THREE RIVERS LEVEE IMPROVEMENT AUTHORITY

Evaluation of Groundwater Impacts from the Upper Yuba River
South Levee Repair Activities

December 2009
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>bgs</td>
<td>below ground surface</td>
</tr>
<tr>
<td>Characterization Study</td>
<td>Hydrogeologic Understanding of the Yuba Basin</td>
</tr>
<tr>
<td>DMS</td>
<td>Data Management System</td>
</tr>
<tr>
<td>DWR</td>
<td>California Department of Water Resources</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>gpm</td>
<td>gallons per minute</td>
</tr>
<tr>
<td>ID</td>
<td>Identification</td>
</tr>
<tr>
<td>MCL</td>
<td>maximum contaminant level</td>
</tr>
<tr>
<td>mg/L</td>
<td>milligrams per liter</td>
</tr>
<tr>
<td>msl</td>
<td>mean sea level</td>
</tr>
<tr>
<td>RD 784</td>
<td>Reclamation District 784</td>
</tr>
<tr>
<td>SYSGB</td>
<td>South Yuba Subbasin Groundwater Basin</td>
</tr>
<tr>
<td>TDS</td>
<td>total dissolved solids</td>
</tr>
<tr>
<td>TRLIA</td>
<td>Three Rivers Levee Improvement Authority</td>
</tr>
<tr>
<td>YCWA</td>
<td>Yuba County Water Agency</td>
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Section 1.0 INTRODUCTION

Three Rivers Levee Improvement Authority (TRLIA) has been conducting levee repairs for Reclamation District 784 (RD 784) since 2004. Repairs are designed and implemented to provide a minimum level of protection of 200 years to the RD 784 area. Design of repairs to the Upper Yuba River South Levee from Simpson Lane to the Goldfields is currently underway. One of the alternatives under consideration is construction of low-permeability soil-cement-bentonite slurry cutoff walls (slurry walls), through the crown of the levee and extending below the foundation of the levee, to mitigate under- and through-seepage concerns during flood stage. By removing direct pathways for water to flow underneath a levee during a flood event, a levee breach is less likely. Slurry walls have been constructed throughout the Sacramento Valley, especially along urbanized river reaches that rely on levees for 100- to 200-year flood protection.

Slurry walls are proposed to be constructed along the Yuba Patrol Road Levee from the community of Linda and extending northeast to the Yuba Goldfields (Proposed Project). Another alternative being considered is the use of wider seepage berms that provide a means to control the flow of water through and under the levee without compromising the integrity of the levee’s flood control benefits. Seepage berms are ideal for highly permeable hydrogeologic conditions, especially in the vicinity of the Yuba Goldfields given the presence of very coarse textured material at depth. The final project may be a combination of slurry walls and seepage berms. There is a concern that an extensive (in terms of depth) slurry wall in this location could cause impacts to the South Yuba Subbasin Groundwater Basin (SYSGB). Impacts could potentially result from one or more of the following:

**Problem Statement 1 – Regional impacts to groundwater recharge due to slurry wall:** Regional groundwater elevations could be lowered by the slurry wall potentially cutting off natural recharge from the Yuba River to the SYSGB.

**Potential Impacts:** Regional increase in energy costs to extract groundwater; potential need to deepen or replace existing groundwater wells; and possible water quality impacts due to changes in the vertical movement of groundwater.

**Problem Statement 2 – Localized impacts to wells near the slurry wall:** Local groundwater elevations could be lowered near the slurry wall, and the slurry wall can be identified as an impediment to continued pumping in existing wells at the rate and depth pumped before implementation of the Proposed Project.

**Potential Impacts:** Local increase in energy costs to extract groundwater; and potential need to deepen or replace existing groundwater wells.

**Problem Statement 3 - Extended time of water saturation of root zone due to slurry wall:** The time needed for the groundwater basin to reach equilibrium on the waterside of the levee after a flood event could increase.
Potential Impacts: Potential long-term saturation of the soil root zone, leading to root rot and disease in existing tree crops.

Evaluation of these three potential problems and their associated impacts is based on 1) characterizing local groundwater conditions, and 2) applying analytical methods and tools to assess the level of significance.

1.1 Study Objectives

This study is intended to characterize local groundwater conditions in the vicinity of the Proposed Project (project area), develop an inventory of existing wells in the project area, determine the appropriate tools and level of analysis required for evaluating the three key problem statements, and assess possible impacts to these wells and to basin-wide recharge and water quality as a result of the Proposed Project. The report is organized into six sections, which can be summarized as follows:

1) Introduction – This section describes the current setting and role of TRLIA in improving levees throughout Yuba County. Key questions evaluated in this study are presented.

2) Hydrogeologic Setting – This section describes the groundwater conditions in the SYSGB and includes summaries of the geologic setting, general aquifer characteristics, water use in the project area, horizontal groundwater flow directions, and groundwater quality.

3) Well Inventory Results – This section briefly describes and summarizes the inventory of existing wells in the project area.

4) Site-specific Aquifer Characterization – This section describes the groundwater basin in the project area through the selection and interpretation of up to six aquifer cross sections.

5) Evaluation Methods – This section describes the methods employed to evaluate potential impacts on groundwater elevations, flow, recharge, and water quality.

6) Evaluation Results - This section summarizes potential Proposed Project impacts to the groundwater system and also presents recommended mitigation measures if significant impacts are anticipated based on the evaluation results.
Section 2.0 HYDROGEOLOGIC SETTING

The SYSGB underlies southwestern Yuba County in the Sacramento Valley, as shown in Figure 2-1. It is bounded on the north by the Yuba River, on the west by the Feather River, on the south by the Bear River, and to the east by the Sierra Nevada foothills (DWR, 2003).

2.1 Description of Groundwater Basin

Ground elevations in the SYSGB range from about 150 feet above mean sea level (msl) in the northwest basin to about 30 feet msl in the southwest basin near the confluence of the Feather and Bear rivers (DWR, 2003). The SYSGB is located within two distinct topological features: the Sacramento Valley and the Sierra Nevada foothills. The Sacramento Valley consists of flat to low rolling hills that gradually increase in relief toward the east.

