March 16, 2022

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Re: **Westlands' Broadview Aquifer Storage and Recovery (ASR) Project (DWR Grant Agreement No. 4600013845 Proposition 1 Funding) – Adequacy of Hydrologic Analysis, CEQA Compliance and Potential for Mobilizing Contaminated Shallow Groundwater**

Dear Director Nemeth, Executive Director Sobeck, Mr. Pulupa, Mr. Rogers, Mr. Albright and Mr. Higgins:

HydroFocus was asked by the Planning and Conservation League (PCL) to assess the adequacy of hydrologic analysis of the Broadview Aquifer Storage and Recovery (ASR) project and its potential to mobilize contaminated shallow groundwater. Attached is our report which describes the results of our assessment.

As background, a 2019 Mitigated Negative Declaration (MND) [October 4, 2019 (SCH # 2019089109)] for a regional ASR project, Westlands Water District (which owns Broadview Water District) determined that the Broadview ASR project would not have significant environmental impacts. However, the 2019 MND or subsequent analysis for the Broadview ASR project did not evaluate the potential mobilization of shallow contaminated groundwater in the Broadview area as the result of injection of water into the ASR well planned for installation within Broadview Water District. In a letter to you, Executive Director Sobeck, Patrick Pulupa, Clay Rogers, David Albright and Damian Higgins, the PCL and seventeen other organizations identified this deficiency and pointed out the need to address it.

Westlands Water District in a letter to DWR in November 2021, disagreed and claimed that the shallow groundwater is isolated from ASR well effects and that the regional model used for the MND shows that there will be no significant effects. This exchange raised four questions that HydroFocus addressed in the attached report.

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1. **What do data and modeling demonstrate about the connection between the Upper Aquifer and the shallow groundwater?** Multiple peer-reviewed studies, including historical hydrologic analysis, modeling, lithological analysis, and aquifer tests, demonstrate the active hydrologic connection of the deep and the shallow groundwater and drainage systems. This hydrologic connectivity indicates the potential for increasing shallow groundwater levels resulting from the injection of water into an ASR well.
2. **What are the potential effects of increased shallow groundwater levels on groundwater and drain-water quality?** Peer-reviewed results of data collection and modeling in Broadview Water District indicate that if shallow groundwater levels increase as the result of the Broadview ASR project, there is the potential for movement of the high-selenium groundwater to drainage systems within the district and in adjacent areas. Higher groundwater levels can potentially reinitiate flow in drainage systems which can become discharges of high-selenium groundwater to surface waters, as well as cause discharge of contaminated shallow groundwater to surface water.
3. **How effective is the regional model used in the 2019 MND for simulating the Broadview ASR Project?** The modeling described in available documentation does not include the Broadview ASR well and indicates three additional model shortcomings. First, the model is based on a paradigm of discontinuity between the deep and shallow groundwater which is contrary to previous peer-reviewed analyses. Also, the model does not explicitly simulate agricultural drainage. Lastly, analysis needed to provide an understanding of the level of confidence in model results, especially for site specific conclusions for the Broadview ASR project, is missing.
4. **What monitoring should be implemented if injection moves ahead?** Because injection of water into groundwater wells screened in the Upper Aquifer can induce changes in the shallow groundwater, monitoring of the hydraulic effects of aquifer storage and recovery should be designed and conducted to evaluate these effects. We provide recommendations for monitoring in the report.

Based on our review of substantial data and analysis conducted in the western San Joaquin Valley, we conclude that if the Broadview ASR project proceeds with injection and pumping cycles as planned, there can be hydrologic and water-quality impacts which include discharges of groundwater and drain water with selenium concentrations to surface waters. Should the project proceed, sufficient monitoring and technical analysis should be implemented to assess these impacts.

Thank you for considering the attached report.

Sincerely,

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Potential Hydrologic and Water-Quality Effects of an Aquifer Storage and Recovery Well in Broadview Water District

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March 16, 2022

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Potential Hydrologic and Water-Quality Effects of an Aquifer Storage and Recovery Well in Broadview Water District

Contents

Executive Summary

The Broadview Aquifer Storage and Recovery (ASR) Project, partially funded by the Department of Water Resources (DWR 2021), will install a well and above-ground equipment to inject Westlands Water District's Central Valley Project water into the Westside Subbasin's Upper and Lower Aquifer for later recovery for irrigation. The location of the proposed ASR well is in the southeast corner of Broadview Water District (BWD). Westlands Water District (Westlands) is also proposing a regional-scale aquifer storage and recovery (ASR) project within Westlands' boundaries. Surface water, when available, would be injected in hundreds of wells for aquifer storage and subsequently extracted from the same wells when needed. One of the first injection wells for the regional ASR project is planned to be the Broadview ASR well.

Based on a 2019 Mitigated Negative Declaration (MND) [October 4, 2019 (SCH # 2019089109)] for the regional ASR project, Westlands determined that the specific Broadview ASR project also would not have significant environmental impacts. Neither the 2019 MND or subsequent analysis for the Broadview ASR project evaluated the potential that injecting water into these aquifers would mobilize existing contaminated groundwater to drainage systems and surface waters.

The Planning and Conservation League and 17 other environmental, fishery, and tribal groups wrote to the Department of Water Resources and other state and federal agencies regarding the failure of the Broadview ASR project to meet the legal requirements of CEQA and NEPA due to the inadequate assessment of potential hydrologic and water quality effects of the Westlands Broadview ASR project (Planning and Conservation League et al., 2021 See https://calsport.org/news/wp-content/uploads/Env-Advocates-Ltr-to-DWR-et-al-Re-SLDMWA-WWD-ASR-Broadview-WD_10_18_-2021.pdf). One of the primary deficiencies identified is related to the failure of the hydrologic analyses to evaluate and disclose the potential for the project to mobilize contaminated shallow groundwater that could flow to drainage systems or surface water. Westlands, in a letter to DWR in November 2021, disagreed and claimed that the shallow groundwater is isolated from ASR well effects and that the regional model used for the MND shows that there will be no significant effects. This exchange raised four questions addressed in this report that are related to the Broadview ASR project reliance on the 2019 CEQA regional review conducted by Westlands Water District.

1. **What do data and modeling demonstrate about the connection between the Upper Aquifer and the shallow groundwater?** Multiple studies demonstrate the active hydrologic connection within the semiconfined zone of the deep and the shallow groundwater and drainage systems. This connection is evidenced by the hydrologic changes in the evolution of the flow system which resulted in groundwater level changes in the deep and shallow parts of the semiconfined zone. Results of modeling based on extensive data collection and analysis demonstrate the effect of pumping on shallow groundwater levels. The demonstrated absence of a continuous confining layer provides further evidence for the hydrologic connection of the deep and shallow parts of the semiconfined zone, which includes the Upper Aquifer. This hydrologic connectivity indicates the likelihood that shallow groundwater levels will rise with the injection of water into the semiconfined zone.
2. **What are the potential effects of increased shallow groundwater levels on groundwater and drain-water quality?** Peer-reviewed results of data collection studies and modeling in Broadview Water District (BWD) indicate that if shallow groundwater levels increase as the result of the BWD ASR project, there is the potential for movement of the high-selenium groundwater to drainage systems within BWD and in adjacent areas. Higher groundwater levels can potentially reinitiate flow

in drainage laterals which can become discharges of high-selenium groundwater to surface waters. There is also potential that higher groundwater levels could cause discharge of contaminated shallow groundwater to surface water channels and sloughs.

