regional groundwater flow directions since groundwater generally flows from higher elevations toward lower elevations. In general, water level elevations appear to be influenced by the distance from the well to Miner Slough and the well’s north-south location on the island. Wells closer to the slough generally have higher water levels, indicating flow away from the slough toward the island. For example, P-1A is slightly closer to the slough than P-1B and has consistently higher water levels (Figure 2 and Figure 4). However, the lowest water levels are recorded in the southernmost well R-6, even though R-6 is closer to the slough than other wells to the north. This may indicate the influence of southerly to southwesterly regional groundwater flow in addition to the local island groundwater flow away from the slough.

Over the last two years, depth to water in the wells has ranged from approximately one foot to almost six feet below the ground surface. Water level elevations have ranged from approximately -1 feet to -7 feet NGVD, except for the May 1996 measurements in Prospect Island wells when water levels rose above 0 feet NGVD (Figure 4). This sudden increase in water levels was in response to the pumping of flood water from Prospect Island into Miner Slough. Because the Prospect Island wells are closer to Miner Slough than the Ryer Island wells, they recorded the largest impacts. In general, all of the wells appear to respond together with the exception of R-6 during the spring and summer months of 1997 when changes in levels are not consistent with levels in other Ryer Island wells. This and other inconsistencies in the data may reflect local impacts from nearby surface drainage systems that are used on Ryer Island (DWR, 1998b).

The shallow water levels recorded in wells likely represent the water table beneath the islands that is hydraulically connected to surface water levels in Miner Slough. As mentioned previously, wells closer to Miner Slough are first to respond to stage changes in Miner Slough and demonstrate the largest fluctuations in water levels. Wells farther away also respond to stage changes in Miner Slough, although the lag time is longer and the fluctuations are smaller.

The correlation between water level changes and Miner Slough level changes were examined in detail using the electronic recorder data from R-1 and stage recorder data on Miner Slough at Five Points Marina (Figure 5). As seen on Figure 5, the groundwater levels vary less than one foot over the two-month period while stages in Miner Slough vary up to seven feet over the period with average daily tidal fluctuations of approximately three feet (DWR, 1998a). Because the relative changes in groundwater levels are small compared to the stage changes in Miner Slough, it is difficult to examine relative changes when groundwater and surface water levels are plotted on the same scale as on Figure 5.
To allow a more detailed comparison, water levels in R-1 are re-plotted on an expanded scale (10:1) with the Miner Slough data shown on Figure 6. As seen on this plot, the two curves generally correspond well together even though the actual changes in groundwater levels are very small compared to the stage changes. During the few days surrounding April 27 and May 20, the curves appear to diverge and do not show similar relative changes (Figure 6). These inconsistencies in the data are unexplained, but some may be related to the location of a surface drainage system near R-1 (DWR, 1998b).

Despite these inconsistencies, levels in R-1 generally rise with rising stage levels in Miner Slough and fall with falling stage levels, although changes in well R-1 occur slightly later in time. To examine this time lag, these two data sets are plotted together over a much shorter time interval (3 days) (Figure 7). As seen on Figure 7, the R-1 water levels generally mimic the Miner Slough stage with a response time lag of 2 to 3 hours and an average time lag of 2.5 hours. An unexplained change in R-1 water levels can be observed in the second half of the presented data. Beginning about 8:00 p.m. on April 21, R-1 levels do not rise as high as in previous high levels in response to similar Miner stage levels, although the response time lag remains consistent. Again, this may be related to nearby surface drains, but was not investigated in detail.

These comparisons are consistent with the concept of water table conditions being influenced by stage changes in Miner Slough, although changes in water levels are small. This interaction of the groundwater-surface water system beneath the two islands and in Miner Slough is illustrated on a northwest-southeast profile across Miner Slough (Figure 8). The profile shows the geometry of the island/slough system between the two parcels involved in the complaint; the location of the profile is shown on Figure 2. Soils and subsurface geology on the section represent average thicknesses as reported by the Corps (1997) and are not profile-specific. The vertical scale of the profile has been exaggerated to better illustrate the small changes in water levels across the area. The approximate location of the Prospect Island flood waters from the March 1995 flooding are depicted by blue waves on the northwest side of the section.