The eastern SYSGB in the Sierra Nevada foothills has steeper topography and is mainly underlain by consolidated sedimentary rocks of Oligocene to Pliocene age. Older crystalline basement rock, ranging from Paleozoic to Mesozoic age, is exposed above ground surface along the eastern basin boundary (Law Environmental, Inc., 1998). The crystalline basement rock dips gently to the west, and the overlying sedimentary water-bearing units accordingly thicken to the west. The cumulative thickness of these deposits increases from a few hundred feet in the Sierra Nevada foothills on the east to over 1,400 feet along the western margin of the Yuba Basin (DWR, 2003).

Regional groundwater elevations in Yuba County in the spring of 2008 are shown in Figure 2-2. Groundwater generally travels through the SYSGB from recharge areas along the Sierra Nevada foothills and the Yuba River in the north and east to discharge areas, including the Feather River, in the southwest. No areas of significant groundwater drawdown are apparent. Figure 2-3 shows local groundwater elevations in the project area. Groundwater elevations range from 45 feet msl in the southwest project area to 75 feet msl in the northeast project area. Groundwater flow direction is generally parallel to the Proposed Project. Depth to groundwater averages approximately 20 feet below ground surface (bgs), as shown in Figure 2-4.
Figure 2-1. Project Location Map
Figure 2-2. Spring 2008 Groundwater Elevation Contours in North and South Yuba Subbasins

Figure 2-3. Spring 2008 Groundwater Elevation Contours in Project Area

Arrows indicate local groundwater flow direction
Figure 2-4. Spring 2008 Depth to Groundwater in Proposed Project Area
Figure 2-5 and Figure 2-6 show simplified conceptual drawings of the aquifer system in the project area. Figure 2-5 represents a dual aquifer system characterized by a continuous confining unit, which allows little communication between the upper and lower aquifers. Figure 2-6 represents a dual aquifer system with a discontinuous semi-confining unit, resulting in a semi-confined to unconfined condition in the lower aquifer, which provides the major water supply. In Figure 2-6, the piezometric surface of the semi-confining unit is close to the upper aquifer, indicating a reduced vertical gradient. This study analyzes these two bookends of our geologic understanding to determine which aquifer system characterization or combination of characterizations is appropriate for evaluation of potential impacts from the Proposed Project.
2.2 Groundwater Recharge and Discharge

Figure 2-3 illustrates that the gradient of the regional groundwater aquifer moves from sources of recharge along “losing” portions of the Yuba River and along the eastern foothills of the Sierra Nevada to sources of discharge. Sources of discharge include pumping within the SYSGB and gaining reaches of downgradient rivers and streams where shallow groundwater flows into the surface water system. The local groundwater flow direction (Figure 2-3) is from northeast to southwest, general parallel to the Proposed Project levee alignment, at approximately 20 to 25 feet bgs. The relative velocity of groundwater movement is faster towards the foothills (elevation contours closer together indicate a steeper gradient) compared with velocities along the western side of the Proposed Project. The significance of the general flow direction and velocity of groundwater will be discussed in Section 4 of this report.

2.3 Flooding and Levee Protection

When a flood event occurs, the water pressure against the levee becomes significant and flood waters can potentially begin internal erosion (piping) of the levee embankment and find and make pathways through the levee. Levee through and underseepage of flood waters is a concern regarding two potential modes of failure: 1) blowout/erosion at the landside toe due to excess seepage pressure (exit gradient), and 2) increased seepage pressures decreasing the levee’s landside slope stability. As a result of under or through seepage, flood waters can boil on the landside of the levee and rapidly erode the levee and eventually lead to a levee failure.

This report will provide a scientific characterization of the aquifer over the length of the Proposed Project levee. As a worst case, this report assumes groundwater movement to be perpendicular to the levee (rather than parallel as indicated by the groundwater contour map), and to generally move from north to south (or right to left) based on the sources of recharge (e.g., Yuba and Feather River) and sources of discharges (e.g. private, public, and agricultural well productions). A perpendicular gradient could occur if flood waters are significantly higher on the water side of the levee during a flood event.

Under the illustrated conditions in Figure 2-7, flood waters backup behind the levee with a good portion of the water still moving downstream, and some percolating vertically downward into the unsaturated zone of the upper aquifer with further vertical movement to the saturated zone. Flood waters that find conduits (i.e., small rodents can burrow through levee and create pathways or the flood waters can seep through sand and gravel materials beneath the levee) through or under the levee are shown to be unimpeded indicating the potential for a breech in the levee.

In an effort to strengthen the levee system, TRLIA has been working with soil-cement-bentonite slurry wall technologies to prevent flood waters from undermining the levee by creating an impervious wall between the water side and the land side of the levee. The depth of the slurry wall is typically based on the identification of impervious soil layers beneath the levee. The depth of the Proposed Project slurry wall is planned to extend anywhere from 60 to 100 feet bgs dependent on the depth of the semi-confining layer beneath the levee section (Kleinfelder Report and TRLIA staff).

Figure 2-8 is the same figure as Figure 2-7 with the proposed slurry wall project reaching to a depth that ties the slurry wall into a continuous layered impermeable subsurface unit. This figure
illustrates how flow-through pathways are essentially cut off; thereby reducing the chance for a levee breech during flood events. However, under this conceptual model, the slurry wall is tied into a semi-confining layer, creating the potential to cutoff recharge to the landside of the levee in the upper unconfined aquifer which could lead to the potential effect of drying up wells or making it more costly to pump from deeper aquifer systems. For this reason, the consequence of the slurry wall construction (using this conceptual drawing) on the existing well located on the landside of the levee is a worst case conditions and requires further characterization through this report (see Problem Statement 1 in Section 1).

