



November 6, 2014

Kevin M. Kauffman, P.E.  
Eastside Water District, Acting General Manager  
P.O. Box 692632  
Stockton, California 95269-2632

Dear Mr. Kauffman:

**Subject: Eastside Water District – Geologic, Hydrologic, and Hydrogeologic Characterizations for Potential Managed Aquifer Recharge of Diffused Stormwater**

In accordance with our Contract, Wood Rodgers, Inc. (Wood Rodgers) is pleased to submit this letter report that details our Geologic, Hydrologic, and Hydrogeologic Characterizations for Potential Managed Aquifer Recharge (MAR) of Diffused Stormwater. This report is the major deliverable for this project.

### **Introduction**

Eastside Water District (EWD) solicited qualifications in April 2014 for a design effort to develop MAR for what has been identified as up to 60 cfs' of inflow into the Highline Canal. This specific stormwater is considered runoff, or "diffused" overland flow, that has not or will not gather to a natural watercourse. Turlock Irrigation District (TID) operates 49 inlets into its Highline Canal, which passively allows this diffused overland flow to enter the canal in order to protect its levees from erosion or damage. EWD has conducted four earlier studies on the development of groundwater recharge via MAR in: 1990 (Boyle Engineering Initial Site Identification), 1995-1996 (Boyle Engineering and Ken Schmidt), 2003 (Joe Marcotte and Ken Schmidt), and aspects of an October 2003 study by Psomas.

Wood Rodgers and E-PUR LLC (Project Hydrogeologists) collaborated to provide EWD with hydrologic, geologic, and hydrogeologic site characterization. The objective of this study was to identify suitable locations for intercepting diffused stormwater and direct it to potential MAR facilities. One of the objectives of this project was to develop data and information needed to support Provost & Pritchard (Project Engineer) in completing a 30% design of MAR facilities across EWD and also areas within TID and the Ballico-Cortez Water District (Study Area). This letter report summarizes work efforts of the Project Hydrogeologists. Electronic files of our data

will be sent to EWD for the design effort currently being conducted by the Project Engineer and for future projects.

The Project Hydrogeologists provided a proposal to EWD to complete six tasks to characterize the hydrologic, geologic, and hydrogeologic potential for MAR sites, particularly in the area of the Highline Canal. These tasks are detailed below:

Task 1 – Groundwater Elevation Contour and Depth Maps

Task 2 – Evaluate Diffused Stormwater Flow to TID Canals and Existing Ponding Areas

Task 3 – Subsurface Sediment Texture Analysis and Estimated Hydraulic Conductivity

Task 4 – Geologic Cross-Sections of Eastside Water District and Adjoining Regions

Task 5 – Surface and Shallow Subsurface Soil Mapping of Area

Task 6 – Develop MAR Site Selection Criteria and Prospective MAR Site Locations

The methods, analyses, and recommendations for each task is reported in the following sections, followed by a section of Recommendations of additional steps anticipated for final design in the areas of geologic, hydrologic and hydrogeologic assessment.

### **Task 1 – Groundwater Elevation Contour and Depth Maps**

The Project Hydrogeologists assessed data to evaluate groundwater elevations over time and current depth to groundwater. The Project Hydrogeologists developed time-series plots of groundwater elevations (hydrographs), groundwater elevation contour maps, and a map of depth to groundwater in 2014 for the Study Area.

EWD is located within the Turlock Groundwater Subbasin (Subbasin) of the San Joaquin Valley Groundwater Basin. The Turlock Groundwater Basin Association (TGBA) maintains a database of wells throughout the Subbasin to monitor groundwater elevation changes and for California Statewide Groundwater Elevation Monitoring (CASGEM) compliance. The TGBA database is managed and maintained by TID. The Project Hydrogeologists acquired this database from TID at the request of EWD and also obtained data from the Modesto Irrigation District and the City of Modesto on select groups of wells along and near the north side of the Tuolumne River. The Project Hydrogeologists also acquired CASGEM data for wells located throughout the Subbasin from the California Department of Water Resources (DWR) Water Data Library (WDL) online database.