DWR groundwater data from three wells, P-1A, P-1B, and R-3, and stage recorder data from Miner Slough are incorporated into the profile. High and low groundwater levels in the wells for the overlapping portion of the monitoring record are shown along with corresponding high and low stages in Miner Slough. Low water levels were recorded in November 1996 and high water levels were recorded in May 1996 when the flood waters were being pumped into Miner Slough. As seen in Figure 8 and mentioned previously, water level fluctuations are greater in the wells closer to the slough (P-1A and P-1B) and smaller with distance away from the slough (R-3). Flood waters on Prospect Island were not impacting the levee between Miner Slough and Ryer Island, as described in more detail below.

SEEPAGE

Seepage is a general term describing the movement of water through porous media such
as soils, and consolidated and unconsolidated geologic units. The term is well established in the engineering literature in connection with groundwater movement from and to surface water bodies, particularly where associated with structures such as dams, canals, and levees (Todd, 1980). In the Sacramento delta, seepage is a regional problem because much of the land surface is below sea level (Priestaf, 1983). Of importance to this project is the seepage from Miner Slough into the groundwater system through and below the surrounding levees, and the relationship to flooding on Prospect Island.

In general, seepage rates are governed by the difference in elevation between the surface water stage and the water table (Todd and Bear, 1959). Therefore, the controlling factor for seepage through the Miner Slough/Ryer Island levee is the stage in Miner Slough. As this stage increases, seepage from Miner Slough increases through the levee and may result in high water levels creating wet or flooded conditions on the surface of Ryer Island, especially near the levee toe where the Sam Sakata Farms parcels are located (Figure 2). As shown on Figure 8, because the elevation of the 1995 Prospect Island flood waters (near sea level) were not higher than recorded elevations in Miner Slough, the flood waters did not contribute to the Miner Slough stage and thus, had no impact on the Miner Slough/Ryer Island levee. The suggestion in the complaint (Sam Sakata Farms v. United States of America, 1996) that the flood waters caused “hydrologic pressure” on this levee does not appear to be valid. Rather, wet conditions on Ryer Island were likely the result of high rainfall on the island and high stages in Miner Slough from increased precipitation (Figure 3). Upstream dam releases and tidal fluctuations also could have contributed. The conditions could have resulted either from Miner Slough seepage (rising groundwater from below) and/or ponding of rainwater that could not be drained.

As standing flood waters remain on Prospect Island in the future, seepage into the fully saturated ground below will continue. In areas of low-permeability peat and clays, this seepage amount will be very small. If there are areas where sands are at or near the surface, seepage will be greater.

However, even this increased seepage is unlikely to impact water levels beneath Ryer Island. First, as discussed previously, the rate of seepage through the Miner Slough/Ryer Island levee is controlled by the stage of the slough. Because the flooding and circulation of flood waters over Prospect Island will not increase the stage in Miner Slough, the flooding should have no adverse impact on the Miner Slough/Ryer Island levee. In fact the project may result in slightly decreased flows in Miner Slough (Corps, 1997), which may decrease seepage. The incised channel of Miner Slough remains a groundwater divide for the shallow areas affected by seepage.

Second, if seepage occurs into a deeper permeable zone, increased groundwater flow will occur predominantly in that zone and in the direction of regional groundwater flow, which is likely southwest. To illustrate this concept, consider a groundwater flow net, or sketch of groundwater flow patterns shown near a hypothetical river channel (Figure 9). The groundwater flow net consists of two types of lines. The dashed lines represent equal hydraulic pressure. The arrows are flow lines showing the seepage pathways. The numbers on the arrows are the
percentage of seepage flow above the arrow.

In Figure 9, the river channel seepage occurs in stratified sediments of varying permeabilities analogous to the low-permeability upper layers of peat and clay and the higher-permeability lower layer of sand as seen in Prospect Island boring logs (Figure 8). Similar to Miner Slough, the channel in Figure 9 penetrates the lower sand layer and because of the increased permeability, most of the seepage (90%) moves into the lower unit and becomes horizontal groundwater flow. Only a small percentage of the seepage (10%) moves into the upper unit. This seepage is dependent on channel geometry, permeability of the layers, and the stage in the channel, and occurs independent of any nearby flooded islands. If the channel is expanded laterally, somewhat similar to the flooding of Prospect Island, the flow lines representing the percentage of seepage spread out beneath the channel bottom, but do not increase the contribution to the upper layer. The actual situation of Prospect Island seepage is even less dramatic than a theoretical channel expansion because the standing water on the island is not near as deep as the channel.