3. **How effective is the regional LSCE model used in the 2019 MND for simulating the BWD ASR Project?** The modeling described in LSCE (2019) does not include the WWD ASR well. Moreover, three additional issues indicate model deficiencies. First, the LSCE model is based on a paradigm of discontinuity between the deep and shallow zones within the semiconfined zone, which contrasts with previous peer-reviewed modeling results. Second, the LSCE model does not explicitly simulate agricultural drainage. Third, there is a lack of sensitivity analysis that can provide an understanding of the level of confidence in model results, especially for site specific conclusions.
4. **What monitoring should be implemented if injection moves ahead?** Injection of water into groundwater wells screened in the Upper Aquifer can induce changes in the shallow groundwater and laterally in the semiconfined zone. Monitoring of the hydraulic effects of aquifer storage and recovery should be designed to evaluate vertical and horizontal effects in the shallow groundwater of injection and pumping. Specific recommendations follow.

   Multiple-depth piezometers should be installed in the area of the ASR well. Piezometers should be at depths ranging from 50 feet below land surface to the water table and be located at varying distances from the well up to about 200 feet. Groundwater levels should be monitored continuously. This will provide insight about the processes affecting groundwater levels changes and the potential for reinitiating drain flow or other discharges to surface water. In addition, regular water-level monitoring of monitoring wells within the BWD area should be undertaken to assess potential regional effects. Groundwater quality samples should be collected from the piezometers to assess the levels of salinity and selenium and other constituents of concern identified within the Grasslands Bypass Project. Considering the shallow groundwater levels that likely exist within BWD, drain flow and quality within BWD and Firebaugh Canal Water District also should be monitored during the injection period.

Overall, our analysis supports the concern that there is potential for the Broadview ASR project to mobilize high-selenium shallow groundwater, causing it to flow to drainage systems or surface water.

Introduction

The Broadview ASR Project, partially funded by the Department of Water Resources (DWR 2021), will install a well and above-ground equipment to filter, monitor, and inject Westlands Water District's Central Valley Project water into the Westside Subbasin's Upper and Lower Aquifer for later recovery for irrigation. The project estimates groundwater storage of up to 2,000 AFY. The proposed BWD ASR is shown on page 58 of the grant proposal to DWR as located in the southeast corner of Broadview Water District.

The Broadview ASR project is part of a regional-scale ASR project within the Westland Water District (District) boundaries. Approximately 400 existing wells within the District would ultimately be converted to ASR wells (Brown and Caldwell, 2019). Modeling and other analyses conducted for the Mitigated Negative Declaration for the regional ASR project were used as the basis for assessing the Broadview ASR project.

Several concerns were expressed by the Planning and Conservation League and 17 other environmental, fishery, and tribal groups regarding the potential hydrologic and water quality effects of Westlands Broadview ASR project (Planning and Conservation League et al., 2021). The primary concerns related to hydrologic analyses were as follows.

- The MND did not consider the potential for mobilization of contaminated shallow groundwater that could flow to drainage systems or surface water.
- Modeling used to support the Mitigated Negative Declaration (MND) for the Westlands ASR program did not include any wells in BWD and did not fully consider potential hydraulic impacts of an ASR program in BWD and adjacent areas.
- The Monitoring and Reporting Program (IMRP) did not require monitoring of changes in the water table in shallow wells in BWD and vicinity and changes in flows into the tile drains.

Reponses to the comments by the Planning and Conservation League et al. (2021) were provided in a letter to Mr. Arthur Hinojosa, Division Chief, Division of Regional Assistance Department of Water Resources, from Westlands Water District. In response to comments alleging lack of consideration of the potential hydraulic and surface water impacts of the BWD ASR well, Westlands stated that “the MND describes the modeling used to assist with the analysis of the effects of the BWD ASR, which included simulations of several composite ASR wells and Upper Aquifer wells in the northeastern area of the WWD (which includes BWD)”. Westlands also stated that the shallow groundwater above the A-Clay is not connected to the Upper Aquifer and injecting into the lower portion of the Upper Aquifer will not materially influence the shallow zone.

The hydrologic influence of the proposed Ag-ASR program was evaluated using a numeric flow model developed for the Westside Subbasin by Ludhorff and Scalmanini Consulting Engineers (LSCE). The LSCE model used the One-Water Hydrologic Flow Model modeling platform developed by the USGS. The MODFLOW Farm Process (FMP4) was utilized in the model to simulate agricultural water supply and demand, agricultural water budgets, groundwater pumping and recharge. This model was calibrated to a historic period and then used to simulate projected groundwater conditions through a 54-year period from 2017 through 2070. A period of approximately 7 years from within the projected period containing conditions most favorable to injection was used to evaluate transport paths and travel time for water injected and changes in groundwater elevations.

Objective

The objective of this analysis and report is to address Westlands’ responses and assess the potential effects of the BWD ASR project on the shallow groundwater and potential discharges to drains and surface waters. The primary concern is the potential for the project to mobilize contaminated shallow groundwater that could flow to drainage systems or surface water and that this potential has not been adequately assessed. The objective was addressed in relation to four questions:

1. What do the data and modeling demonstrate about the connection between the Upper Aquifer and the shallow groundwater?
2. What are the potential effects of increased shallow groundwater levels on groundwater and drainwater quality?
3. How effective is the regional LSCE model used for the 2019 MND for simulating the BWD ASR Project?
4. What monitoring should be implemented if injection moves ahead?

Findings

Question 1. What do the data and modeling demonstrate about the connection between the Upper Aquifer and the shallow groundwater?

Evolution of the groundwater flow system

Westlands stated the following in response to the Planning and Conservation League et al. comments. "The shallow zone in this area is not considered a principal aquifer or hydrologically connected to a principal aquifer, such as the Upper Aquifer. The nearest available drilling log to the site shows the A-Clay layer above the recharge zone as having approximately 200 feet thickness of pure clay." However, there is no evidence presented to show the continuity of the A-Clay in the Broadview area.
To further answer the question and address the Westlands' comment, we herein provide a summary of the relevant hydrogeologic conditions and results of previous investigations that provide evidence of the connectedness of Upper Aquifer and the shallow groundwater in BWD and surrounding areas.

First, relevant insight is provided by extensive data collection, analysis and modeling conducted by the US Geological Survey in the 1980s and 1990s, which provide a comprehensive understanding of the groundwater flow system. The evolution of the groundwater system as summarized by Belitz and Heimes (1990) provides evidence for the connection between the Upper Aquifer and the shallow groundwater (collectively denoted by Belitz and Heimes as the semiconfined zone). The semiconfined zone includes the Coast Range sediments, Sierra Nevada sediments, and flood-basin deposits, which differ in texture, geohydrologic properties, and oxidation state. Under the predevelopment conditions, groundwater recharge to the semiconfined zone occurred in the alluvial fan heads and discharged from the system by evapotranspiration and streamflow in the axis of the valley. Artesian conditions prevailed along a broad stretch of the valley trough in the early 1900s. The presence of artesian conditions and wetlands point to the valley trough as the discharge area for the groundwater system and thus hydraulic continuity within the semiconfined zone and the shallow groundwater.

