March 12, 2020

Michael Brinton, PE
Project Manager
Stanislaus County Public Works
1010 Tenth Street, Suite 4200
Modesto, CA 95354

Re: Evaluation of Stormwater Management and Groundwater Recharge Projects in the Dry Creek Watershed of Stanislaus County

Dear Mike,

Please find attached the FINAL Evaluation of Stormwater Management and Groundwater Recharge Projects in the Dry Creek Watershed of Stanislaus County report. The draft report was revised per comments received from Stanislaus County and other stakeholders. Under separate cover, we will provide a list of the comments and our response/action taken.

We appreciate this opportunity to serve Stanislaus County. If you have any questions, please do not hesitate to contact me.

Best Regards,

Michael Milczarek
Program Director

cc: Dhyan Gilton, Stanislaus County

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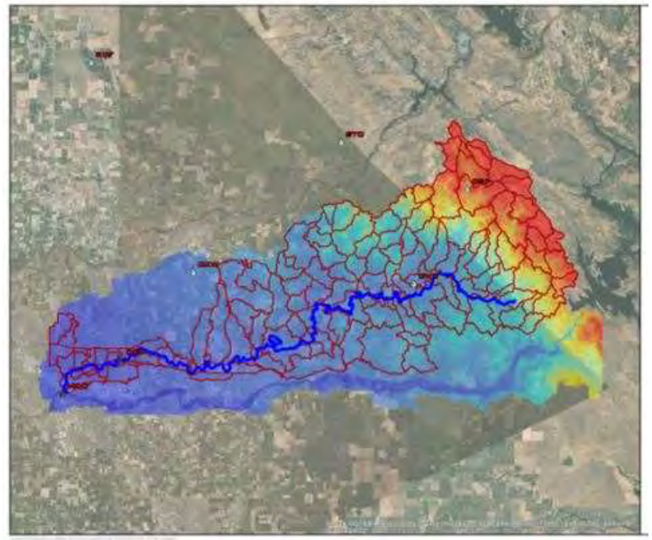

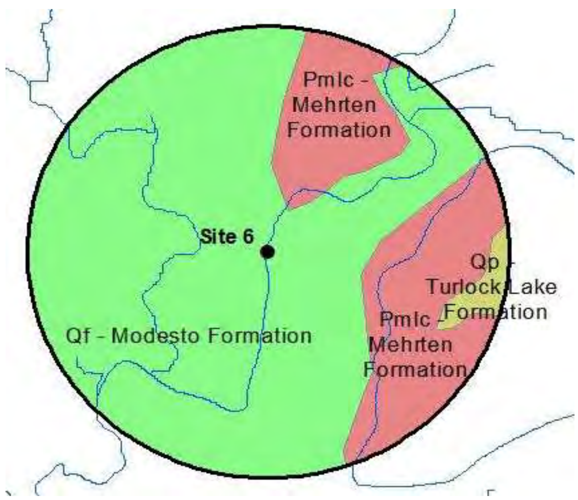

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Phase I Evaluation of Stormwater Management and Groundwater Recharge Projects in the Dry Creek Watershed, Stanislaus County

March 2020

CALIFORNIA DEPARTMENT OF WATER RESOURCES

This project was funded by the Prop 1 Disadvantaged Community Involvement Grant Program through the Department of Water Resources

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EXECUTIVE SUMMARY

This technical memo summarizes the results of a Phase I screening-level investigation to identify potential sites for stormwater management within the Dry Creek Watershed (DCW) that can control flooding within the DCW. The goal of this evaluation was to identify 10 or more potentially suitable locations that may meet general criteria of providing flood control and suitable subsurface conditions to enable enhanced groundwater recharge. This study is the first phase of a multi-phase stormwater management and groundwater recharge program designed to identify and implement multi-benefit flood control projects that will protect downstream Disadvantaged Communities (DAC) and provide water resources benefits:

- Phase I - identify potential flood control projects within the DCW that can reduce the risk of downstream flooding to DACs and enhance local water resources (minimum of 10 target/prospective project site locations)
- Phase II - identify and evaluate three high-priority projects (Priority Projects) for stakeholder engagement around prospective benefits and costs
- Phase III - bring three Priority Projects to the implementation grant-ready stage from an engineering standpoint and provide sufficient documentation for preparation of the related and necessary environmental permits and water rights documents.

Results of this Phase I investigation will be used to prioritize and conduct detailed evaluation of three potential project sites in the DCW that are most suitable for stormwater management and groundwater recharge in subsequent phases of the program, Priority Projects.

A two-component analysis of the DCW was performed: 1) a surface water analysis and modeling to determine estimated flow rates and flow volumes during design storm events of different frequency (i.e. 2-year, 5-year, 10-year, 25-year and 50 -year storm return intervals); and; 2) a hydrogeologic suitability analysis for groundwater recharge. The following information was evaluated as part of this Phase I investigation:

- An HEC-HMS model was developed for the DCW and calibrated to historic precipitation and Dry Creek flow data above the City of Modesto. The model was then used to predict peak flow rates and stormwater volumes for various design storm events at potential stormwater capture sites within the DCW.
- Surface and subsurface conditions, including soil, surface and subsurface geology types and estimated permeability of these materials.

- Hydrogeology, including aquifer properties, groundwater elevation and water quality.

The DCW is approximately 215 square miles (or 137,000 acres) in size and is located north/north east above the City of Modesto. The top elevation of the watershed is within Tuolumne County at approximately 1,500 feet above mean sea level (amsl) with the bottom elevation at approximately 50 feet amsl. Land use within the DCW is predominantly agricultural and rural.

Evaluations here indicate that surface water flows in Dry Creek above approximately the 5-year return interval cause downstream flooding, if they are coincident with required releases from the Don Pedro Reservoir on the Tuolumne River for its floodwater management and dam safety control. Precipitation and stormflow frequency analyses conducted herein, indicate the 5-year return interval is approximately 4,710 cubic feet per second. Eight storms occurred between 1986 and 2019 in the DCW above the 5-year recurrence interval; most of these storms occurred in a similar pattern, with rainfall spread out over a 4-5-day period.