Figure 2-7. Continuous layered Aquifer Levee Failure Concerns During Flood Events

Another consequence of the slurry wall is a potential increase in groundwater elevations (or piezometric head) on the waterside of the levee as shown in Figure 2-8. There is a need to quantify the amount of increase in groundwater elevations with and without the slurry wall and the difference in time required for the groundwater system to reestablish an equilibrium after the flood event (see Problem Statement 3 in Section 1).
Figure 2-8. Continuous layered Aquifer Levee with Slurry Wall During Flood Event

Based on the above scenario and figures, the groundwater impacts of constructing the levee in a conceptual one layer aquifer has a definite possibility of impacting regional groundwater basin trends and groundwater wells on the land side of the levee. It is this two-layer conceptual assumption that needs further study with respect to the actual field data that has been collected for over 50 years for each of the wells on record that exist within two miles of the TRLIA Proposed Project. This data may indicate that the layer cake model of the aquifer is not the best model for evaluating groundwater impacts.

Section 3 provides a summary of the collected well field data including the collection and interpretation of soil conditions of wells along predefined cross-sections along the length of the Proposed Project levee.
Section 3.0 WELL INVENTORY RESULTS

This section summarizes the existing well inventory completed to identify all existing wells in the project area and to develop geologic cross-sections along five transects of the levee and one along the length of the levee.

3.1 Need for Well Inventory

On behalf of TRLIA, MWH requested well completion reports on file from the California Department of Water Resources (DWR) that covered an approximate 2-mile area around the Proposed Project. This resulted in a list of 695 well completion reports. In addition to the DWR well completion reports, exploratory borings drilled and logged for the Proposed Project as part of the Draft Problem Identification Report (here referred to as the Kleinfelder Report; Kleinfelder, 2009) were used to characterize the shallow aquifer system along the length of the existing levee affected by the Proposed Project. Lastly, Yuba County Water Agency (YCWA) has a Data Management System (DMS) that includes existing wells that were populated for purposes of the Hydrogeologic Understanding of the Yuba Basin (Characterization Study) completed by MWH in 2008.

Of the 695 wells collected from DWR, the shallow (less than 125 bgs) landside wells were selected as the most probable wells to be impacted by the Proposed Project. As a worst case, the conceptual continuous layered model (See Figure 2-4) is used for illustration of potential impacts until findings are made that show different. Figure 3-1 and Figure 3-2 provide a simple illustration of the possible impacts that could occur with the construction of a slurry wall that is constructed to depths of identified impermeable lenses of soil. Figure 3-1 illustrates a single shallow well pumping in close proximity to the existing levee; the actual distance to which the levee could cause potential impacts to wells is identified in Section 5. When a well extracts water, a localized cone of depression occurs that reflects the natural steepening of the slope of the piezometric surface of the groundwater aquifer to enable a sustainable flow to the well (i.e., groundwater flow into the well equals the extraction rate). The rate of groundwater extraction by the well dictates the depth and diameter of the cone of depression.
**Figure 3-1. Existing Condition – No Flood Event and Shallow Groundwater Pumping Without Slurry Wall**

*Figure 3-2* illustrates the impact of constructing a barrier within the cone of depression from the extraction well. A barrier essentially cuts off a portion of the cone of depression requiring more water from other portions of the aquifer to meet the given extraction rate. The effect is an overall lowering of the groundwater piezometric surface (see downward arrows in *Figure 3-2*) creating a significant drop in groundwater elevations and the depth to groundwater in the well during periods of groundwater extractions. This lowering of the groundwater piezometric surface could lead to drying up of wells (See *Figure 3-3*) and higher energy costs to pump water from greater depths.

*Figure 3-2* and *Figure 3-3* show that deeper wells typically used for agricultural irrigation and municipal drinking water are screened in the deeper aquifer zones so that groundwater flow to these wells would likely not be impeded by a slurry wall in the upper aquifer zone or the possible confinement of the lower aquifer represented by the conceptual continuous layered aquifer.
**Figure 3-2. Potential Future Condition - No Flood Event and Shallow Groundwater Pumping with Slurry Wall**

**Figure 3-3. No Flood Event with Dry Well with Slurry Wall**
3.2 Well Summary

Wells constructed within the SYSGB serve many uses including, but not limited to, private domestic water supplies, agricultural irrigation supplies, municipal water supplies, groundwater monitoring, and other miscellaneous uses including large industrial uses and golf course irrigation supplies. Under separate cover, the electronic table and well completion reports used in this report include 226 existing wells along with attribute information from each well’s well completion report. A summary of the data is provided in Table 3-1 below.

<table>
<thead>
<tr>
<th>Table 3-1. Summary of DWR Well Completion Report Inventory</th>
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<tbody>
<tr>
<td>Total Number of Wells</td>
</tr>
<tr>
<td>Average Depth of Wells</td>
</tr>
<tr>
<td>Number of Monitoring Wells</td>
</tr>
<tr>
<td>Average Depth of Monitoring Wells</td>
</tr>
<tr>
<td>Number of Agricultural Wells</td>
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<tr>
<td>Average Depth of Agricultural Wells</td>
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<tr>
<td>Number of Domestic Wells</td>
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<tr>
<td>Average Depth of Domestic Wells</td>
</tr>
<tr>
<td>Number of Public/Municipal Wells</td>
</tr>
<tr>
<td>Average Depth of Public/Municipal Wells</td>
</tr>
<tr>
<td>Number of Undefined Wells</td>
</tr>
<tr>
<td>Average Depth of Undefined/Other Wells</td>
</tr>
</tbody>
</table>

Table 3-1 indicates 277 wells that have well completion reports on file with DWR. For purposes of this study, we assume this to be the total population of landside wells within 1 mile of the proposed project (note: this table also includes the small number of waterside wells mostly located near the golf course at the southwest portion of the Proposed Project.) Table 3-1 also shows private domestic wells as being most shallow and, as a result, will potentially be the most impacted by a lowering of groundwater elevations.

3.3 Locating of Wells

The process of locating the 227 wells summarized in Table 3-1 at their approximate location on the ground is dependent on the quality of data included as part of the well completion report. Figure 3-4 is an example of a fully detailed well completion report that has been assigned a full State Well Id, has a drawn and written location of the well, includes good soil profiling, identifies perforation depths and lengths, and has the diameter and age of the well.
Both automated and manual processes are used to best locate the wells. In most cases the assigned State Well Identification (ID) can be used to approximate a well’s location to the nearest quarter-mile section. A well with a State Well ID does not guarantee an exact location but will locate the well to the nearest quarter-mile. Figure 3-5 illustrates how a State Well ID is assigned based on well location.
Absent a complete State Well ID, well address information can be used to locate wells through geo-referencing address information within GIS. The one limitation of using address information from the well completion report is that resulting geo-referenced locations are along public rights-of-way only. Finally, the last method is to manually translate a hand drawn map that is often included on the well completion report. Well completion reports without location data to support these methods are placed in the nearest one-mile section and listed as low confidence wells for use in this study. The resulting location map of the 227 wells is shown in **Figure 3-6.** This figure also includes the Kleinfelder Report exploratory wells along the levee and wells that are already located and included in the existing YCWA DMS.