Agricultural development and the pumping of groundwater during the early twentieth century significantly altered the groundwater flow system. Extensive pumping during the first half of the 20th century caused a lowering of the water table along the distal fan margins and the valley trough (Belitz and Heimes, 1990). Delivery of surface water from northern California further altered the groundwater system. Percolation of imported water used for irrigation into the semiconfined zone, combined with a decrease in pumping, caused a rise in the elevation of the water table throughout much of the western Valley (Belitz and Heimes, 1990). As of 1984, a large portion of the study area was underlain by shallow groundwater within 20 feet of land surface. In contrast, much of this shallow-water table area was characterized by a water table depth of 100 to 200 feet in 1952 (Belitz and Heimes, 1990).

Groundwater level data presented in Belitz and Heimes (1990) (Figures 20 and 22) illustrate the changes in groundwater levels in wells in the area of the Panoche Creek Alluvial Fan during the 1970s and 1980s. Groundwater levels in shallow wells between 29 and 48 feet deep located upslope of the drained area increased concomitantly with increasing water levels in the well that was 184 feet deep. Groundwater levels in the shallow wells in the drained area were relatively constant over time because of the stabilizing influence of the agricultural drains on water levels. The synchronous responses of water levels across multiple depths indicate the active hydrologic connection between shallow and deep aquifer zones.

In contrast, Luhdorff and Scalmanini (2020), referring to Figure 2-33, stated that “It is evident that groundwater elevations in the shallow zone do not correlate with climatic conditions or seasonal pumping patterns”. However, for example, the hydrograph 15S13E11 shows there was a rise in the shallow groundwater levels of about 12 feet temporally consistent with the increasing groundwater levels in the deep wells from about 1993 to 2001. Also, for hydrograph 14S13E24, there was a water-level increase of over 20 feet consistent with water level rise in the deep well during 1996 – 2001. The responses in the shallow groundwater system are generally small relative to the changes in the deeper wells, but they are correlated and significant.

Geohydrologic sections through Panoche Creek Alluvial Fan presented in Deverel et al (1994) graphically illustrate the distribution of salinity and the evolution of the groundwater flow system in the western San Joaquin Valley (Figure 1). In addition, Dubrovsky et al. (1994) illustrated the change in the water-table elevation from 1952 to 1984 along a generalized geohydrologic cross section that includes BWD and a well cluster at FYR that is within Broadview Water District (Figure 2).

In summary, during the 20th century, the variation in the shallow groundwater water table depth varied concomitantly with variations in the semiconfined zone, thus indicating the active connection between the Upper Aquifer and shallow groundwater. The results of pump tests, modeling and lithologic data collection and analysis, as discussed below, provide further evidence for the connection of the Upper Aquifer with the shallow groundwater.

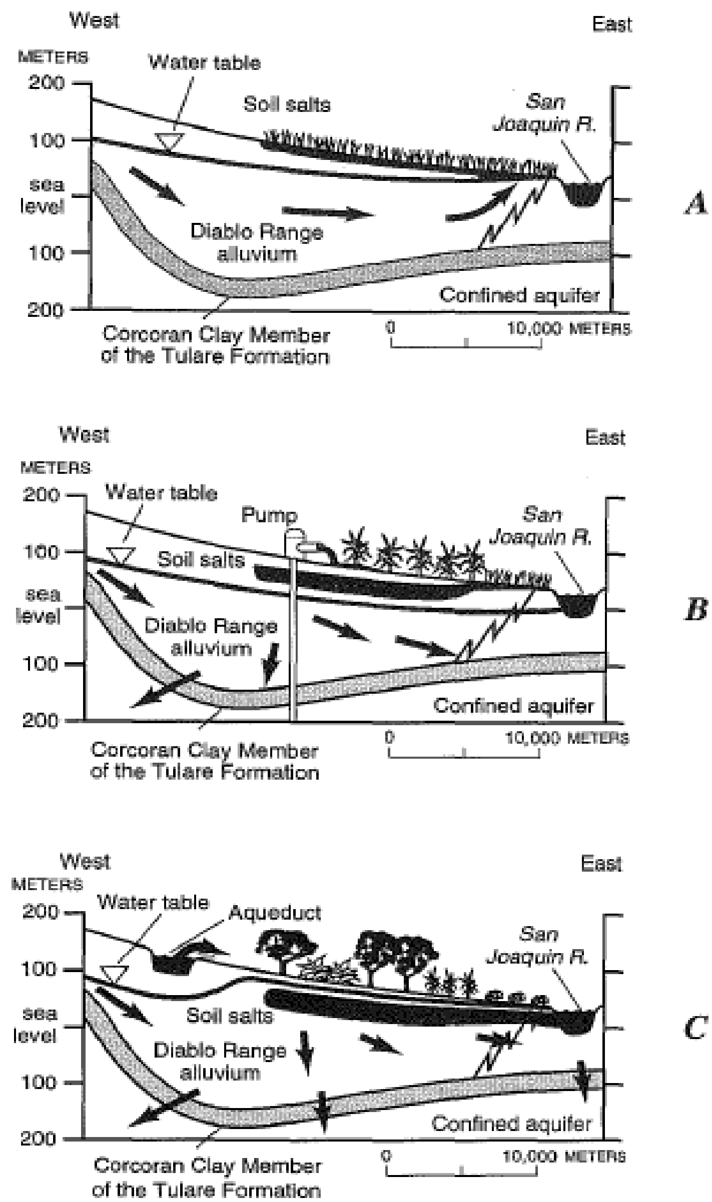

Figure 1. The evolution of the groundwater flow system in the western San Joaquin Valley . Arrows indicate direction of flow. Cross section A shows the shallow distribution of soil salts and primarily horizontal direction of groundwater flow between recharge areas in the upper part of the fan and discharge areas along the San Joaquin River during predevelopment. Cross section B shows the changes in groundwater flow direction and distribution of soil salts from the 1930s through the 1960s. Application of water pumped for irrigation during this period resulted in the redistribution of salts and selenium into the subsurface. (C) Discontinuation of pumping in the late 1960s and application of surface water caused a rise in the water table and the need for subsurface drains that collected highly saline and selenium laden shallow groundwater. (From Deverel et al.1994).

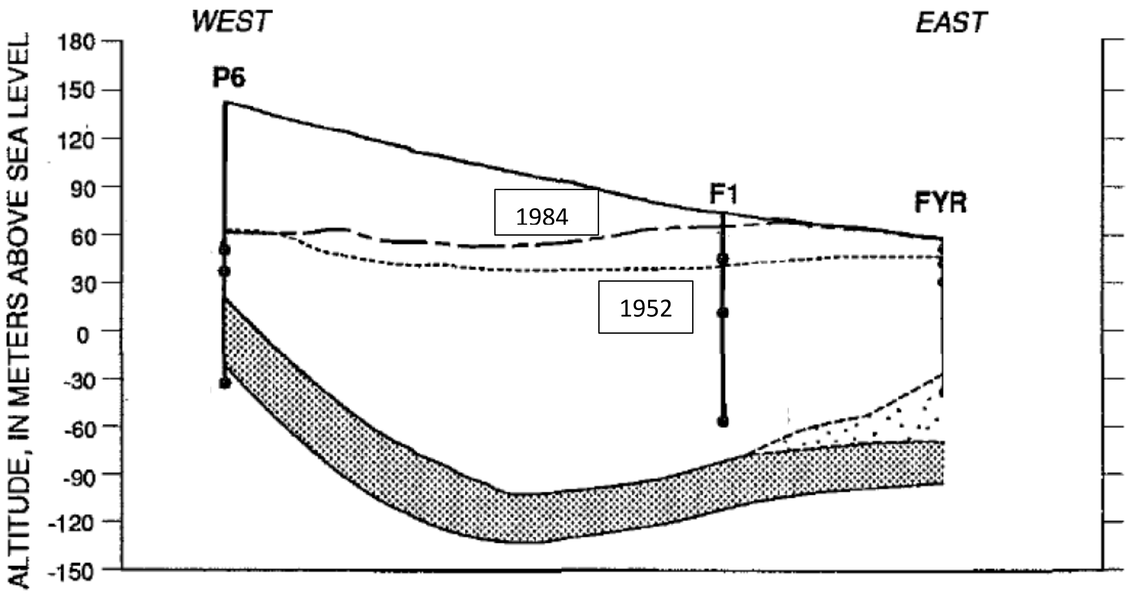

Figure 2. Hydrologic cross section extending from the Panoche Creek alluvial to the western extent of Broadview Water District (from Dubrovsky et al. 1993) showing water table elevations in 1952 and 1984.