Near-surface and subsurface soil and geologic conditions are highly variable throughout the DCW. Most of the soils in the DCW have low estimated relative permeability, or are underlain by restrictive soil units; the estimated soil permeabilities are highest in the western portion of the DCW. Soil Agricultural Banking Index (SAGBI) maps also indicate higher potential for groundwater recharge in in the northwestern and western portion of the DCW. Review of field boundaries and crop types within the DCW as of September 2019 indicate that almond orchards and grapes vineyards predominate in the DCW. Both of these agricultural crop types have been shown to be suitable for Flood Manage Aquifer recharge if properly managed.

The primary water bearing geologic formations in the DCW that may be suitable for groundwater recharge include the unconsolidated Modesto, Riverbank and Turlock Lake Formations and the semi-consolidated Mehrten and Ione Formations. Because of potential permeability restrictions from near-surface restrictive units or fine-grained layers at depth, potential groundwater recharge may require the use of recharge enhancement features (i.e. drywells or infiltration galleries) at different locations. Processing of textural data from borehole geologic logs is limited at this time and additional textural analysis is needed to evaluate site-specific conditions.

Fifteen (15) potential flood control and stormwater capture sites within Dry Creek were identified in this Phase I based on the contributing sub-watershed area, potential access to the site, distance from nearby infrastructure and also proximity to irrigation canal networks. The Dry Creek channel is highly incised at most of the 15 locations (20 to 77 feet below the off-channel surface). The degree of incision will impact the type of designs for flood control structures. A preliminary review of potential conceptual flood control structure designs is provided; actual design work will occur in subsequent phases.

In-channel stormwater detention designs would facilitate groundwater recharge by detaining water upgradient of the structure thereby increasing recharge through permeable sediments in the sidewalls of the channel, and via longer periods of wetting from a slow release of water out of the detention structure.

Recommendations for Phase II of the Stormwater Management and Groundwater Recharge program include:

- Reduce the 15 initial prospective project sites to a smaller number of sites based on discussion with the Stanislaus County Project Development Team.
- Conduct surface water modeling to predict peak flow reduction and the area of inundation at each site for different return interval storm events.
- Update hydrogeologic data with additional data collection for the SGMA groundwater sustainability plan.
- Evaluate and map hydrostratigraphic units in detail at potential project locations
- Select and contact various well owners to obtain depth to water data within the central and eastern portion of the DCW to improve understanding of groundwater elevations.
- Conduct field site reconnaissance work to provide needed information for conceptual designs.
- Perform data and modeling analyses to assess project benefits and risks, and prepare preliminary project designs and estimated costs.
- Conduct additional DAC stakeholder outreach and meetings designed to educate the communities in IRWM, provide opportunities for involvement and to obtain feedback / comments on the Dry Creek Priority Projects.

DEFINITIONS

Cuestas – ridges with a steep face on one side and a longer, gentler slope on the other

Deltaic – characteristic of geologic deposits at a delta (river mouth); usually triangular and consisting primarily of alluvium

EGRP™ - Energy Passive Groundwater Recharge Product from Parjana Distribution; a device designed to increase the infiltration of surface water into near-and-sub-surface soils

Hydrostratigraphic unit –below-land-surface rock units with distinguishing characteristics related to water-bearing capacity or water flow

Incised – cutting through of a rock unit by a river

IRWM – Integrated Regional Water Management; a California Department of Water Resources program to manage all aspects of water resources in a region across jurisdictional lines

Lateritic – containing laterite, a reddish clayey soil layer containing iron and aluminum oxides and formed by weathering of igneous rocks in warmer, wetter climates

NRCS – U.S. Natural Resources Conservation Service

Thalweg – a line connecting the deepest points along the length of a river or other water channel

Upgradient – from a higher-elevation groundwater position

Vadose – groundwater below the land surface and above the water table

Volcaniclastic – rock derived from volcanic activity; natural materials, usually mineral, composed of volcanic fragments

1.0 INTRODUCTION

Stanislaus County is evaluating the feasibility of developing stormwater management projects and facilities within the Dry Creek Watershed (DCW, the watershed). The DCW is an approximately 137,000-acre area (~215 square miles) straddling Stanislaus County and Tuolumne County between the Stanislaus and Tuolumne Rivers (Figure 1). Uncontrolled flow in Dry Creek during high intensity precipitation and runoff events can cause flooding of portions of the City of Modesto and affects both downstream and upstream floodwater levels within the Tuolumne River and Stanislaus River systems. Consequently, controlling stormwater in Dry Creek and the watershed is a regional goal with various local and regional stakeholders.

Stanislaus County and the City of Modesto jointly proposed a reconnaissance level study for developing a floodwater detention program for Dry Creek in the Mid San Joaquin River Regional Flood Management Program (Reclamation District 2092 and Stanislaus County, 2014 also http://www.midsjrfloodplan.org/). Further, Stanislaus County has integrated the development of floodwater detention projects with multiple benefits to the recent Stanislaus Multi-Agency Regional Stormwater Resources Plan (Woodard & Curran, 2019).

1.1 Project and Program Scoping

Stanislaus County has taken the floodwater detention and stormwater resource management concepts identified in 2014 and 2019 and developed a three-phase stormwater management and groundwater recharge program to identify and evaluate potential flood control and groundwater recharge projects in the DCW, with priority to those that provide flood risk reduction to local disadvantaged communities (DACs).

For the purposes of focus and funding for the Stormwater Management and Groundwater Recharge program, Stanislaus County Public Works has taken the lead role to develop three (3) high-priority projects in the three initial phases of the program study:

- Phase I - identify and develop potential flood control projects within the DCW that can reduce the risk of downstream flooding to DACs and enhance local water resources (minimum of 10 target/prospective project site locations)
- Phase II - identify and evaluate three high-priority projects (Priority Projects) for stakeholder engagement around prospective benefits and costs
- Phase III - bring three Priority Projects to the implementation grant-ready stage from an engineering standpoint, and provide sufficient documentation for preparation of the related and necessary California Environmental Quality Act (CEQA) and water rights documents.