The circular well images on the figure represent the use and depth of the wells. Wells along the levee (yellow line) with a green inner circle are the Kleinfelder Report exploratory wells and wells without an outer ring circle are wells that are included in the existing YCWA DMS.
Figure 3-6. Well Inventory and Attributes
Section 4.0  SITE-SPECIFIC AQUIFER CHARACTERIZATION

This section characterizes the aquifer zones along the levee corridor looking at both the land and water side of the levee. Five cross-sections were sited based on the number of wells with “good” quality soil profiling (or lithologic) data, and to achieve an approximate uniform spacing along the levee corridor. A “good” quality well completion report is one that includes good location data, has a well documented drilling profile of the soil types encountered during well construction, and is of a depth that represents the typical well depth for uses taking place along the levee corridor. Figure 4-1 illustrates the five cross-sections that lie roughly perpendicular to the levee, and the sixth cross-section that follows the length of the levee.

To characterize the aquifer, each of the good-quality well reports were further reviewed and interpreted to assign uniform classification codes of each soil type to align each well along the cross section and visualize the aquifer system and understand the range in permeabilities (i.e., water’s ability to move through a given soil type) vertically downward and then horizontally along the cross-section alignment. The wells and corresponding lithologic codes (i.e., Uniform Soil Classification System) were entered into the YCWA DMS to include the added wells along with the existing wells already included in the DMS. The DMS generated base cross sections included in Appendix “B” correspond to the cross-section lines shown in Figure 4-1. The cross-sections also include annotation to represent the levee, and the approximate measured (Spring 2008) groundwater elevations along the centerline of each cross-section.

Each of the cross-sections was reviewed by a licensed hydrogeologist for the interpretation of the soil strata and determining the depth and extent of the likely water bearing portions of the subsurface soils. The cross-sections depicting the project extents along the levee are shown in Figure 4-1 below.
Figure 4-1. Aerial Imagery of Proposed Project and Geologic Cross-Sections
Figure 4-2. Levee Cross-Section L-L'
4.1 Impact of Slurry Wall on Regional South Yuba Sub-Unit Groundwater Basin

From Figure 4-2, it becomes apparent that the two layer approach taken in understanding of the questions in Section 2 has to be modified to reflect the predominant permeable soil types (i.e., blue shaded areas) and their inter-fingering permeable layers (i.e., sand, gravel, and cobble) and the less permeable soil conditions (i.e., brown colored clay and cemented sediments). The large blue area depicts areas of medium to highly permeability soils capable of moving groundwater vertically and horizontally to depths greater than 300 feet bgs. The less permeable soils are interspersed allowing groundwater to move vertically and horizontally with little effect on groundwater movement in the project area.

The cross-sections perpendicular to the levee included in Appendix “A” show much of the same inter-fingering with a predominance of mostly permeable soils. Section E-E’, shown in Figure 4-3 below is located at the furthest westerly extremity of the Proposed Project and is the only cross-section that likely has lower permeabilities, shown as the brown shaded areas, relative to the other five.

![Figure 4-3. Cross-Section E-E’](image)

4.2 Groundwater Basin Characterization

Based on the collection of geologic cross sections and data taken from the Yuba Groundwater Characterization Study, the geologic profile along the Proposed Project corridor includes young alluvial deposits that store and transmit groundwater vertically downward to the underlying continental and marine deposits that do not store or yield significant amounts of groundwater.
The primary water-producing aquifers in the corridor are within the Riverbank, Laguna and Mehrten formations. These units are composed of lenticular sand and gravel beds that occur between finer-textured materials deposited during the Miocene to Pliocene.

As shown in Cross-Section L-L’ (See Figure 4-2), The present day alluvial sediments in the Yuba River predominantly comprise mining debris from the processing of gold-bearing gravels both in hydraulic mines and early dredging operations in Yuba Goldfields. The area of the Yuba Goldfields located at the northeast termination point of the Proposed Project, containing gravel and cobble-sized materials deposited over the past 50 million years, is a recent geomorphic feature, providing a significant groundwater recharge mechanism to the SYSGB. Younger stream channel deposits also exist at the subsurface indicating the Yuba River’s alignment prior to man’s movement of the river north of the proposed project. The older natural streambed channel can still be identified on an aerial as indicated in Figure 4-1. There is also further evidence that the river crossed through the levee at different points in time as indicated by the highly permeable deposits located approximately 100 feet bgs.

As noted in Section 2, the natural gradient of groundwater is currently almost parallel to the levee alignment; as a result, under normal river flow conditions there is currently little flow of groundwater moving across the levee boundary from the water side to the land side. The cross-sections indicate that if a barrier is placed down the centerline of the levee to depths of 60 to 100 feet, a sufficient thickness of highly permeability soils still exists below the slurry wall allowing the water to move vertically and then horizontally beneath the slurry wall to recharge groundwater on the land side of the levee if the general groundwater flow direction were to change from its current parallel path to a perpendicular flow direction from north to south.

4.3 Vertical Flow Direction and Water Quality

Groundwater levels in the Yuba Basin are simultaneously monitored at different depths in several multilevel piezometers. Vertical flow direction can be defined by comparing groundwater levels at different depths within a single piezometer. Although no multilevel piezometers are found at the project site, data from piezometers YR-1, PMW-02, and PMW-07 can be used to understand flow directions at the project site (see Figure 2-2 for piezometer locations). PMW-02, in the north Yuba subbasin, and PMW-07, in the south Yuba subbasin, are a similar distance from the Sierra Nevada mountain front as the project location, although they are more distant from the Yuba River. Additionally, their well logs indicate a similar subsurface distribution of coarse and fine material to that of the project area, suggesting a similar degree of groundwater interconnectivity. YR-1, co-located with the MRY stream gage on the Yuba River, is the closest piezometer to the project location. Vertical flow gradients in the project area likely fall within the range of gradients observed at PMW-02, PMW-07, and YR-1.