Aquifer test results

Aquifer tests were conducted by Ken Schmidt and Associates (1988, 1989). The purpose of the aquifer tests was to determine if pumping large capacity wells tapping the Sierran sands could lower water levels in the overlying shallow groundwater. For both tests, Kenneth D. Schmidt and Associates concluded that the results “indicated good hydraulic communication between the groundwater above a depth of ten feet in fine-grained deposits and under-lying groundwater in course-grained deposits” (Kenneth D. Schmidt and Associates, 1988) and “indicated that pumpage from the Sierran sands could cause water levels at shallow depth to decline” (Kenneth D. Schmidt and Associates, 1989). The pumping wells were about 1 mile north and about 4 miles northeast of Broadview Water District for the two reports.

Kenneth D. Schmidt and Associates (1988) also reported the results of a pump test in Broadview Water District (near Ashlan and Douglas avenues) where 10-ft piezometers were installed in the overlying fine-grained deposits (silty clay, silty sandy clay, and silty clay). The pumping well was screened in the underlying coarse-grained deposits and was pumped for almost 2 days and the maximum drawdown was 45.4 feet. Drawdown in the piezometers ranged from 2 to 2.2 feet. Water levels in the piezometers recovered to within 0.3 to 0.4 foot within 4 hours after the cessation of pumping. Water levels in a monitoring well located 163 feet east of the pumping well dropped 0.7 feet during the pumping test. The results of these tests indicate that shallow groundwater levels change less than those in the deep wells, as expected, but are significant. If the pumping well were instead an injection well and the changes were increases in water levels rather than decreases, these changes are likely significant because a relatively small rise in the water table can affect drain flows or groundwater discharge to surface water. The significant water level change at the distance of 163 feet indicates that water-level increases of that magnitude would be expected from an otherwise similar injection well.

Modeling Results

Belitz et al. (1993) developed a MODFLOW model of the regional groundwater system in the central part of the western San Joaquin Valley which simulates transient flow in the semiconfined and confined zones above and below the Corcoran Clay. The model was developed and calibrated with extensive data collected throughout the western San Joaquin Valley and incorporated areally distributed ground-water recharge, areally and vertically distributed pumping, and on-farm drains in Panoche, Broadview, and Firebaugh Water Districts. The calibrated model reproduced the average change in water-table altitude (1972-84) to within 0.4 foot (the average measured change was 11.5 feet) and the average change in confined zone head (1972-84) to within 19 feet (average measured change was 120 feet). Belitz and Phillips (1995) used the model described in Belitz et al (1993) to evaluate the response of the water table to various management alternatives that affect recharge and discharge from the groundwater flow system. The modeling results demonstrated that if pumping is increased in the Upper and Lower aquifers, (semiconfined and confined zones) the area subject to bare soil evaporation (shallow groundwater areas where the water table is within 7 feet of land surface) and drain flow will decrease. The opposite would also be true—if water were to be injected into wells rather than pumped out, then the water table would rise.

Lithology

The semiconfined zone defined by Belitz et al. (1993) and Belitz and Phillips (1995) (which includes the Upper Aquifer) can be subdivided into three hydrogeologic units: Coast Range alluvium, Sierran sand, and flood-basin deposits (Belitz and Heimes, 1990). The thickness of the Coast Range alluvium is more than 800 ft near the Coast Ranges and thins to O ft near the valley axis. The Sierran deposits are primarily well sorted, medium- to coarse-grained micaceous sands. The flood-basin deposits overlie the Sierran sand and consist primarily of moderately to densely compacted clays. The thickness ranges from 5 to 35 ft (Laudon and Belitz, 1991) based on evaluation of over 400 well logs.

Croft (1972) described the flood-basin deposits and stated that the A clay is a fine-grained lacustrine or paludal deposit composed mainly of plastic silty sandy gypsiferous highly organic clay that is blue, olive brown, or dark greenish gray. The deposit generally is less than 60 feet thick and occurs at a depth of 10-60 feet beneath Buena Vista, Kern, and Tulare Lake beds and parts of Fresno Slough. Consistently, Ken Schmidt and Associates (1997) stated that the A-clay is part of the flood-basin deposits and "normally, this clay is present only near the trough of the valley". Kenneth D. Schmidt and Associates (1997) also stated that the A-clay is normally from about 10 – 30 feet thick and is a locally important confining bed present primarily south of Mendota.

Consistently, LSCE (2020) stated in the Groundwater Sustainability Plan (LSCE, 2020) for the Westside Subbasin stated that "The A and C-Clays are restricted to a narrow band below the Fresno Slough floodplain area (Croft, 1972). The northern extent of these upper Lake Beds is not well known." A northwest-southeast cross section illustrating the groundwater model discretization of the lithology, used in both LSCE (2019) and for the Groundwater Sustainability Plan, does not show the presence of the A, B, C, or D Clays for much of the basin (Figures 3 and 4). Specifically, figures 3 and 4 do not show the presence of the A-Clay in BWD.