A number of CASGEM monitored wells were selected throughout the EWD study area to assess historic and current groundwater elevations. The locations of these wells, along with their historic groundwater levels, are shown in Figure 1A. Groundwater levels within EWD (and within TID) have experienced significant declines over a 50-year period of record from the mid 1960's through 2014. Groundwater levels have declined 50 to 70 feet in the western and central portions of the EWD. Water level declines have been more severe in the eastern portion, with declines of up to 85 feet. The average annual rate of groundwater decline from wells located in the western and central portion have been observed to be between 1 and 2 feet per year. In the eastern portion, the annual rate of groundwater decline has been estimated at 1.5 feet per year from 1971 to 2000, and 3.8 feet per year from 2000 to 2011, as illustrated within the hydrographs shown on Figure 1A.

For analysis of area-wide historic groundwater elevations, Steven Phillips of the United States Geological Survey (USGS) was consulted regarding his groundwater modeling efforts in the region (Phillips, 2007). Mr. Phillips noted that groundwater elevations have been in continuous decline through 2004 (the period of record). The USGS groundwater model was initiated on groundwater elevations observed and interpreted for the year 2000. These groundwater elevations are a good representation of historic groundwater elevations for the Subbasin. Figure 1B depicts the groundwater elevations contoured from the groundwater model data-set for the year 2000. Groundwater elevations in 2000 indicate a depression in groundwater beneath EWD that extends westward under TID. The groundwater elevations indicate a groundwater mound around Delhi that may be a result of canal leakage in the area. The groundwater contours also indicate that the Merced River is generally discharging to groundwater but with a reversal to a gaining stream southwest of the EWD associated with the mounding near Delhi. This groundwater mound and the associated groundwater movement toward EWD and the Merced River, demonstrated by Figure 1B, is a key feature for the MAR project. Our assessment of groundwater movement is discussed further under Task 6 in the evaluations for site identification and site selection.

To analyze historic lows for groundwater elevations, the historic trends indicated that the most recent data collected under CASGEM and other Subbasin monitoring efforts represent the historic low. Thus, spring 2014 data were used to evaluate groundwater elevations and depths to groundwater. From the groundwater elevation data acquired for this study, a subset of wells were selected for analysis. Contouring of groundwater elevations from April and March 2014 data was accomplished using natural-neighbor interpolation for the wells depicted on Figure 1C; natural neighbor interpolation uses only local data points and thereby does not overestimate or underestimate the interpolated values. Figure 1C depicts spring 2014 groundwater elevation data beneath the Study Area. Groundwater elevations in spring 2014 indicate two groundwater depressions, one beneath EWD and one beneath TID and the City of Turlock. Similar to the 2000 contours, the groundwater elevations in 2014 indicate a groundwater mound around Delhi. The

dataset of groundwater elevations and wells for this study does not extend to the Merced River and thus a data gap exists as to whether the Merced River is discharging to groundwater or gaining from groundwater south of EWD (for example, where the Highline Canal turns at South Avenue).

The depth to groundwater is a critical consideration for artificial recharge projects. If there is no room for additional groundwater storage, recharge projects are not needed and could be detrimental. Groundwater recharge projects have the potential to bring the groundwater table to near the land surface, which can cause a variety of problems to infrastructure and crops. To evaluate the depth to groundwater, the data from the field measurements in spring 2014 were contoured directly rather than subtracting groundwater elevations from land surface elevations. Land surface elevations are usually taken from a digital elevation model (DEM) and the field data were of higher precision than a DEM, even though the heights of some of the measurement points above land surface are unknown. Figure 1D provides contouring of the depth to water measurements. The potential to have groundwater mounding near the land surface does not appear likely along the Highline Canal, as depths to groundwater is greater than 70 feet as compared to Delhi, where groundwater is approximately 20 feet below land surface. This assessment does not take into consideration the potential to create perched water on top of impermeable or very low permeable formations. Soil assessments with exploration drilling will be imperative to characterize the potential to create perched water layers.