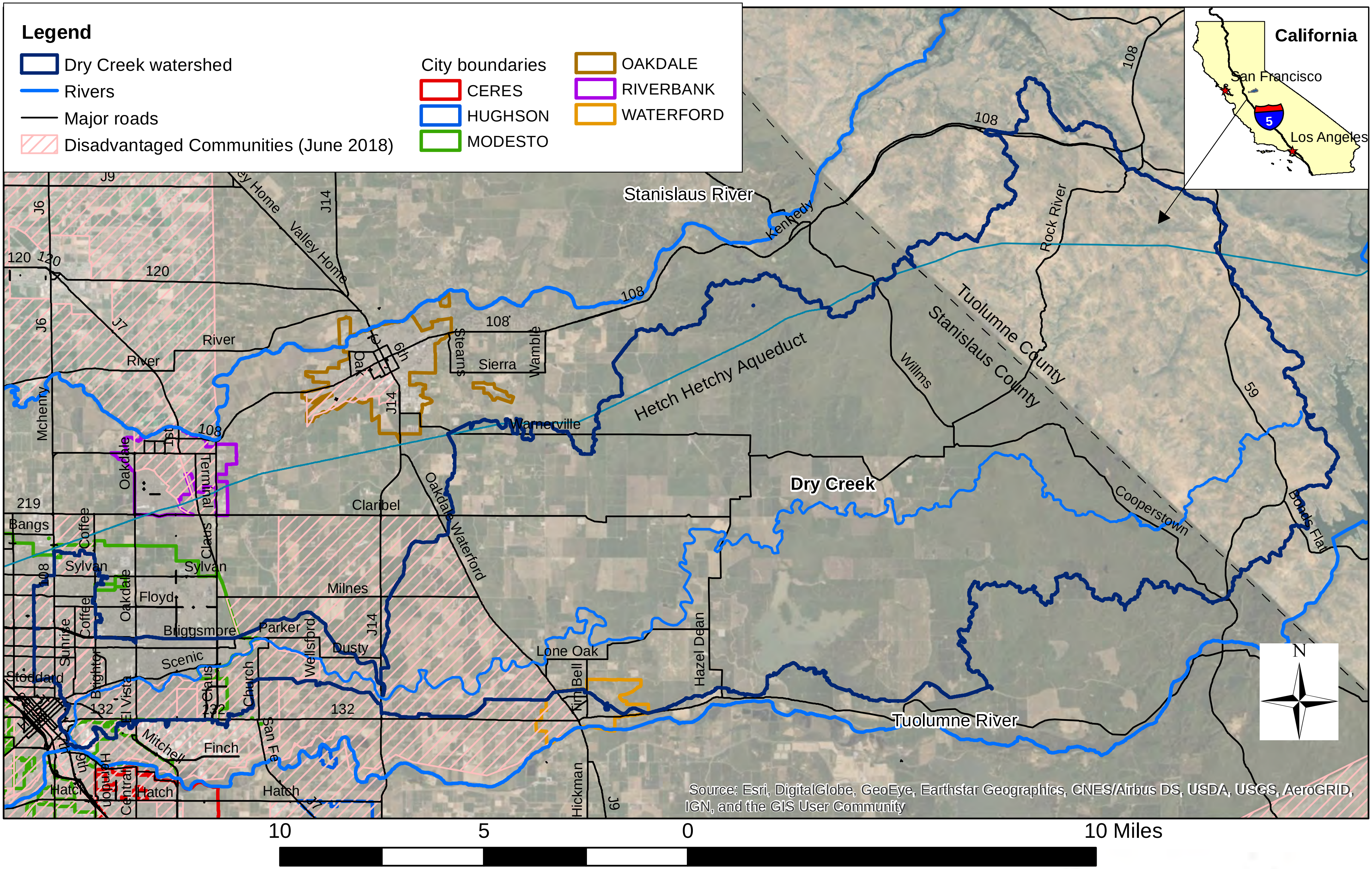

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Figure 1. Location of the Dry Creek Watershed

In August 2019, GeoSystems Analysis, Inc. (GeoSystems), in collaboration with Wood Rodgers, Inc. (Wood Rodgers) and E-PUR, LLC (E-PUR), together the GeoSystems Team, were contracted to conduct Phase I with Stanislaus County. The project was awarded by Stanislaus County, utilizing grant funding from the Prop 1 Disadvantaged Community Involvement Grant Program, administered by the Contra Costa Water District on behalf of the seven IRWM regions in the San Joaquin River Funding Area. Stanislaus County is presently pursuing and evaluating funding for Phases II and III.

Additional evaluations such as CEQA, water rights and property access are beyond the scope of these three phases for the program but some or all will be necessary to take one or more of the Priority Projects toward construction and operation.

1.2 Stormwater Management and Groundwater Recharge Program Objectives

The primary objectives for consideration of the Stormwater Management and Groundwater Recharge projects within the DCW are to:

- Reduce flooding near the confluence of Dry Creek and Tuolumne River and downstream of the confluence toward the San Joaquin River
- Reduce flood risks for local DACs
- Increase groundwater recharge within the DCW
- Improve ecosystem function and enhance sustainable water resources
- Provide recreational space or other multi-benefit projects

1.3 Technical Memorandum Organization

This document is Technical Memorandum 1 as per the approved scope of work. The technical memo is organized as follows: Section 2 provides project technical background information. Section 3 reviews the hydrogeologic suitability analysis. Section 4 summarizes the surface water analysis. Section 5 presents the areas identified as potential multi-benefit project-site locations and makes recommendations for further investigations. Section 6 provides references to information sources. Attachment A presents a detailed description of the surface water analysis and modeling; Attachment B presents a discussion of the soil survey data and analysis performed, and; Attachment C provides a detailed description of groundwater quality data.