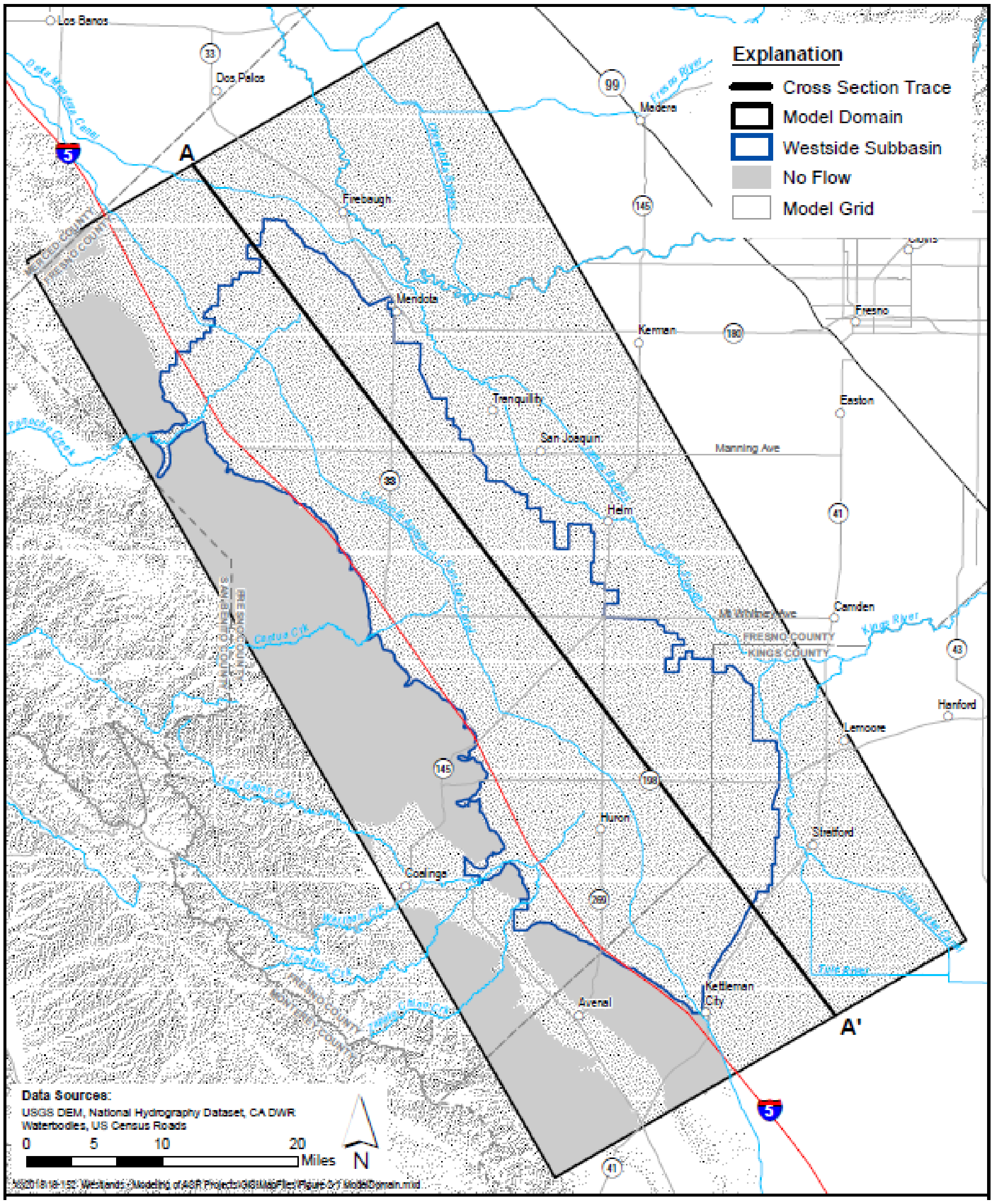

Figure 3. Model domain and map view of cross section A-A' from LSCE 2019 (Figure 2-1) and LSCE 2020 (Figure 3-1).

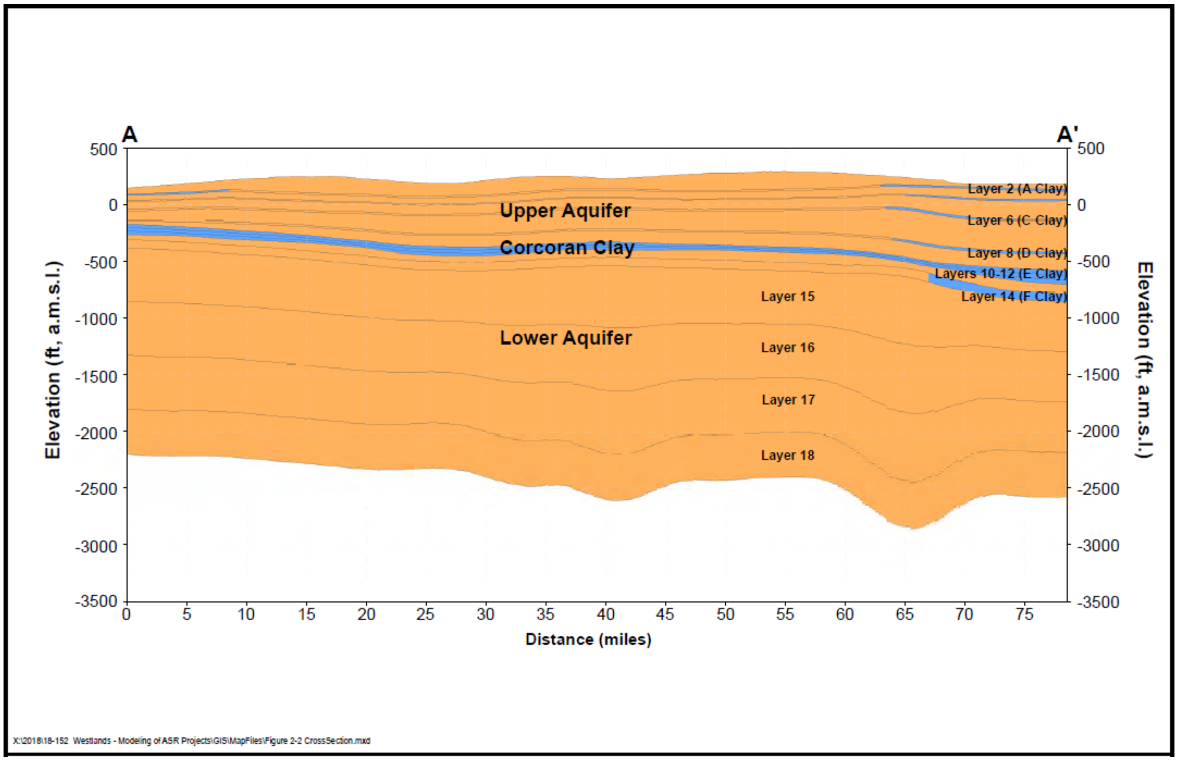

Figure 4. Model vertical discretization through model cross section A-A' from LSCE 2019 (Figure 2-2) and LSCE 2020 (Figure 3-2).

In summary, peer-reviewed studies conducted by the USGS, and reports written by Kenneth D. Schmidt and Associates demonstrate the hydrologic connection within the semiconfined zone of the deep and the shallow groundwater and drainage systems through multiple lines of evidence.

- The evolution of the flow system which included the presence of wetlands and artesian conditions during predevelopment resultant from the discharge of groundwater recharged at the head of the alluvial fans, provides evidence for the hydrologic connection. The subsequent lowering of the shallow groundwater levels during post development pumping and the increase in shallow groundwater levels, which resulted in the need for drainage after the cessation of pumping (Belitz and Heimes, 1990), provide further evidence.
- The results of modeling based on extensive data collection and analysis demonstrate the effect of pumping on shallow water levels and the active hydrologic connection of shallow groundwater and deep parts of the Upper Aquifer (Belitz and Phillips, 1995).
- The documented absence of a continuous confining layer provides further evidence for the hydrologic connection of the deep and shallow parts of the semiconfined zone which includes the Upper Aquifer.

This hydrologic connectivity indicates the potential for increasing shallow groundwater levels with the injection of water into the semiconfined zone.

Question 2. What are the potential effects of increased shallow groundwater levels on water quality?

Westlands stated the following in response to comments with respect to concerns about water quality; "the lands within the BWD were retired from irrigated agriculture and have not discharged drainage water since 2005. The drain lines and shallow wells in the BWD area have been dry since 2007. Further, the Upper Aquifer within the Project area is confined between the A-Clay Layer above and Corcoran Clay Layer below." We find, however, that due to connectivity of the shallow groundwater and Upper Aquifer described previously, increasing groundwater elevations in the Upper Aquifer resultant from injection can increase water levels in the shallow groundwater and potentially reinitiate groundwater flow to drains and surface waters in areas where there are high selenium concentrations.