## **Task 2 - Evaluate Diffused Stormwater Flow to TID Canals and Existing Ponding Areas**

The ground surface that slopes toward the Highline Canal within the EWD boundary was modeled in GIS using the National Elevation Dataset 1/3 arc second (10 meter) grid. The grid was projected from the horizontal datum NAD83 (North American Datum 1983) in meters to NAD83 in feet, which converted the grid size to approximately 33 feet by 33 feet. The elevation values of the grid were converted from vertical datum NAVD88 (North American Vertical Datum of 1988) in meters to NAVD88 in feet and presented in Figure 2A (located as a plate in the Appendix). The Highline Canal alignment and inlet gate locations were provided by TID in the AutoCAD drawing file format and were converted to GIS Shapefiles for this analysis.

The watersheds that drain from east to west were analyzed using the converted elevation data set above to determine the watershed extents and the breaks between watersheds that flow to the existing inlet gates along the Highline Canal, as shown in Figure 2B (located as a plate and table in the Appendix). The ESRI ArcHydro data model and tools were implemented to automate the delineation of the watersheds. The 33 foot grid resolution was too coarse to depict the high ground of the canal banks that would impound runoff flowing west, so a visual inspection was conducted to refine the watershed boundaries at the canal alignment location. Aerial imagery was used to identify open, unplanted locations, adjacent to the existing inlet gates that could serve as potential MAR pond sites. The pond sites were delineated in GIS based on the extents of the

unplanted areas in the aerial imagery. These ponds or existing detention areas are also shown in Figure 2B.

### **Task 3 – Subsurface Sediment Texture Analysis and Estimated Hydraulic Conductivity**

The Project Hydrogeologists developed a detailed hydrogeologic evaluation of the ground beneath EWD using sediment-texture analysis. Sediment-texture analysis was developed as a scientific and engineering methodology by the USGS and researchers at the University of California at Davis in the 1990s. It was subsequently used on a wide scale by the USGS for estimating hydraulic conductivity of geologic layers in their 2009 Central Valley Hydrologic Model (CVHM). From that study and others, there is a large set of existing Percent-Coarse data points in the region.

The Project Hydrogeologists set out to augment the existing Percent-Coarse data of the Modesto to Turlock area with areas close to EWD that needed more data for estimating purposes. To accomplish this, the Project Hydrogeologists acquired DWR Well Completion Reports (WCRs) in the area of interest via a letter request for those confidential records. Where there were apparent data gaps within and near EWD, the WCRs were carefully vetted for those that could be precisely located (i.e. within a quarter of a quarter Section) and those with higher quality lithologic logs. This was done over an area roughly 10 miles by 10 miles in size. In addition to the WCRs, EWD provided 29 boring logs from testing it had conducted in 1996 and 2003 within and just south of EWD. The locations of the lithologic data beneath and around EWD are shown on Figure 3A, both those created for this study and those obtained from the USGS CVHM study.

EWD logs and the higher quality WCR lithologic data were located laterally and reduced into a database with the lithologic data classified via the USGS method. The lithologic data was then reduced to sequential vertical packets of estimated Percent-Coarse over 15-foot intervals. These newly generated Percent-Coarse data developed by the Project Hydrogeologists were combined with the previously existent USGS Percent-Coarse data throughout the region provided by the USGS at 50-foot vertical intervals. From this more comprehensive data, we applied geostatistical analysis of the coarse- and fine-grained sediment textures to assess the patterns and spatial trends within the data. The sediment-texture modeling was to have been done using the Stanford Geostatistical Modeling Software (SGeMS) for geospatial modeling; however, it was found that SGeMS was unable to perform ordinary block-kriging, the type of geospatial modeling called for by the trends in the data, on the grid size selected for horizontal resolution. The geostatistician working with the Project Hydrogeologists, Dr. Bill Huber, developed and tested a software program that performed ordinary block-kriging for the geospatial estimates of Percent-Coarse throughout a roughly 40 mile by 40 mile area. The geospatial data model utilized both vertical samplings of lithologic data at 15-foot and 50-foot to arrive at a sediment-texture model in three dimensions that estimates the Percent-Coarse.