Groundwater elevations have been measured at PMW-02 and PMW-07 since January 2007, as shown in Figures 4-4 and 4-5. Groundwater at all three depths monitored by the PMW-02 piezometers responded to and recovered from pumping in summer 2008 nearly equally, indicating a high degree of connectivity between aquifer units to nearly 300 feet in depth. Given that groundwater elevations between piezometers are nearly identical, no significant vertical flow component can be identified at this location. Groundwater elevations in PMW-07A and PMW-07B are similarly nearly identical, both nearly equally responding to and recovering from summer pumping of the confined aquifer represented by PMW-07C. This suggests a high degree
of interconnectivity within the shallow aquifer materials, as well as connection with the deeper aquifer. Groundwater elevations are highest in PMW-07A and lowest in PMW-07C, indicating a downward vertical gradient throughout the groundwater profile at this location.

Since September 2004, groundwater elevations have been measured at four different depths within the multi-level monitoring well YR-1, located near the Yuba River (See Figure 2-2 for well location). Groundwater elevations in the two shallowest piezometers, YR-1A and YR1-B, are most relevant for determining potential impacts of the levee-stabilizing slurry wall. Figure 4-6 shows groundwater elevations measured in piezometer YR-1A, screened from 70 to 80 feet bgs in the unconfined aquifer comprising the Riverbank and Laguna formations, and in piezometer YR-1B, screened from 250 to 260 feet bgs in the underlying confined aquifer, the
Mehrten Formation. Figure 4-6 also shows gaged streamflows at Marysville (gage MRY) during this period.

From 2004 to 2009, groundwater elevations in the shallow piezometer, YR-1A, closely followed changes in Yuba River stage, increasing during spring snowmelt runoff and precipitation high-flow events and decreasing between events. The observed higher water levels in YR-1A than in the river indicate an upward flow gradient between the two, and that the Yuba River gains water from the shallow unconfined aquifer at this location.

During the same period, groundwater elevations in the deeper piezometer, YR-1B, fluctuated up to 30 feet seasonally, corresponding with seasonal pumping for irrigation. Groundwater elevations in YR-1B generally were lower than groundwater elevations observed in YR-1A from May through October and were higher from December to April. This indicates that the vertical groundwater flow gradient is upward during the rainy season and downward during the drier months. The response to pumping of the confined aquifer seen in YR-1B has not been observed in the shallow unconfined aquifer monitored by YR-1A, most likely due to the strong influence of Yuba River flows at this proximity to the river. Any groundwater connection between the shallow and deeper aquifers that may exist at this location is overwhelmed by river recharge.

Vertical downward groundwater flow gradients observed at all depths in well PMW-07, in the shallow aquifer in well YR-1, and seasonally between the shallow unconfined and confined aquifers monitored by YR-1 are common throughout the Yuba Basin (MWH, 2008). Downward flow gradients between the unconfined and confined aquifers have been observed in most multilevel piezometers in the basin, including in the southeast basin at Beale Air Force Base piezometers and along the Feather and Bear rivers. Given the general vertical downward groundwater flow in the basin and the observed interconnectivity between aquifers up to nearly 300 feet deep in most locations, the presence of the slurry wall would likely not significantly impact groundwater recharge in the basin.
Existing groundwater quality data in the Yuba Basin are analyzed in the Characterization Report (MWH, 2008). The spatial distribution of total dissolved solids (TDS) concentration in groundwater was mapped based on data collected from 93 wells between 2000 and 2003. Generally, TDS concentrations increased with distance from the Yuba River and with depth. TDS and nitrate concentrations as well as ratios of stable isotopes of oxygen and hydrogen observed at different depths in multilevel piezometers PMW-02, PMW-07, and YR-1 in 2004 are shown in Table 4-1.

At YR-1, near the Yuba River, observed TDS and nitrate concentrations were similar in the three shallowest piezometers, and were well below State and Federal primary and secondary maximum contaminant levels (MCL) of 500 milligrams per liter (mg/L) for TDS and 45 mg/L for nitrate. The high TDS found in the deepest piezometer, YR1-D, likely represents brackish groundwater found near the base of freshwater in the Yuba Basin. In well PMW-02, TDS and nitrate concentrations were observed to be similar and below MCLs at all sampled depths. Groundwater quality in well PMW-07 was also observed to be similar between the two shallowest piezometers, representing groundwater at depths that could be affected by the levee-stabilizing slurry wall. The similar groundwater quality at varying depths within each well suggests existing interconnectivity between most shallow and deeper aquifers. It is unlikely that groundwater mixing due to changes in groundwater flow paths at depths affected by the slurry wall would result in significant changes in water quality.