Selenium is the primary constituent of concern in shallow groundwater. Deverel and Fio (1991) and Fio and Deverel (1991) conducted extensive data collection, analysis, and modeling in an agricultural field underlain by a tile drainage system in BWD to understand the movement of groundwater and transport of dissolved constituents in groundwater associated with agricultural drainage. Monitoring wells were installed in and adjacent to the field with screened intervals centered at about 10, 20, 30, 45 and 90 feet below land surface. About 30 feet of fine-grained deposits were underlain by sand (Figure 3 in Deverel and Fio, 1991). These authors found that the hydraulic gradient was upward from the 45-ft well screened in the sand to the 10-ft well screened in the fine-grained deposits and to drainage laterals. The upward movement of groundwater was driven by water discharging to drainage laterals and to the drainage sump and illustrates the connectivity of the shallow groundwater and the underlying sand within the semiconfined zone. Moreover, hydrographs presented in Figure 4 in Deverel and Fio (1991) show the similarity in temporal changes in groundwater levels in monitoring wells ranging in depth from 3 to 27 meters (9.8 to 88.6 feet).

Figure 1 and Deverel and Fio (1991) illustrate the processes that resulted in high selenium in shallow groundwater in the BWD area and other areas of the Western San Joaquin Valley. Soil salts containing selenium were leached during application of irrigation water prior to delivery of surface water and moved the salts downward into the groundwater. Cessation of pumping and application of imported irrigation water resulted in the increase in shallow groundwater levels which resulted in groundwater containing selenium close to land surface. Evapoconcentration of shallow groundwater increased selenium concentrations. Drainage systems were installed to lower the groundwater table and these systems collected the evapoconcentrated water containing high selenium concentrations.

Selenium concentrations reported by Deverel and Fio (1991) for the BWD study ranged from 10 to 1,100 micrograms per liter. Concentrations in samples collected in 1987 and 1988 in the wells screened in the sand underlying the fine-grained deposits (denoted as clay loam in Deverel and Fio,1991) ranged from 270 to 1,100 micrograms per liter. Selenium concentrations in two samples collected from the 27-m well were 480 and 400 micrograms per liter.

The sources of groundwater to the drainage laterals were delineated using tritium and stable isotopes of oxygen and hydrogen. The results of this analysis demonstrated the temporal variability in the sources of water to drainage laterals. During baseflow, non-irrigated conditions, deeper and older groundwater within the sand layer (more than 30 feet below land surface) was a substantial source of drain-water, ranging from 30 to 60% (Fio and Deverel, 1991). Concentrations in samples collected in wells installed in this deeper groundwater had higher selenium concentrations than the shallowest groundwater. Using groundwater flow modeling and particle tracking and the results of the geochemical analysis, Fio and Deverel (1991) estimated deep groundwater travel velocities of 40 to 55 feet per year to drain laterals.

Considering the slow movement of groundwater, it is highly probable that high selenium concentrations measured in groundwater within the coarse-grained deposits in the BWD are still present. Also, the soil and aquifer matrices can be a continuing reservoir of selenium and other solutes. As evidence of persistent high concentrations, HydroFocus (2006) collected samples in 2003 which were analyzed for selenium and other trace elements from 20 wells initially sampled in 1984 (Deverel et al. 1984). These wells ranged from 18 to 30 feet deep. Analysis of the two sampling events 19 years apart indicated no statistically significant differences between sampling events for concentrations of boron, molybdenum, selenium, or salinity as represented by electrical conductivity (HydroFocus, 2006).

In conclusion, if groundwater levels increase as the result of the BWD ASR project, there is the potential for movement of high-selenium groundwater to drainage systems and surface waters in adjacent areas. Higher groundwater levels can potentially reinitiate flow in drainage laterals, which can become discharge points for high-selenium groundwater.

Question 3. How effective is the regional LSCE model used in the 2019 MND for simulating the BWD ASR Project?

Westlands offered the following response to comments. “The modeling performed for the ASR Program including the BWD area showed that after 3 consecutive years having injection periods, water levels in the Upper Aquifer near four composite ASR wells in the northeast portion of the District (which includes lands within BWD; Report of Waste Discharge (RWD) Appendix E, Figure E-3C), would be at approximately 205 feet elevation versus a ground surface elevation of 240 feet, i.e. the pressure would still be negative 35 feet relative to ground surface. Therefore, in addition to the physical barriers to movement from the Upper Aquifer to the shallow zone (~200 feet of clay), the modeling referenced in the MND shows that even during maximum injection conditions, there would not be sufficient driving pressure to raise the shallow water table into tile drains or surface waters”.

Based on the available documentation, the proposed BWD ASR well was not simulated in the LSCE model. Figure 5 shows the proposed location of the BWD ASR well which was not included among the ASR wells simulated in the LSCE model. It is unclear what area is referred in Figure E-3C in the Westlands response to comments. In Figure E-3C, simulated groundwater elevations within BWD range from 150 – 190 feet above sea level. Based on Google Earth imagery, land surface elevations range from about 178 to 212 feet above sea level, much less than the 240 feet claimed in the Westlands response.