Ground surface elevations were incorporated into the sediment-texture model from a DEM of the area. Other vertical controls applied to the sediment-texture model were the groundwater elevations in the year 2000 (Phillips, 2007), the regional depth to the top of the Corcoran Clay as the first group of water bearing intervals or similar depth where the Corcoran Clay is not present such as beneath EWD, and the estimated bottom of the sedimentary aquifer in the region as the second group of water bearing intervals.

The sediment-texture model provides a semi-continuous estimate of regions with the highest probability of good connection to the water bearing zones at and near ground surface.

A probable hydraulic-conductivity value was then assigned to the Percent-Coarse estimates for three depth-based intervals to aid in site selection and characterization: (1) just below land surface (e.g. 7.5-feet), (2) the unsaturated zone, and (3) the interval of the first groundwater bearing zone. Using the vertical controls of depth to groundwater and the depth of the first water-bearing intervals, hydraulic conductivity of the subsurface and near surface was then estimated from the sediment-texture model.

Horizontal hydraulic conductivity, represented as  $K_h$ , was estimated using methodology developed by the USGS in CVHM (Faunt, 2009). Relative values of horizontal hydraulic conductivity for different sediment textures were calculated across EWD for each cell within the Percent-Coarse texture model.

$$K_h = K_c F_c + K_f F_f$$

*where:  $K_h$  represents the horizontal hydraulic conductivity for the Geolayer*

*$K_c$  represents the hydraulic conductivity of the end member for coarse*

*– grained sediments; value of  $820 \text{ ft}/\text{day}$  used (Faunt, 2009)*

*$K_f$  represents the hydraulic conductivity of the end member for fine*

*– grained sediments; value of  $0.24 \text{ ft}/\text{day}$  used (Faunt, 2009)*

*$F_c$  represents the Percent Coarse as a fraction*

*$F_f$  represents the Percent Fine as a fraction*

For horizontal hydraulic conductivity of the subsurface, Percent-Coarse estimates were averaged arithmetically over the unsaturated zone and over the first water-bearing intervals weighted by the layer thickness in the texture model using published methods (Maasland, 1957).

$$K_h = \frac{\sum_{i=1}^n K_i * d_i}{D}$$

where:  $K_h$  represents the horizontal hydraulic conductivity for the Geolayer

$D$  represents the GeoLayer thickness

$d_i$  represents the cell thickness

$K_i$  represents the cell horizontal hydraulic conductivity

For example, there are 44 layers in the unsaturated zone of the texture model and the  $K_h$  for each layer was computed and then the thickness-weighted arithmetic average was calculated. The resulting estimates of  $K_h$  across EWD and the surrounding area are provided in GIS Shapefiles accompanying this report.

For vertical hydraulic conductivity, represented as  $K_v$ , the estimating method developed by the USGS in CVHM (Faunt 2009) was utilized to calculate relative vertical hydraulic conductivity across EWD. This was done for each cell within the Percent-Coarse texture model via the following formula.

$$K_v = [K_c^p F_c + K_f^p F_f]^{\frac{1}{p}}$$

where:  $K_v$  represents the vertical hydraulic conductivity

$p$  represents the averaging power mean exponent

[for the San Joaquin Valley, this value was given as (-0.8)]

and  $K_c, K_f, F_c, F_f$  as previously defined

For vertical hydraulic conductivity of the subsurface, Percent-Coarse estimates were averaged following the equation for an averaging power mean exponent between that of a harmonic mean (conventional at  $p = -1.0$ ) and a geometric mean ( $p = 0$ ) for each individual layer in the texture model. The resulting value of  $K_v$  is calculated by taking a weighted harmonic mean of the individual values where the weighting was again the individual layer thickness.

$$K_v = \frac{D}{\sum_{i=1}^n \frac{d_i}{K_i}}$$

where:  $K_v$  represents the vertical hydraulic conductivity for the Geolayer

$D$  represents the GeoLayer thickness

$d_i$  represents the cell thickness

$K_i$  represents the cell vertical hydraulic conductivity

For example, there are 44 layers in the unsaturated zone of the texture model and the  $K_v$  for each layer was computed and then the layer-thickness-weighted harmonic mean calculated. The resulting estimates of  $K_v$  across EWD and the surrounding area are depicted on Figures 3B and 3C for the near surface and unsaturated zone, respectively.