Table 4-1. Yuba Basin Water Quality with Depth

<table>
<thead>
<tr>
<th>Well</th>
<th>Screened Interval (feet bgs)</th>
<th>Total Dissolved Solids</th>
<th>Nitrate (mg/L)</th>
<th>Oxygen 18 (δ18O)</th>
<th>Hydrogen (δ2H)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Bottom</td>
<td>mg/L</td>
<td>Top</td>
<td>Bottom</td>
</tr>
<tr>
<td>PMW-02A</td>
<td>92</td>
<td>122</td>
<td>266</td>
<td>3.9</td>
<td>-7.4</td>
</tr>
<tr>
<td>PMW-02B</td>
<td>150</td>
<td>180</td>
<td>235</td>
<td>&lt; 0.1</td>
<td>-7.6</td>
</tr>
<tr>
<td>PMW-02C</td>
<td>210</td>
<td>240</td>
<td>286</td>
<td>&lt; 0.1</td>
<td>-7.6</td>
</tr>
<tr>
<td>PMW-07A</td>
<td>56</td>
<td>66</td>
<td>276</td>
<td>25.5</td>
<td>-7.5</td>
</tr>
<tr>
<td>PMW-07B</td>
<td>142</td>
<td>212</td>
<td>266</td>
<td>28.6</td>
<td>-7.5</td>
</tr>
<tr>
<td>PMW-07C</td>
<td>425</td>
<td>445</td>
<td>340</td>
<td>0.7</td>
<td>-8.7</td>
</tr>
<tr>
<td>YR-1A</td>
<td>70</td>
<td>80</td>
<td>244</td>
<td>1.7</td>
<td>-10.6</td>
</tr>
<tr>
<td>YR-1B</td>
<td>250</td>
<td>260</td>
<td>104</td>
<td>&lt; 0.1</td>
<td>-11.5</td>
</tr>
<tr>
<td>YR-1C</td>
<td>430</td>
<td>450</td>
<td>119</td>
<td>&lt; 0.1</td>
<td>-11.2</td>
</tr>
<tr>
<td>YR-1D</td>
<td>600</td>
<td>620</td>
<td>874</td>
<td>&lt; 0.1</td>
<td>-8.4</td>
</tr>
<tr>
<td>Yuba River (MRY gage)</td>
<td>--</td>
<td>--</td>
<td>52</td>
<td>&lt;0.1</td>
<td>-11.2</td>
</tr>
</tbody>
</table>


Key:
- -- =not applicable
- 0/00=per mill (parts per thousand)
- bgs=below ground surface
- mg/L=milligrams per liter
- δ = del; indicates an isotope ratio present in a sample, as compared to the isotope ratio present in Vienna Standard Mean Ocean Water.
Ratios of stable isotopes of oxygen ($^{18}$O/$^{16}$O, or $\delta^{18}$O) and hydrogen ($^{2}$H/$^{1}$H, or $\delta^{2}$H) can be used to determine the major recharge source and age of groundwater. Groundwater recharged mainly by runoff from snowmelt-fed rivers, including the Yuba River, has relatively isotopically light (smaller) $\delta^{18}$O and $\delta^{2}$H values compared to groundwater recharged mainly by infiltration of local valley precipitation. As shown in Table 4-1, groundwater in the shallowest three piezometers of well YR-1 have isotopically light $\delta^{18}$O and $\delta^{2}$H values similar to those of the Yuba River, indicating that groundwater at this location is recharged mainly by snowmelt runoff from the river. On the other hand, relatively isotopically heavy groundwater was observed in all piezometers of well PMW-02 and in the two shallowest piezometers of well PMW-07. This isotopically heavier groundwater reflects recharge mainly from infiltration of local precipitation. Isotope ratios found in the deepest piezometers, PMW-07C and YR-1D, may represent paleogroundwater recharged by local precipitation that fell under cooler climatic conditions than those that exist today.

This is consistent with stable isotope data collected from wells used for groundwater substitution transfer pumping in 2002, which suggest that recharge water for most Yuba Basin wells is derived from infiltration of local precipitation (MWH, 2008). Stable isotope data from the 2002 transfer wells and YCWA monitoring wells show that shallow wells within 1 mile of the major rivers (Yuba, Bear, and Feather rivers) in the Yuba Basin appear to be recharged primarily by river water. Wells between about 1 and 2 miles appear to be sourced by a combination of river water and infiltration from local precipitation. Wells beyond about 2 miles from the major rivers appear to be sourced primarily by infiltration of local precipitation. This suggests that the levee-stabilizing slurry wall will not significantly affect recharge of groundwater greater than 2 miles from the Yuba River.
Section 5.0 EVALUATION METHODS

With the improved understanding of the local hydrogeology the conceptual figures shown in Section 3 can be revised to incorporate the finding of the inter-fingering of highly permeable soils with less permeable soils. These are shown in Figure 5-1 and Figure 5-2.

Figure 5-1. Updated Conceptual Drawing without Slurry Wall

Figure 5-2. Updated Conceptual Drawing with Slurry Wall

Figure 5-1 characterizes the natural groundwater flow process in a semi-confined aquifer. Water moves vertically in accordance with the piezometric head of each aquifer layer. In the case of
Figure 5-1 there is an upward migration of groundwater due to the higher piezometric head of the lower aquifer. The opposite would be true (i.e., downward migration) if the lower aquifer head was lower than the upper unconfined aquifer. Given the proven connectivity between both the upper and lower groundwater aquifers, and based on groundwater monitoring of the multiple groundwater aquifer layers, the piezometric head of the lower aquifer can fluctuate above and below the upper unconfined aquifer head. This is best visualized using data from multipiezometer monitoring wells and the behavior of piezometric heads between multiple adjacent aquifers.

With the construction of the slurry wall, Figure 5-2 illustrates how the piezometric head from the upper aquifer increases to move water downward into the lower semi-confined aquifer and then water moves upward on the land side of the slurry wall and levee due to the lower semi-confined head being higher than the upper aquifer. This illustrates how groundwater recharge will continue to take place after the slurry wall construction.

Figure 5-2 shows that impacts to the regional groundwater recharge from the construction of the slurry wall will be negligible. From the data and findings above, regional groundwater impacts (Problem Statement 1) should not occur as a result of the construction of the Proposed Project.

5.1 Impact of Slurry Wall on Private Well Owners

The above does not address impacts to wells located in close proximity to the slurry wall (Problem Statement 2). Anytime a barrier is placed within the capture area (or zone of recharge) for an individual well, the shape and depth of the localized cone of depression surrounding the well will change. The likely consequence of the slurry wall placement near an existing well is a lowering of groundwater elevations at the well during periods of extraction and the local cone dipping down near the slurry wall barrier. Where the cone of depression meets the wall, it will deepen, creating a steeper gradient to possibly sustain the extraction amounts. Figure 5-3 illustrates this change in the local cone of depression in plan view and in profile.
To account for lowering of the groundwater cone of depression when a barrier is introduced, the Theis methodology of calculating radial well drawdown can be used to estimate drawdown in wells located in close proximity to the Proposed Project.

The Theis equation is one of the most commonly used and fundamental solutions to the groundwater flow equation; it can be used to predict the transient evolution of head due to the effects of pumping one or a number of pumping wells.