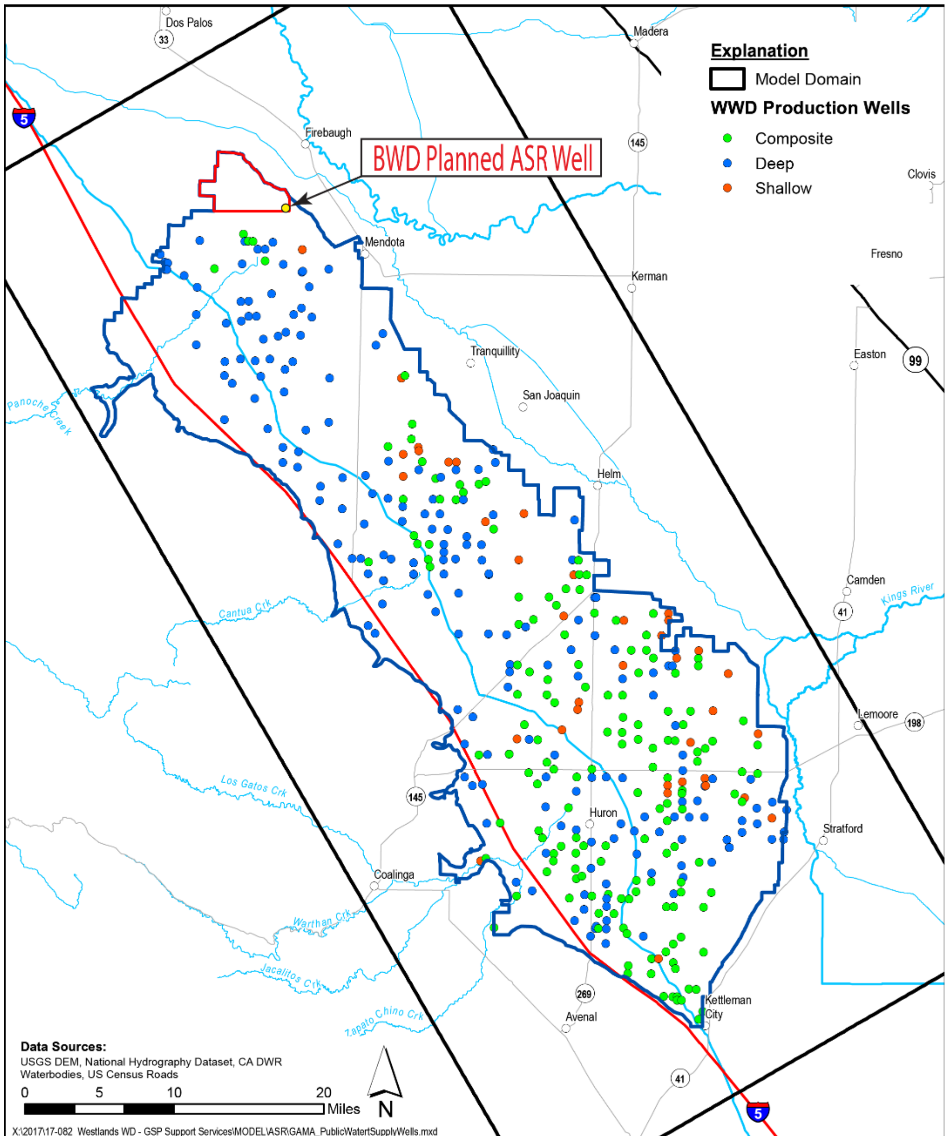

Figure 5. Locations of ASR wells simulated in the LSCE model (modified from Figure 3-2 in LSCE, 2019). The area outlined in red is BWD. The planned ASR well within BWD was not included in the original Figure 3-2.

As stated above, the available evidence discussed above indicates that the A-clay is not present in BWD and there are multiple lines of evidence for the connection between the shallow and deep zones within the semiconfined zone. Moreover, LSCE (2019, 2020) did not include a continuous A-clay in the groundwater flow model and the A-clay is absent in the BWD area (figures 3 and 4). In addition, LSCE (2019) stated that "The assignment of model hydraulic properties is based on a stochastic model of subsurface hydrofacies architecture […] in locations where there is no subsurface data included in the conditional simulation, the arrangement of low and high permeability material is determined by a random process and likely not representative of local geology […]"

We could find no indication that drains were simulated in the model using the Farm Package or the MODFLOW drain package. Thus, it appears that the model did not account for the tile drain systems in BWD and the drainage systems in the immediately adjacent Firebaugh Canal Water District. The lack of drain flow simulation would likely result in inaccurate simulation of groundwater elevations and down-gradient groundwater-surface water interactions.

LSCE (2020) reported a calculated root mean squared error (RMSE) of 60.5 ft and mean absolute error (MAE) of 40.3 ft for their model (LSCE, 2020). Figure 4-4 in the LSCE report, which shows graphs of simulated versus observed groundwater elevations, shows a root mean square error (RMSE) of 45.8 ft and NRMSE (normalized RMSE) of 6.3%. The RMSE (or standard deviation) is thought to be the best measure of model error if errors are normally distributed (Anderson and Woesner, 1992). Thus, the LSCE model generally predicts groundwater elevations within plus or minus about 45.8 ft. The LSCE report also states: "Maps of the average residuals at the calibration wells shows that the model overpredicts groundwater levels in the wells in the southern portion of the model domain while the average residual error suggests simulated heads are generally lower than observed in the norther portion of the Subbasin" (LSCE, 2020; Figure 4-5). This suggests that groundwater levels in the BWD would be higher than the current simulation results.

Considering the uncertainty in the model-calculated water levels, it is important to express the uncertainty in estimated groundwater level changes resultant from aquifer injection based on a sensitivity analysis. We could not find evidence that a sensitivity analysis was conducted for the LSCE (2019) model. The purpose of a sensitivity analysis is to quantify the uncertainty in the calibrated model caused by uncertainty in the estimates of aquifer parameters, stresses, and boundary conditions. A sensitivity analysis is an essential step in all modeling applications (Anderson and Woesner, 1992). It is a means to identify the model inputs that have the most influence on model calibration and predictions and can provide users with an understanding of the level of confidence in model results (ASTM, 2017), especially in the BWD area where there were few wells used for calibration. There were no calibration wells within the BWD. There was one calibration well about 1 mile south and another about 2 miles northwest of BWD.

In conclusion, the available information indicates that more work is required to effectively simulate the Broadview ASR project. There are four apparent model deficiencies. First, based on the available documentation, the LSCE model did not simulate the proposed BWD ASR well. Second, the LSCE model is based on a paradigm of discontinuity between the deep and shallow zones within the semiconfined zone. This contrasts with peer-reviewed modeling results presented by Belitz et al. (1993, 1995) and evidence described above under question 1. Third, the LSCE model does not explicitly simulate agricultural drains for the areas east of BWD where drains collect shallow groundwater and, based on Deverel and Fio (1991), influence groundwater flow in the semiconfined zone. Fourth, sensitivity analysis is missing which can provide an understanding of the level of confidence in model results. Data collection in conjunction with an ASR well test will be essential for addressing these three issues. We conclude that the LSCE model in its current form is not an appropriate tool to effectively assess hydrologic and water quality effects related to the BWD ASR well.

Question 4. What monitoring should be implemented if injection moves ahead?

Proposed Monitoring

The Monitoring and Reporting Program (MRP) for the Westlands ASR project submitted to the Regional Water Quality Control Board states that monitoring will record injection well operations, how many days injections occur, the daily average injection rate, and the cumulative volume of water injected for each injection well in the program. Injection water will be sampled and analyzed monthly for pH, EC, TDS, general minerals, arsenic, total coliform, giardia, cryptosporidium, other primary bio-indicators, and total trihalomethanes. The injection water will be sampled and analyzed quarterly for total chromium, uranium, and vanadium. The average pumping rate and volume of extracted water will be continuously recorded for all extraction wells used injection and/or recovery during the previous or current calendar year. These wells will also be sampled quarterly for pH, EC, TDS, total coliform, and general minerals. Arsenic, total chromium, uranium, vanadium, giardia, cryptosporidium, other primary bio-indicators, and total trihalomethanes will be sampled quarterly for the first 2 quarters of recovery after the first injection period and then once three months after each time recovery begins. If an MCL is exceeded or giardia or cryptosporidium are detected, then quarterly sampling will continue through the next recovery period. We note the MCL for Selenium is 50 ppb and not protective of fish and wildlife and other beneficial uses.

Nearby drinking water wells and other wells influenced by ASR process (determined by modeling or monitoring) will be part of the groundwater quality monitoring network. These wells will be sampled and analyzed quarterly for pH, EC, TDS, nitrate, arsenic, boron, iron, manganese, sulfate, and total coliform. These wells will be sampled and analyzed annually for giardia, cryptosporidium, other primary bio-indicators, and total trihalomethanes.

Recent monitoring

We could find no recent monitoring data for water levels or drainage in BWD or vicinity. Agricultural drainage related monitoring conducted under the auspices of Grasslands Bypass Project includes the collection and analysis of surface-water samples in the San Luis Drain, Mud Slough, wetlands channels, and the San Joaquin River. As per the most recently available monitoring report (Summers Engineering, 2021), approximately 10,800 acre-feet of drain water was discharged through the San Luis Drain to Mud Slough that originated from the Grasslands Drainage Area which includes BWD. Measures to eliminate irrigation-related discharges with the GDA include irrigation improvements, drainage recirculation, drainage reuse and short-term storage basins. However, shallow groundwater levels throughout the westside of the San Joaquin Valley causes seepage into the San Luis Drain, which are ultimately discharged to Mud Slough throughout the year. Also, storm-induced discharges from the GDA tend to have elevated levels of selenium (Summers Engineering, 2021). Therefore, increased shallow groundwater levels within BWD and the surrounding area could potentially increase flow and selenium transport to the San Luis Drain and Mud Slough.