The estimates of vertical hydraulic conductivity for the unsaturated zone do not represent rates of percolation, but rather they represent the relative ability of different areas to percolate water. On Figures 3B and 3C, the blue coloring represents areas where water will percolate more rapidly than the brown areas. The estimates of hydraulic conductivity are modeled on a relative basis and likely do not represent the absolute values. It is anticipated that clay and duripan areas will have even lower values than estimated here and that areas with coarse sand to gravel near the surface will have higher values. It is our professional judgment that in utilizing the calibrated values of vertical hydraulic conductivity from CVHM textural modeling, that the hydraulic conductivity for soils and sediments between the high and low values for Percent-Coarse are well represented. Comparison of the regional model hydraulic conductivity values derived in this study using CVHM (Faunt 2009) and those hydraulic conductivity values resulting from USGS local textural model (Phillips 2007) are favorable, 0.24 feet/day vs. 0.46 feet/day for vertical conductivity of the fine-grained end member (meaning only silt and clay with no sand). These estimates of vertical hydraulic conductivity are shown in Figure 3C in particular have been utilized in Task 6 to identify the locations for MAR facilities that are best suited to conveying water more rapidly into the subsurface.

Each of these  $K_v$  estimates has a projected estimation error associated with it from the geospatial modeling; the smaller that estimation error the more confidence we have in the prediction. Figure 3D depicts the estimation error for  $K_v$  in the unsaturated zone via transparency; the more visible the  $K_v$  estimate the lower the error, and the darker the background the higher the uncertainty in the predicted values. These vertical hydraulic conductivity estimates were generated as GIS Shapefiles along with the  $K_v$  for the first-water bearing interval and are attached to this report.

#### **Task 4 – Geologic Cross-Sections of Eastside Water District and Adjoining Regions**

The Great Valley of California is an asymmetrical trough filled with Mesozoic (deposited 248 million years ago [mya] to 99 mya) and Cenozoic (65 mya to present) sediments that reach a thickness of approximately 30,000 feet. The Great Valley consists of the Sacramento Valley in the north and the larger San Joaquin Valley in the south. The San Joaquin Valley represents the lower two thirds of the Great Valley and is approximately 200 miles long and up to 70 miles wide, bound on the north by the Sacramento-San Joaquin Delta, the Sierra Nevada mountains on the east, the Coast Range Mountains on the west, and the Tehachapi and San Emigdio mountains to the south.

The geologic formations that make up the freshwater-bearing groundwater system underlying EWD include (from youngest to oldest): the Modesto Formation, Riverbank Formation, Turlock Lake Formation, and Mehrten Formation. The surface exposures of each of these formations are shown in Figure 4A. Each of these units is summarized below.

Within EWD, the strike and dip of the formations are generally northwest to southeast, with a dip of approximately 1 to 3 degrees to the southwest. The geologic formations form a wedge shaped geometry, which increases in thickness from east to west.

#### *Modesto Formation*

The Modesto Formation is of late Pleistocene age (about 1 mya to recent). The formation consists of mostly sand, gravel, silt, and contains some silt and clay units. A majority of the Modesto Formation is observed to outcrop to the west of EWD; however, smaller outcrops of the formation are observed along low lying drainage areas and river channels throughout the study area. There does not appear to be much saturated thickness of the Modesto Formation within EWD.

#### *Riverbank Formation*

The Riverbank Formation, which is of middle Pleistocene age (about 1.5 mya to 1 mya), underlies the extent of the Modesto Formation. The thickness of the formation increases westward, with a thickness of generally less than 200 feet. The formation consists primarily of sand with scattered gravel and silt lenses. A majority of the Riverbank Formation outcrops west of EWD, between the TID Main Canal and the TID Highline Canal. However, smaller portions of the formation are observed to outcrop along low-lying drainage areas and river channels throughout the study area. There does not appear to be much saturated thickness of the Riverbank Formation within EWD.