2.0 PROJECT TECHNICAL BACKGROUND

2.1 Summary Information on Dry Creek Watershed

Excess stormwater in the DCW during peak rainfall and runoff events can cause flooding in portions of the City of Modesto. Estimated peak flow rates in the lowermost reach of Dry Creek range from 2,690 cubic feet per second (cfs) for a two-year event to 15,700 cfs for the 50-year event. Flows above 6,000 cfs in Dry Creek, an approximately 5-year return interval, have been identified to cause downstream flooding if they are coincident with required releases from the Don Pedro Reservoir on the Tuolumne River for floodwater management and dam safety control. This situation occurred in January 2017.

Flooding can also occur solely due to runoff from large, high intensity storm events over the DCW such as occurred on December 22, 1996; this event flooded large areas within the City of Modesto into January 1997. In response to the 1996 flooding, the U.S. Army Corps of Engineers (USACOE) conducted a background study on flood management options in the Tuolumne River watershed including Dry Creek (USACE, 1998). FEMA (2014) conducted the most recent hydraulic analysis and modeling on Dry Creek.

The current study incorporates the flood control concepts of previous studies and extends them to include stormwater capture for multi-benefit projects and specifically reducing impacts from floodwaters from the Dry Creek watershed to DACs.

Dry Creek has a California Department of Water Resources (DWR) surface water gauging station at Claus Road in the City of Modesto. Flow data for that gauging station is maintained on the California Data Exchange Center (DCM). Additionally. there is a gauging station at the Crabtree Road overcrossing of Dry Creek that is operated and monitored by the Turlock Irrigation District (TID).

The DCW includes various sub-watersheds and numerous smaller channels in addition to Modesto Irrigation District (MID) and Oakdale Irrigation District (OID) canal networks which move water across the watershed (Figure 2). As stated previously, the DCW is approximately 215 square miles (or 137,000 acres) in size and is located north/north east above the City of Modesto. The top elevation of the watershed is approximately 1,500 feet above mean sea level (amsl) with the bottom elevation at approximately 50 feet amsl. Land use within the DCW is predominantly agricultural and rural.

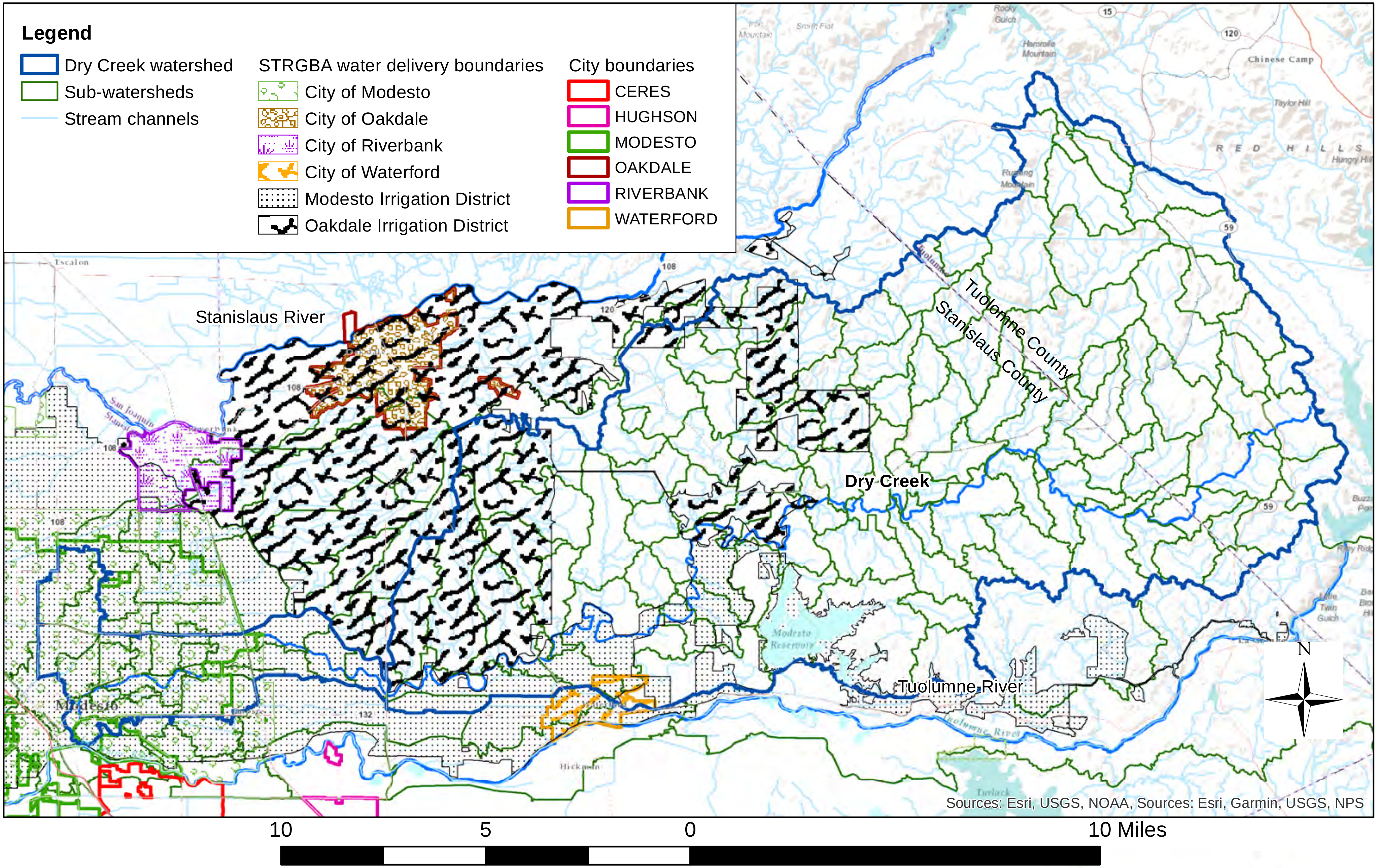

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Figure 2. Dry Creek sub-watersheds and Stanislaus and Tuolumne Rivers Groundwater Basin Association water delivery boundaries

The Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA) formed a Groundwater Sustainability Agency (GSA) under California's Sustainable Groundwater Management Act (the SGMA). Some of the STRGBA members such as MID and OID, manage irrigation canals in the DCW.