Figure 6 shows the most recent depth-to-groundwater (DTW) measurements retrieved from CASGEM for wells in and near the BWD with a total well depth of no more than 30 feet. The planned ASR well within BWD is plotted in the southeast corner of BWD. The water levels in wells within and near BWD were last measured in 2009. In the well within BWD, the depth to groundwater was measured at 11.6 feet below land surface in 2009. In the monitoring well nearest to the planned ASR well, the measured depth to groundwater was 14.1 feet. The average depth to water in the five wells within, or on the immediate edge of, the BWD was 10.7 feet. Considering that irrigation ceased and there was no drain flow in BWD after 2005 as per the Westlands response letter, the 2009 groundwater level data indicate that in the absence of water application, shallow groundwater levels likely persist. Injection of water into the BWD ASR well could increase the shallow groundwater levels and potentially reinitiate drain flow in BWD and increase shallow groundwater movement to Mud Slough. Monitoring should address this possibility.

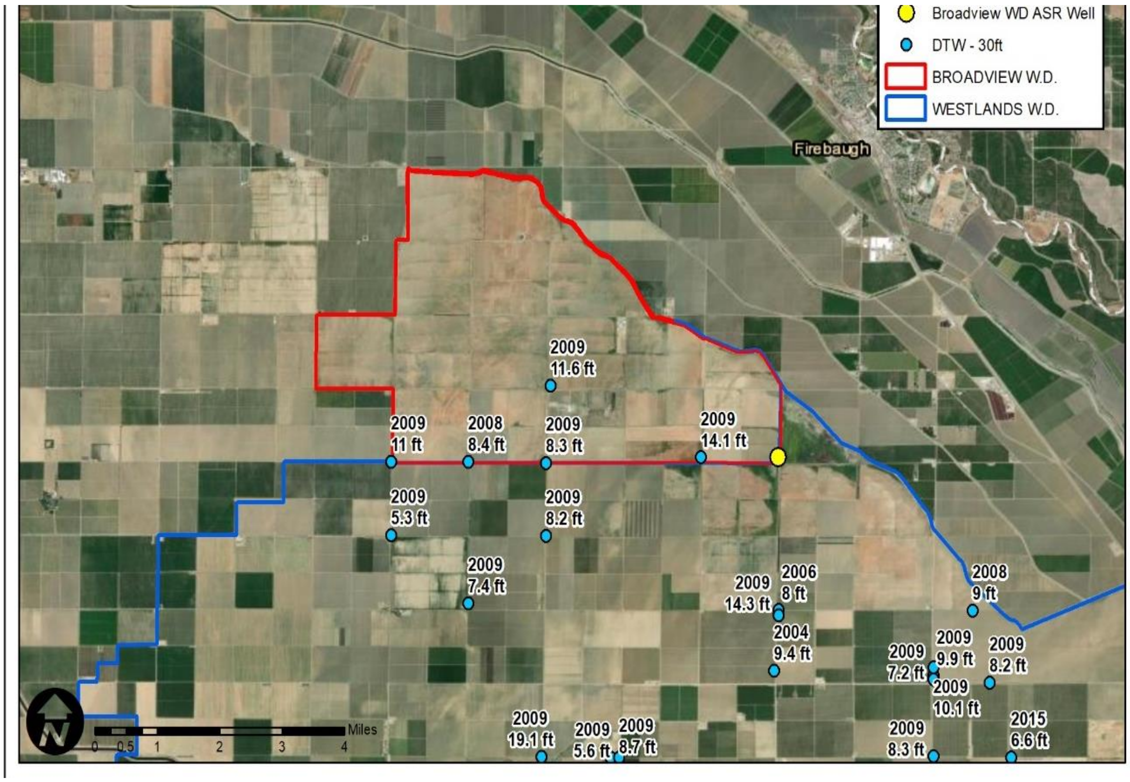

Figure 6. Most recently reported depth-to-groundwater measurements in wells <30ft deep in and around BWD. Groundwater measurement data was provided by CASGEM.

Recommended monitoring

Based on the study results described previously, injection of water into groundwater wells can induce changes in the shallow groundwater and laterally in the semiconfined zone. Therefore, we recommend that monitoring of the hydraulic effects of aquifer storage and recovery be designed to evaluate vertical and horizontal effects of injection and pumping. Piezometers should be installed adjacent to ASR wells to varying depths ranging from 10 to 50 feet below land surface at varying distances from the well up to about 200 feet. We recommend that groundwater levels be monitored continuously using transducers. This will provide insight about the processes affecting ground levels changes and the potential for reinitiating drain flow.

Moreover, regular water-level monitoring of monitoring wells within the BWD area should be undertaken to assess potential regional effects. Groundwater quality samples should be collected from the piezometers to assess the levels of salinity and selenium and other constituents of concern identified within the Grasslands Bypass Project. Considering the shallow groundwater levels that likely exist within area adjacent to the proposed ASR well, drain flow and quality within BWD and Firebaugh Canal Water District should be monitored during the injection period. Groundwater hydrologic data can be used to compare with modeling results and thus provide an opportunity for model modification and validation.

Implications

The Broadview-ASR groundwater related issues illustrate the hydrogeologic heterogeneity within the Westside Subbasin and the need for monitoring which accounts for this spatial variability. The primary goal of SGMA is to bring this and other groundwater basins into hydrologic balance. Aquifer storage and recovery projects represent a proposed solution for achieving this goal and the continuation of irrigated agriculture in these basins. As shown above, injection can potentially induce consequences beyond those intended or considered within the proposed project monitoring plan. The monitoring recommended here can provide essential insight into potential hydrologic changes within the shallow groundwater system as related to SGMA activities.

Conclusions

Multiple studies demonstrate the hydrologic connection within the semiconfined zone of the deep and the shallow groundwater and drainage systems. This connection is evidenced by the hydrologic changes in the evolution of the flow system which resulted in groundwater level changes in the deep and shallow parts of the semiconfined zone. Results of modeling based on extensive data collection and analysis show the effect of pumping on shallow water levels. The absence of a continuous confining layer provides further evidence for the hydrologic connection of the deep and shallow parts of the semiconfined zone which includes the Upper Aquifer. This hydrologic connectivity indicates the potential for increasing shallow groundwater levels with the injection of water using ASR wells.

Peer-reviewed results of data collection and modeling in BWD indicate that groundwater levels will likely increase as the result of the BWD ASR project. If groundwater levels increase, there is potential for movement of the high-selenium groundwater to drainage systems and surface water within BWD and in adjacent areas. Higher groundwater levels can potentially reinitiate flow in drainage laterals and discharge to surface waters of high-selenium groundwater.

The regional LSCE model used in the 2019 MND has some structural shortcomings for simulating the BWD ASR Project. First, the available information indicates that the LSCE model does not include the proposed BWD ASR well. Second, the LSCE model is based on a paradigm of discontinuity between the deep and shallow zones within the semiconfined zone which contrasts with previous peer-reviewed studies and modeling results. The LSCE model provides no documentation for the existence of this discontinuity in the BWD area. Third, the LSCE model does not explicitly simulate agricultural drainage. Fourth, there lack of uncertainty analysis that can provide an understanding of the level of confidence in model results.

Lastly, if the Broadview ASR project proceeds with injection and pumping cycles as planned, hydrologic and water-quality monitoring should be implemented to assess the impacts of the project on shallow groundwater, drainage, and potentially discharges to surface waters.

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