#### *Turlock Lake Formation*

The Turlock Lake Formation, which is of early Pleistocene and late Pliocene age (2.5 mya to 1.5 mya), underlies the Riverbank Formation. The thickness of the unit increases westward, but the thickness is generally less than 600 feet. The formation consists of mostly fine sand and silt (Marchand and Allwardt, 1981). The Corcoran Clay member of the Turlock Lake Formation ranges in thickness from 10 to 100 feet. The Corcoran Clay is generally dark greenish-gray in color, but is commonly referred to as “the blue clay”. The Corcoran Clay lies in the upper part of the Turlock Lake Formation; however, the extent of the Corcoran Clay which has been locally mapped in the subsurface (by others) along and west of North Santa Fe Avenue was not observed during this investigation and is not thought to be present in the subsurface underlying EWD. The Turlock Lake Formation is the primary aquifer for shallow wells within EWD and also along the majority of the Highline Canal. This formation would be the primary target of MAR projects

within the study area near the Highline Canal. While the Turlock Lake Formation contains significant layers of sandy material, it also contains highly cemented sandstone layers (duripan) that are thought to have low permeability.

Deposition of the Turlock Lake Formation appears to have eroded portions of the Mehrten Formation, which suggests that there is an erosional unconformity between these formations within portions of the Study Area.

#### *Mehrten Formation*

The Mehrten Formation is Miocene to late Pliocene in age (5 mya 2.5 mya) and consists of a sequence of volcanoclastic and volcanic rocks. The Mehrten Formation is comprised of two distinct geologic units: the Upper Mehrten Formation and the Lower Mehrten Formation. The Upper Mehrten Formation consists of gravels, well sorted black andesitic sands (reported by well drillers as “black sands”) and interbedded blue to brown silts and clays (DWR 1974). The Lower Mehrten Formation consists of dense volcanic flows of tuff breccias with interbedded conglomerates and sandstones. This unit acts as a confining layer between sand intervals. In the vicinity of EWD, the Mehrten Formation ranges in thickness from 200 feet along the eastern portions of the study area, to over 600 feet west of the TID Main Canal. While the Mehrten Formation contains significant layers of sandy material, the location and depth of the deposits in relation to the potential MAR sites more than likely precludes these deposits from directly benefiting the project.

#### *Geologic Cross-Section*

A geologic cross section was prepared with existing data from EWD, DWR, and the California Department of Conservation Division of Oil, Gas, and Geothermal Resources (DOGGR) geophysical logs. The available lithologic data and geophysical logs were used to prepare geologic cross section A-A’, as shown in Figure 4B. The geologic cross section depicts the general elevation (relative to mean sea level) that each geologic formation is anticipated to exist within the EWD study area.

One prominent feature identified while correlating the geologic units was vertical offset of the formations traversing west to east along the cross section line. This suggests faulting has occurred, with apparent vertical upward movement on the west side relative to the east side. The exact location of the fault is unknown, but has been referred to in previous work conducted in the area. To the east of the fault, a prominent erosional contact was identified between the top of the Mehrten Formation and the bottom of the Turlock Lake Formation, as discussed briefly above. The data suggest that prior to the deposition of the Turlock Lake Formation, the deposits of the Mehrten Formation were disrupted by deformational stresses that enhanced erosion of the existing sediments.

The surface exposures of the geologic formations relative to the potential surface water available near the Highline Canal indicate that the deposits of the Turlock Lake Formation would be the primary target for the percolation of diffused stormwater flows for aquifer recharge to meet the project objectives.

### **Task 5 – Surface and Shallow Subsurface Soil Mapping of Area**

The Project Hydrogeologists reviewed Soil Survey Geographical (SSURGO) datasets for EWD gathered in parts of Stanislaus County and Merced County from the Natural Resources Conservation Service (NRCS) online sources. The SSURGO soil data was reviewed for key data including rated depth of soil and the presence of hardpan layers for the area soil types. A GIS shapefile was generated from SSURGO data tables to provide useful data regarding surface soils, including: vertical hydraulic conductivity, hydrologic soil type, and depth of soil.

The SSURGO data gathered was representative of the EWD, and was drawn from SSURGO studies in both Stanislaus and Merced Counties. SSURGO soil data was associated with location data through database queries. Additional queries converted SSURGO soil data units into project appropriate units of feet per day. Additionally, the data reported as saturated hydraulic conductivity was confirmed to be saturated vertical hydraulic conductivity through a phone conversation with NRCS staff.