A previous groundwater recharge site alternative analysis and screening evaluation was performed by the City of Modesto that included the westernmost part of the DCW within the City limits (Todd Groundwater, 2016). This analysis was focused on existing City of Modesto properties (i.e. Parks) and right of ways and consequently has limited applicability to the DCW analysis which is focused on flood control within Dry Creek.

2.2 Overview of Stormwater Capture and Groundwater Recharge Methods

The following sections provide information about certain types of floodwater detention and retention methods and groundwater recharge technologies and techniques.

The use of small detention/check dams and flood control structures in streambeds with subsequent release of captured stormwater to increase natural recharge rates has a long history in many regions (Dillon et al. 2018). Surface water capture and recharge systems can be divided into in-channel and off-channel systems. In-channel systems consist of weirs, dams, and levees to slow down the movement of water, increase the wetted area, and thereby increase infiltration under streambeds or floodplains. Dams may consist of low, closely spaced weirs, or larger dams spaced farther apart and can be made of steel, earthen material, concrete, or inflatable rubber (Bouwer 2002). Levees may be used where channels have small slopes or low water depths to facilitate the spread of water across the channel width or entire floodplain. It is essential to locate in-channel structures and control stormwater releases in such a way that the streambed can scoured by high flows to prevent sediment deposition (Dillon et al. 2018) or provide regular maintenance to remove sediment. A recent study and review of streambed structures found that infiltration rates from in-channel water retention are one to two orders of magnitude lower than for off-channel basins where water quality and flow can be controlled (Dillon et al. 2018).

Off-channel systems consist of natural or constructed basins in areas of permeable soil. For both types of systems, site-specific design and management criteria depend on water quality (sediment load), climate, and soil type to maximize the hydraulic capacity (Bouwer 1988). An example of an off-channel groundwater recharge system is the approximately 150,000 acre-feet/year of surface water diverted from the Santa Ana River into Orange County Water Districts recharge basins (Hutchinson et al. 2017).

In the case of Dry Creek, the channel is heavily incised through most of the watershed (See Section 4.0). Consequently, options for the use of stormwater for groundwater recharge are limited to in-channel recharge unless pumping systems to lift water out of the channel to off-channel basins or Flood MAR (managed aquifer recharge) fields are employed. This indicates that sediment control will be a major issue regarding any stormwater capture and groundwater recharge option. Nonetheless, it is possible that channel incision can facilitate recharge into permeable sediments within the channel walls of Dry Creek, or tributaries.

2.2.1 Infiltration Basins

Surface spreading infiltration basins are the most common groundwater recharge method approach. Infiltration basins are appropriate where near-surface soils are sufficiently permeable to permit percolation of surface water. Basin design optimization requires careful consideration of water supply, water quality, climate, and surface and subsurface variables (Bouwer 1988). These factors include developing schedules for flooding, drying, and cleaning basins, optimum water pre-treatment, water depth, water velocity, and biological factors (insects, algae, odors) (Bouwer 1988). If shallow low-permeability soils are present at the surface, basins can be excavated to expose more favorable sediments for recharge. Well sited and designed basin infiltration rates can frequently exceed 2 feet/day which results in minimal evaporation losses.

To minimize the potential for basin clogging, recharge water should be high quality or pre-treated to remove excess suspended solids, nutrients, and organic carbon. A review of clogging phenomena and methods to control clogging in off-channel systems are provided in Hutchinson et al. (2013). Clogging in surface spreading basins is often managed using a combination of water pre-treatment, regular drying to promote cracking of clogging layers, and physical removal of accumulated sediments (Bouwer 2002). If considerable suspended solids are present in the source water, pre-sedimentation basins can be utilized to separate out sediment.

2.2.2 Groundwater Recharge Enhancement Features

If surface soils are not suitable, or insufficient land is available for infiltration basins, recharge enhancement features can be utilized to direct water to high-permeable layers within the vadose zone. Common surface recharge enhancement features include dry wells and infiltration galleries: other technologies could include passive infiltration technologies such as wick drains or EGRP® from Parjana Distribution.

Drywells are a common solution for capturing and infiltrating stormwater into highly permeable subsurface layers deeper within the vadose zone. Within the Modesto area, “rockwells” are a type of drywell that are used extensively to discharge urban stormwater runoff into the shallow aquifer.

California is currently developing new risk-based drywell design standards. Most work to date (i.e. Edwards et al., 2016) indicates that the vadose zone effectively treats contaminants contained in stormwater, although limited data exist on emerging contaminants (Geosyntec, 2018). Drywells typically include a primary settling chamber at the surface for sediment removal which then routes water into the drywell chamber. Typical drywell dimensions are three to four feet in diameter. Depending on site-specific conditions, drywells typically range from less than 20 feet deep in the Northwestern USA (WA/OR) to up to 100 feet or greater deep in deeper vadose zones in AZ/CA.

At locations where restrictive low permeability soils are shallow (i.e. less than 10 feet deep), infiltration galleries or trenches can also be constructed by excavating a trench, typically less than about 3 feet wide and 10 to 12 feet deep. Trenches are backfilled with sand or gravel to promote rapid downward movement of water to the infiltrating layer. These infiltration galleries can be constructed with a perforated pipeline to apply water on the surface or placed in a channel or conveyance to capture water as it flows along the surface.