PROJECT MODIFICATION REPORT

A preliminary seepage analysis of the Prospect Island/Miner Slough/Ryer Island area was conducted by the Corps using much of the same data used in Todd Engineers' evaluation. The analysis and conclusions were presented in the Draft Prospect Island Project Modification Report (PMR) which described the proposed plan for restoring wildlife habitat and flooding Prospect Island (1997). The seepage analysis reached the conclusion that the groundwater elevations on Ryer Island appear to be governed by the water-surface elevations in Miner Slough, consistent with our analysis. Additional borings and analysis are planned as the Prospect Island restoration project proceeds (Corps, 1997).

Comments submitted to the Corps on the PMR included a discussion of seepage by the consulting firm of Kjeldsen Sinnock Neudeck (KSN) on behalf of Reclamation District No. 501 - Ryer Island. In this discussion, KSN suggests that the flooding on Prospect Island will increase deep seepage into the underlying sand layer, with a corresponding increase in hydrostatic head in the sand. KSN provides two figures in their comments to illustrate their interpretation. These figures, KSN Figures 1 and 2, are provided unmodified as Attachment 1 to this memorandum (Attachment 1). Note that the KSN figures do not include site-specific information on island-channel geometry and are not consistent with the general geologic unit layering as described in the PMR and shown on Figure 8.

As seen on KSN Figure 1, seepage from a slough into an underlying sand layer is shown. Conditions are altered in KSN Figure 2 with the presence of a flooded island which is shown to increase seepage into the sand layer and raise the hydrostatic head in the sand. However, this potential increase in hydrostatic head of a sand layer at depth is not related to surficial flooding. Even if site conditions were as depicted in the KSN cross section, there is no reason to assume
that flooding or even high water levels will result. As shown on KSN Figure 2, groundwater flow is generally horizontal in the sand layer, consistent with the flow net depiction in Figure 9, and does not raise the water table.

In addition, the discussion assumes that groundwater flow is parallel to the cross section with seepage from the flooded island eventually flowing toward the unflooded island. However, in the Prospect Island area, regional flow is likely to the southwest, away from Ryer Island. Finally, on the two-dimensional cross section, the greater impact of Miner Slough and the connected Sacramento River System compared to a small increase in head on Prospect Island is ignored.

PRELIMINARY FINDINGS

- The elevation of the water table beneath Prospect Island and Ryer Island in the vicinity of Miner Slough is controlled predominantly by the stage in Miner Slough.

- Seepage through the Miner Slough/Ryer Island levee is also controlled by the stage in Miner Slough and is not related to the flooding of Prospect Island.

- The suggestion in the complaint (Sam Sakata Farms v. United States of America, 1996) that the flood waters caused "hydrologic pressure" on this levee does not appear to be valid.

- Permanent flooded conditions on Prospect Island as proposed by the Corps are not expected to increase the stage in Miner Slough, and therefore, are not expected to impact water levels beneath Ryer Island.

- Additional borings as outlined in the PMR and groundwater wells will be helpful in developing a more detailed understanding of seepage and groundwater conditions beneath the site.
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FIGURES
Figure 3
Sacramento FAA ARPT Climatological Station

Rainfall, inches

- Actual Rainfall
- Normal Rainfall

Month 1995
- March 1995

Month 1996
- Jan
- Feb
- Mar
- Apr
- May
- Jun
- Jul
- Aug
- Sep
- Oct
- Nov
- Dec

Month 1997
- Jan
- Feb
- Mar
- Apr
- May
Figure 4
Groundwater Elevations
Prospect Island and Ryer Island Wells

Data Source: DWR, 1998a
Figure 5
Miner Stage and Groundwater Elevations beneath Ryer Island

Data Source: DWR, 1998a
Figure 6
Miner Stage and
Groundwater Elevations beneath Ryer Island

Data Source: DWR 1998a
TODD ENGINEERS
Figure 7
Miner Slough Stage and
Groundwater Elevations in R-1

TODD ENGINEERS
Figure 8
Island/Slough Profile
A - A'
Figure 9
Hypothetical Flow Net
Beneath a River Channel and Levee in Stratified Sediments

Test 13

$K_u; K_u = 1:50$

$K_u = (K_{xu} K_{yU})^{1/2}$

$Q = 16.20 K_u H$

$X_r' = 1.58 X_r (K_{xP}/K_{yP})^{1/2}$

Source: Todd and Bear, 1959 - Plate 13

Emeryville, California

April 1998
Figure 1 - Existing Conditions Between Two Agricultural Islands
Figure 2 - Existing Conditions Opposite A Flooded Island

Direction of Seepage (Typ.)

Hydraulic head
in sand aquifer

Levee

Slough or cut

Flooded island

Clay

Sand

Peat

Source: Hultren & Tillis Engineers
Delta Wetlands Project