Spatially-located SSURGO data was provided to the Project Hydrogeologists as a GIS Shapefile and depicted as Figure 5A. The saturated vertical hydraulic conductivity and hydrologic soil types displayed in Figure 5A provide insight as to the location within the study area where surface soils may be sufficient to meet project goals as well as areas where duripan soil layers can be expected and must be accounted for in site evaluation and design to achieve project goals. Saturated vertical conductivities are described in Figure 5A as minimum and maximum values for the soil column, as well as a NRCS-defined representative value. Hydrologic soil types A and B (depicted in blues) are considered to be soils with high drainage capacity, whereas types C and D (shown in yellows and reds) have very little drainage capacity. Soil depths were also provided to the Project Hydrogeologists in a GIS Shapefile to assist in estimating depth of excavations needed for design locations.

### **Task 6 – Develop MAR Site Selection Criteria and Prospective MAR Site Locations**

The Project Hydrogeologists collaborated closely with the Project Engineer to develop MAR Site-Identification Criterion and MAR site suitability. Subsequently, the Project Hydrogeologists and the Project Engineer met with Kevin Kauffman (District representative) on September 24, 2014 and selected the following five (5) criteria to be used to select potential MAR locations. They are ranked below in relative order of importance, as determined by the Project Hydrogeologists and Engineer.

Prospective MAR Site Identification Criteria:

- 1) Best Unsaturated Zone Relative Hydraulic Conductivity ( $K_v$ ) for Percolation
- 2) Potential to Replenish Groundwater within Eastside Water District, “Fill the Hole”
- 3) Potential Basin Size for Percolation
- 4) Size of Watershed Above Site
- 5) Capability of Percolation Site for Multi-Use (Flood Control and Percolation) and Multi-Water Source (Sand Creek, Mustang Creek, and Dry Creek in addition to Diffused Flow in Highline Canal)

The Project Hydrogeologists and Engineer utilized the project information developed in Tasks 1 through 5 to identify prospective site locations adjacent to, or near the TID Highline Canal, and other areas within EWD with good MAR potential. To evaluate criteria No. 1 and 2, the Project Hydrogeologists created a map depicting the vertical hydraulic conductivity of the unsaturated zone combined with the interpreted groundwater elevation contours from April 2014 data. Figure 6A displays vertical hydraulic conductivity and groundwater elevation contours together with probable groundwater flow directions. Areas with a vertical hydraulic conductivity of greater than 0.5 feet/day were rated as favorable and evaluated further against the other site identification criteria. It should be noted that the site identification criteria will not exactly match the criteria matrix that the Project Engineer is developing for the selection of three sites to be brought to 30% design during the second phase of the project.

For criterion No. 3, the Project Hydrogeologists performed a preliminary visual examination of land use near inlet structures to assess land parcel sizes and areas that might be available and suitable for gravity fed percolation features. A secondary visual examination was made in the September 24<sup>th</sup> meeting of areas with suitable adjoining land uses and potential land parcels available of greater than 10 acres. Percolation areas of 10 acres or more were judged to be capable of providing meaningful capture and infiltration capacity (for example more than 750 acre-feet per year of aquifer recharge at a site).

The watershed areas above select inlets of Figure 2A were compared against criterion No. 4. Significant inflow to the Highline Canal is available at TID Inlet F-1 near the northern upstream end of the Highline Canal. Locations south of TID Inlet F-1 were judged to have water available for diversion from the Highline Canal during “significant rainfall events”. Data from TID on the flow in the Highline Canal during episodic rainstorms was sought during the site identification phase but was not immediately available. The return frequency of these “significant rainfall events” is to be assessed during the preliminary 30% design phase to guide design decisions on the size of groundwater recharge facilities to be built.

A preliminary list of 13 sites that satisfied Site Identification Criteria Nos. 1 through 4 was developed in the September 24, 2014 collaborative meeting. Those sites are identified as Preliminary Sites 1 through 11 in the accompanying Figure 6B. An additional two Preliminary Sites, Sites 12 and 13, that satisfy Site Identification Criteria Nos. 1 through 5 were identified and are also shown in Figure 6B.