Groundwater recharge enhancement technologies are advantageous because they are relatively inexpensive, however, as with all recharge projects, clogging is an issue. Ideally, sediment should be removed prior to recharge, as infiltration galleries and most drywells cannot be pumped or flushed to remove a clogging layer. Infiltration galleries can be designed with sand filters and/or geotextile filter fabric above the backfill, but these need maintenance to maintain infiltration capacity at the surface. Ultimately, it is an economic decision between pre-treating water, screening out sediment to extend the life of the recharge feature, or constructing new ones once clogging occurs (Bouwer 2002).

2.2.3 Flood-MAR

Flood Managed Aquifer Recharge (Flood-MAR) is the practice of diverting flood water resulting from snowmelt or rainfall for groundwater recharge into agricultural and working (refuges, floodplains, flood bypasses) landscapes. The State of California is currently encouraging the implementation of Flood-MAR on multiple scales, from individual landowners using existing infrastructure to flood agricultural fields, to modernizing flood protection infrastructure and operations to use extensive detention/recharge (State of CA, 2018). Fallow farm fields or certain permanent crops can be flooded. To date, crops that have been evaluated and appear to tolerate intermittent (i.e. three to four days), though repeated, submergence of flood waters include grapes, almonds and pistachios (Bachand et al., 2016, 2019).

Successful Flood-MAR projects currently underway in California include the Farmington Groundwater Recharge Program (11,000 acre-feet recharged in 2016), the McMullin On-Farm

Flood Capture and Recharge Project in Kings Basin (20,000 acres of on-farm flood capacity, Bachand et al., 2015, 2016). Other work relevant to the DCW include the Groundwater Recharge Assessment Tool (GRAT, http://www.groundwaterrecharge.org/) developed by Sustainable Conservation and the Earth Genome non-profits.

3.0 HYDROGEOLOGIC SUITABILITY ANALYSIS

Information on the following DCW characteristics were evaluated:

- Surface conditions, including soil and surface geology and estimated permeability of those surface materials.
- Subsurface conditions, based on well driller logs, borehole geophysical testing, and hydrogeologic modeling, including estimated permeability of subsurface materials.
- Hydrogeology, including aquifer properties, groundwater elevations and groundwater quality.

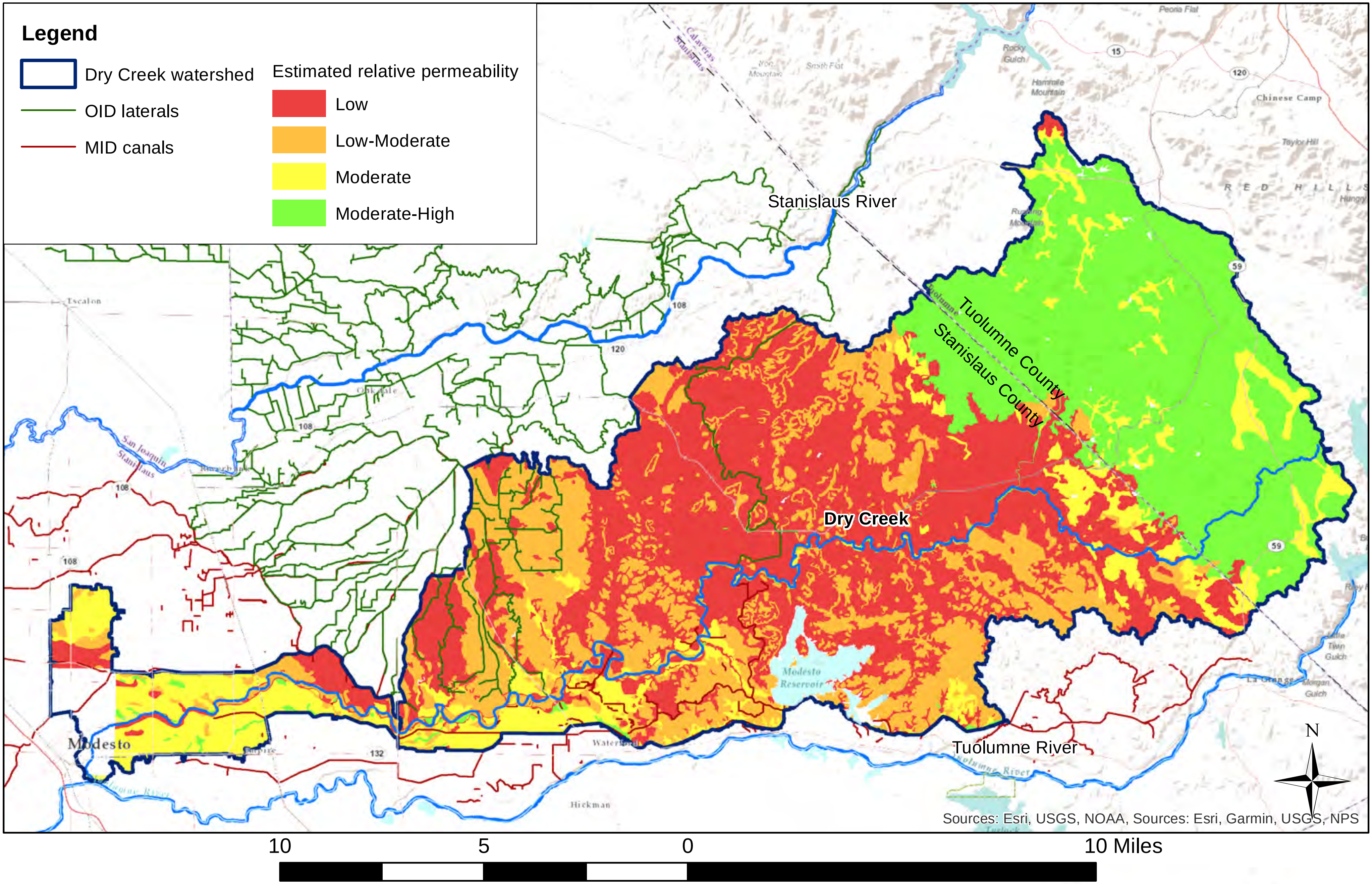
Because flood control and stormwater capture opportunities will be generally constrained to the Dry Creek channel, the focus of the assessment was within the vicinity of Dry Creek. Other data compilation included the MID and OID canal systems and agricultural field boundaries with crop types and topographic assessment to determine potential areas for off-channel recharge areas.