Theis Equation:

\[ s = \frac{Q}{4\pi T} W(u) \]

\[ u = \frac{r^2 S}{4Tt} \]

The Theis equation is a solution to the steady state groundwater flow equation (Laplace's Equation). The Theis equation is a very simple (yet still very useful) analytic solution to the groundwater flow equation.

The premise of a quantitative application of the Theis equation is based on identifying the distance (or bandwidth) from the slurry wall that wells will be impacted. For purposes of this study, significant impact is assumed to be any well where the slurry wall encroaches to the point...
where it creates a decline in groundwater elevations at the well or center of the cone of depression (illustrated in Figure 5-4).

The image well concept represents the simulated effect of the slurry wall on the well. The image well concept has long been used to simulate either no-flow or constant head boundaries near a pumping well. Because the technique is a result of the properties of superposition, it is possible to use it to simulate pumping near a slurry wall with a lower hydraulic conductivity (K) if the storage coefficient (S) is constant. The intersection of the respective cones of depression dictate the additional drawdown at the wall and at the well. Where the cones of depression overlap, or interfere, the drawdown at a point is the sum of the drawdowns caused by the individual wells. Evaluations were completed to identify well distances where 1-foot, 3-foot, and 5-foot declines occur at the well. Any well that is closer than the defined Acceptable Encroachment Distance is viewed as a potentially impacted well.

![Figure 5-4. Acceptable Encroachment Distance for Existing Wells](image)

To apply the Theis methodology over the length of the Proposed Project, variable aquifer characteristics consistent with those shown in Cross Section L-L’ must be considered (Figure 4-2). To account for this variation of aquifer characteristics, a representative hypothetical well was created that best weights the variability in the permeability of soils over the length of the levee. A hypothetical well was created at each of the five perpendicular cross sections along the length of the levee. The variables included in the Theis equation that are of importance to this study are as follows:

- **Transmissivity (T)** - the ability of an aquifer to transmit water;
- **Storage Coefficient (S)** - a measure of the amount of water of a confined aquifer will give up for a certain change in head;
- **Radius (r)** – Radius from the well to calculate depth

Other assumed variables are as follows:
Flow Rate (Q) = 100 gallons per minute (gpm)

Time of Continuous Pumping (t) = 4 days

From these variables, the radial drawdown at any distance away from the well can be calculated. Wells located in highly transmissive soils have a smaller band width as suggested by the Theis equation with Transmissivity being in the denominator. This implies that wells located in low transmissivity soils have a larger radius of influence and deeper drawdown at the well to achieve the same production. One example of a drawdown curve for highly transmissive soils is illustrated in Figure 5-5. In this case, 4.6 feet of drawdown would naturally occur without the slurry wall. The incremental 1 foot of drawdown in the well due to the slurry wall project equates to approximately 5.6 feet of absolute drawdown and an encroachment distance of potentially impacted wells of 475 feet. Encroachment distances for 3 feet and 5 feet of drawdown at the well are within 50 feet of the levee.

For soil conditions that are less transmissive (i.e., wells near Cross-Section E-E', Figure 4-3), the Theis equation provides a larger radial distance in order to sustain the same level of groundwater extractions. Figure 5-6 illustrates the greater draw down and larger radius in less permeable soils with the natural drawdown in the well being 12.5 feet. With the addition of the slurry wall the absolute drawdown increases by 1-foot for wells located within an encroachment distance of 1,160 feet. Encroachment distances for 3 feet and 5 feet of drawdown at the well are within 250 feet and 60 feet of the levee, respectively.
Solving the Theis equation with changing transmissivities along the length of the proposed project results in a recommended encroachment bandwidth as illustrated and summarized in Section 6-Evaluation Results.

5.2 Waterside Levee Impacts and Time Needed for Aquifer to Reach Equilibrium

Responding to Problem Statement 3 requires a method of quantifying the time for groundwater to equilibrate after a flood event to assess potential impacts associated with saturation of the root zone depth of existing tree orchards on the waterside of the levee.

Groundwater gradients underlying the Proposed Project are shown in Figure 2-3 as being parallel to the levee wall. As mentioned in previous sections of the report, the direction of groundwater movement being parallel to the levee reduces the slurry wall’s impact on groundwater flow under the levee section. However, to understand a possible worst-case scenario, there is an interest in assuming that groundwater flows perpendicular to the levee section as explained below.

As a flood event occurs, water backs up on the levee and the hydrostatic head builds until the high point of the flood event and then subsides as the flood waters move downstream. From the point in time when water begins to back up on the levee, there is a downward gradient that pushes the overlying surface waters into the unsaturated zone of the aquifer. The higher the flood stage, the higher the gradient and the more water that flows into the groundwater system.

The problem is defined by the difference in time with and without the slurry wall for high groundwater elevations caused by a flood event to subside to pre-flood conditions. The conceptual flow model is illustrated in Figure 5-7 and Figure 5-8. Figure Figure 5-7 illustrates an initial groundwater head at time equal to zero (t=0) and the final groundwater head at a calculated time. Figure 5-8 shows the same calculation with the slurry wall in place. The
The difference in the calculated time to reach a final groundwater head is the potential impact from the Proposed Project.

Figure 5-7. Existing Condition Time to Reach Groundwater Head Equilibrium

Figure 5-8. Time to Reach Groundwater Head Equilibrium with Proposed Project
Section 6.0  EVALUATION RESULTS

This section provides evaluation results in response to the three Problem Statements identified in Section 1.

Problem Statement 1 – Regional impacts to groundwater recharge due to slurry wall: Based on Figure 4-2 and cross sections included in Appendix A, the discontinuous impermeable layers will continue to permit recharge water from the Yuba River to flow into the SYSGB. Furthermore, existing groundwater flow paths are parallel to the Proposed Project in the project area, minimizing the potential for regional recharge impacts. This report finds that no significant impact to regional groundwater recharge will occur from the Proposed Project.