Criterion No. 5 was used to assess potential recharge sites for multi-use as a flood control feature and as a percolation facility. This criterion is best satisfied in the watercourses of Sand Creek and Mustang Creek, since other drainages when flooding are currently controlled into the Highline Canal. The water in Sand Creek and Mustang Creek is not considered diffused stormwater; however, the stormwater flow in a Sand Creek or Mustang Creek location can conceptually be intercepted and percolated without a water right permit, if an equivalent rate and duration of stormwater flow in the Highline Canal is conveyed downstream. This flow interception in the drainage course could act as a flood control feature and thus be a dual purpose facility. Subsequently, a surface water right may be obtained for unclaimed excess stormwater flow in these natural watercourses. If a subsequent surface water right is obtained for excess stormwater flow, then additional diffused flow would be available to take at these sites or it could be taken to other groundwater recharge sites instead of Sites 12 and 13, depending on economic as well as technical considerations.

The goal for each of these sites is to be able to divert diffused stormwater that enters the Highline Canal during rainfall events into a designed groundwater recharge facility nearby using gravity flow. Site ranking criteria in addition to these site identification criteria were discussed and developed among the Project Hydrogeologists and Project Engineer during August and early September 2014. The site ranking criteria are to be further developed during the design phase to provide a reasonably objective analysis of the relative merits among the thirteen sites identified. There are criteria to be further evaluated in the design, such as recharged water outflowing to nearby watercourses and rivers such as the Merced River; there is a data gap for groundwater elevations and probable flow in the south as noted in Figure 6A. There is also a need to assess the potential for percolating recharge water to impact nearby-crop root-zones. Water quality concerns with regard to nitrate contamination from dairy operations were discussed, but not assessed, as part of this project. Site-specific groundwater quality characterization for select potential MAR sites may be warranted during site exploration (as discussed in Task 1).

The September 24, 2014 meeting served as a handoff meeting from the Project Hydrogeologists to the Project Engineer. It is anticipated that after ranking, three (3) sites will be selected by the Project Engineer and then taken to a 30%- complete engineering design. It is anticipated that the Project Hydrogeologists may be asked by EWD to review additional site ranking criteria developed and their application to the thirteen sites identified herein. The electronic files of technical criteria from hydrologic and hydrogeologic assessments done by the Project Hydrogeologists are provided herein for use by EWD.

## Conclusions

- There appears to be sufficient unsaturated sediments along the Highline Canal that would benefit from groundwater recharge projects.
- Thirteen sites (eleven near the Highline Canal) were identified to have favorable conditions to warrant consideration as MAR locations for diffused stormwater.
- The soil texture analysis suggests that areas in the northern portion of the Highline Canal may not be good candidates for spreading basins. Dry wells in this area may be better suited to develop MAR projects in that area.

## Recommendations

- Site exploration to identify the site specific soil texture and permeability is recommended for all sites to be developed into MAR locations.
- Sonic drilling through the unsaturated sediments should be used to provide continuous soil samples.
- Test holes should be converted into monitoring wells to help track the effectiveness of MAR operations on the unsaturated sediments and to enable passive air pressure testing for hydraulic conductivity.
- A groundwater monitoring well network should also be developed to track water levels in the aquifers near the MAR locations and to establish a pre-project baseline water quality conditions near the MAR locations.

If you have any questions or require additional information, please call us at (916) 341-7447 (Wood Rodgers) or (209) 451-5933 (E-PUR).

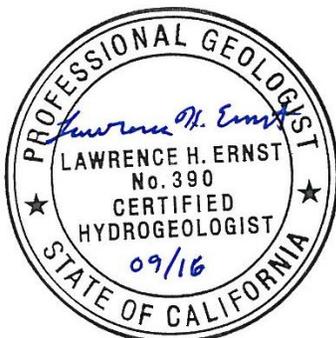
Sincerely,



Lawrence H. Ernst, PG, CEG, CHG  
Principal Hydrogeologist  
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