3.1 Soils

3.1.1 Soil Survey Data

Soils data were retrieved from the U.S. Natural Resources Conservation Service Web Soil Survey (NRCS, 2019). Soil map unit data directly related to soil permeability and water storage capacity, including saturated hydraulic conductivity, clay percentage, and depth to a restrictive soil or rock layer, were mapped and analyzed in order to assign a relative surface permeability category to each soils map unit. The methods used to create the relative permeability determinations and supporting soils data is presented in Attachment B.

Figure 3 shows the spatial distribution of relative soil permeability and areas where a restrictive layer (i.e. duripan, lithic or paralithic bedrock) is present within 5 ft of the surface. There are large, continuous areas of moderately permeable soils along the watershed's southeast edge and some small, discontinuous areas of moderately to highly permeable soils near Dry Creek and its tributaries. Otherwise most soils in the DCW are predicted to have low permeability or be underlain by a restrictive layer within 5 ft of the surface. Except for the western portion of the watershed, and the areas proximal to Dry Creek, depths to a restrictive layer are generally within 5 feet of the surface for most of the soils in the DCW.



Soils data from: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey.Online: https://websoilsurvey.sc.egov.usda.gov/. Accessed 8/16/2019. Data are not available for the Modesto urban area.

Figure 3. Relative soil permeability

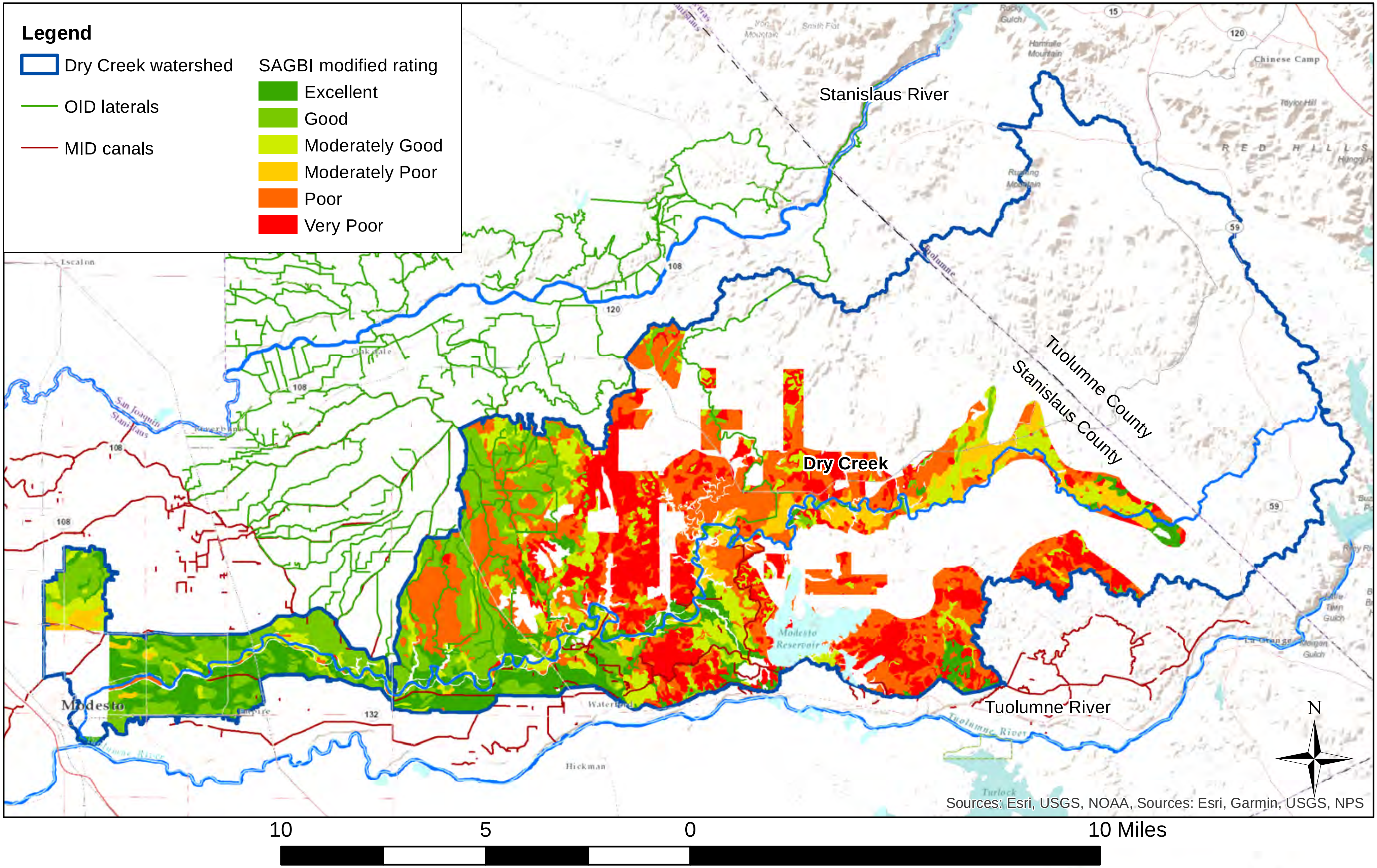
3.1.2 Soil Agricultural Banking Index Classification and Flood-MAR Potential

Data from the University of California, Davis California Soil Resource Lab's Soil Agricultural Banking Index (SAGBI) mapping of the San Joaquin Valley was used as an additional measure of site suitability for groundwater recharge and storage. SAGBI data covers agricultural land in the Stanislaus County portion of the DCW and is based on NRCS soil map unit-based characteristics of deep percolation, root zone, topography, chemistry, and surface conditions to rate soils as having a greater or lesser groundwater recharge and storage potential (O'Geen, et al., 2015).