Problem Statement 2 – Localized impacts to wells near the slurry wall: Using the Theis methodology, two narrow bandwidths along the Proposed Project have been developed that delineate the area where existing wells potentially may be impacted. This is illustrated in Figure 6-1, indicated by the lighter shaded region representing a 1- to 3-foot impact at the well, and the darker shaded area representing a potential 3- to 5-foot impact at the well. Based on the designated bandwidths, the affected wells taken from the Section 3.0 well inventory are reported in Table 6-1. To mitigate for private well impacts as a result of the Proposed Project, TRLIA may either consider: 1) the potential use of seepage berms in lieu of slurry walls along portions of the levee, and/or 2) work with the current land well owners to replace the impacted wells.

Table 6-1. Potential Localized Well Impact Zone Inventory

<table>
<thead>
<tr>
<th>Potential Additional Drawdown Impact at the Well</th>
<th>Well ID</th>
<th>State Well ID</th>
<th>Address Match (if known)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 3 feet</td>
<td>1003</td>
<td>15N04E11K</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>1028</td>
<td>15N04E15M</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>1045</td>
<td>15N04E16R</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>1055</td>
<td>15N04E20H</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>1065</td>
<td>15N04E20K</td>
<td>6223 Mares Way</td>
</tr>
<tr>
<td></td>
<td>1034</td>
<td>15N04E15</td>
<td>6519 Griffith Ave</td>
</tr>
<tr>
<td></td>
<td>1062</td>
<td>15N04E20K</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>1064</td>
<td>15N04E20K</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>1093</td>
<td>15N04E21D</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>1094</td>
<td>15N04E21E</td>
<td>2019 Hammonton Rd</td>
</tr>
<tr>
<td></td>
<td>1091</td>
<td>15N04E21D</td>
<td>2043 Simpson/Dantoni Rd</td>
</tr>
<tr>
<td></td>
<td>1122</td>
<td>15N04E21</td>
<td>6647 Dantoni Dr</td>
</tr>
<tr>
<td></td>
<td>1088</td>
<td>15N04E21B</td>
<td>6425 Dantoni Rd</td>
</tr>
<tr>
<td>3 to 5 feet</td>
<td>1085</td>
<td>15N04E20</td>
<td>1416 Hammonton Rd</td>
</tr>
<tr>
<td></td>
<td>1066</td>
<td>15N04E20K</td>
<td>1898 Hammonton Rd</td>
</tr>
<tr>
<td></td>
<td>1070</td>
<td>15N04E20</td>
<td>1424 Hammonton Rd</td>
</tr>
<tr>
<td></td>
<td>1071</td>
<td>15N04E20</td>
<td>1024 Hammonton Rd</td>
</tr>
<tr>
<td></td>
<td>1073</td>
<td>15N04E20</td>
<td>1204 Ferrell Ave</td>
</tr>
<tr>
<td></td>
<td>1074</td>
<td>15N04E20</td>
<td>1124 Dunning Ave</td>
</tr>
<tr>
<td></td>
<td>1078</td>
<td>15N04E20</td>
<td>808 Hammonton Rd</td>
</tr>
<tr>
<td></td>
<td>1084</td>
<td>15N04E20</td>
<td>Not Available</td>
</tr>
</tbody>
</table>

Note: Designated wells are based on available DWR Well Completion Reports that contained sufficient data to locate well. This list may not include the total population of wells constructed in the designated Impact Zones.
Figure 6-1. Approximate Localized Zone of 1 to 3 Feet of Potential Additional Drawdown Along Levee Corridor
Problem Statement 3 - Extended time of water saturation of root zone due to slurry wall:
As stated in Section 5.2, the existing groundwater flow direction parallel to the Proposed Project makes it unlikely that any increase in saturation time will occur. However, as a worst-case scenario, a planning-level study was conducted using a two-dimensional unsaturated flow model (Hydrus 2D) to assess the potential impact to water content in the shallow root zone (top 7 feet of soil) over a 6-day (144 hours) flood event. Given the general nature of this model, soil water contents are provided numerically strictly for the presentation of comparative changes due to the construction of the slurry wall. Furthermore, a flood event that saturates the root zone could occur with or without the wall, depending on inundation depth and flood event time span.

Figure 6-2 illustrates the two-dimensional soil profile cross-section without the slurry wall, assuming groundwater flow perpendicular to the levee. This figure shows predicted water content at the end of the 6-day simulation period. A water content of 0.046 (blue color) represents dry unsaturated conditions and a water content of 0.430 (red color) represents complete saturation of the unconfined aquifer. Recharge of water through the root zone is indicated by the lighter green colors, showing that water moves through the root zone at the point of recharge on the water side of the levee, into the groundwater aquifer system, and passes under the levee. Figure 6-3 includes the same underlying assumptions as Figure 6-2, and also includes the slurry wall. As illustrated in Figure 5-8 in Section 5, the slurry wall impedes the recharge rate and movement of water to a small degree.

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1 The Hydrus 2D model domain used in this study is considered to be conceptual, because it assumes a homogeneous system and has not been calibrated. Because the model is not based on site-specific hydrogeologic data or flood flow dynamics, results should be considered comparatively rather than as absolute values.
Looking at a discrete soil column within the probable root zone of nearby orchard crops (in the black-outlined box shown at the upper right side of the soil profile in the two figures above), there is little persistence of increased water content after a flooding event as a result of the slurry wall. As shown in Figures 6-2 and 6-3, higher water content is only slightly more prevalent at shallower depths with the slurry wall than without the slurry wall. In conclusion, soil water content would likely be only slightly higher and would persist for only a slightly longer period of time after a flooding event as a result of the slurry wall. In conclusion, no significant root damage impacts will occur from this project.
Section 7.0  REFERENCES


Appendix “A” – Geologic Cross Sections with Wells Only
Cross Section TRLIA C-C'

Legend
FRCT
IR-Ne Recovery
COBL-Cobble
GP-Poorly graded gravel
SP-Poorly-graded sand
GM-Gravel with fines silty gravel
GC-Gravel with fines clayey gravel
SM-Sand with fines silty sand
SC-Sand with fines clayey sand
ML-Inorganic silt
CL-Inorganic clay
SH/E-Shale
HP-Handpan

Prepared by ____________ Date________
Reviewed By ____________ Date________
Appendix “B” – Geologic Cross Sections with Lithologic Interpretation
Cross Section TRLIA C-C'

Prepared by ____________ Date________ Review By ____________ Date________