Figure 4 shows the SAGBI ratings from the version of the dataset with assessment parameters modified to reflect the effect of tillage on native soil characteristics. Acreage and soil map units for each rating class in the watershed are shown in Attachment B. As the SAGBI data are based on NRCS (2019) map units, there are similarities between the spatial distribution of the SAGBI ratings (Figure 4) and the distribution of estimated relative soil permeability (Figure 3). Areas rated as having excellent potential for groundwater recharge and storage are located along the DCW's southeastern edge, with smaller areas in the central watershed. Good and moderately good areas are located primarily in the northwestern portion of the watershed, interspersed with smaller areas of moderately poor to poor potential.

Figure 5 shows field boundaries and crop types within the DCW as of September 2019 as provided by Stanislaus County (Nathan Leon, personal communication, 9/19/19). The most recent Permit Effective Date for each Site ID was used to construct the map as presented, but in some cases, multiple overlapping polygons are present and only the top layer is visible in the map. Non-visible layers may include fields with an extent and/or crop type that differs from the layer shown.

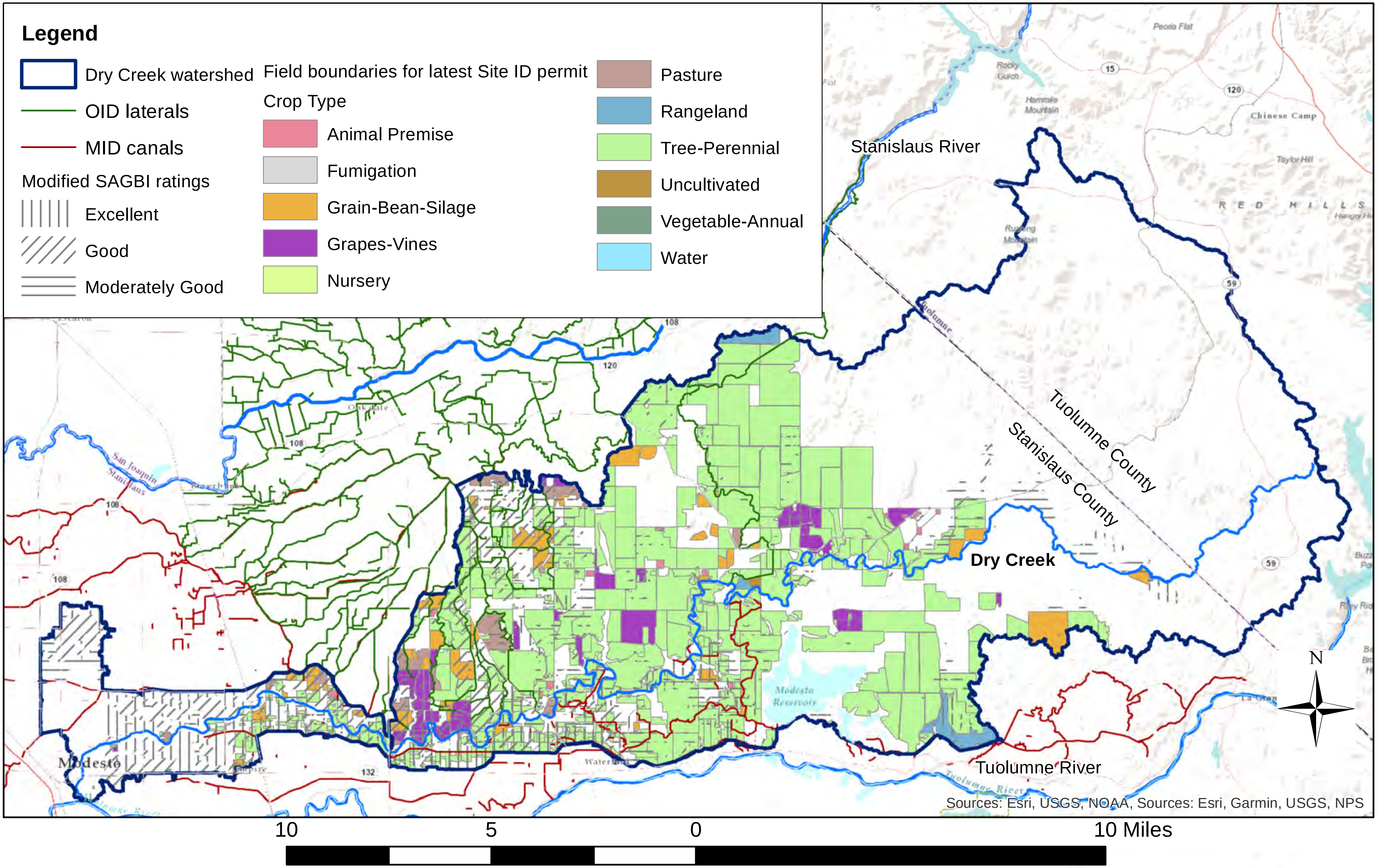
Most crops in the DCW are perennial trees, specifically almonds. Based on research that has been supported by the Almond Board of California among others (i.e. Bachand et al., 2016, 2019), almonds, are a suitable crop for Flood MAR, in addition to grapes and pistachios. Crop areas in the eastern portion and adjacent to Dry Creek in some of the central portions of the DCW may be candidates for Flood MAR diversion of Dry Creek flood capture flows.



Conceptual diversion/aquifer storage location data from: U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2002. Conjunctive Use for Flood Protection. January 2002.

SAGBI data: O;Green, AT, et al., 2015. Soil suitability index identifies potential areas for groundwater banking on agricultural lands. California Agriculture 69(2):75-84. https://doi.org/10.3733/ca.v069n02p75

Figure 4 Modified Soil Agricultural Banking Index (SAGBI) ratings



Source data: Stanislaus County Department of Agriculture & Weights and Measures, 2019. Field Boundaries. N Leon, personal communication, 9/19/19.

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Figure 5. Stanislaus County field boundaries for latest Site ID permit

3.2 Surface and Subsurface Geology

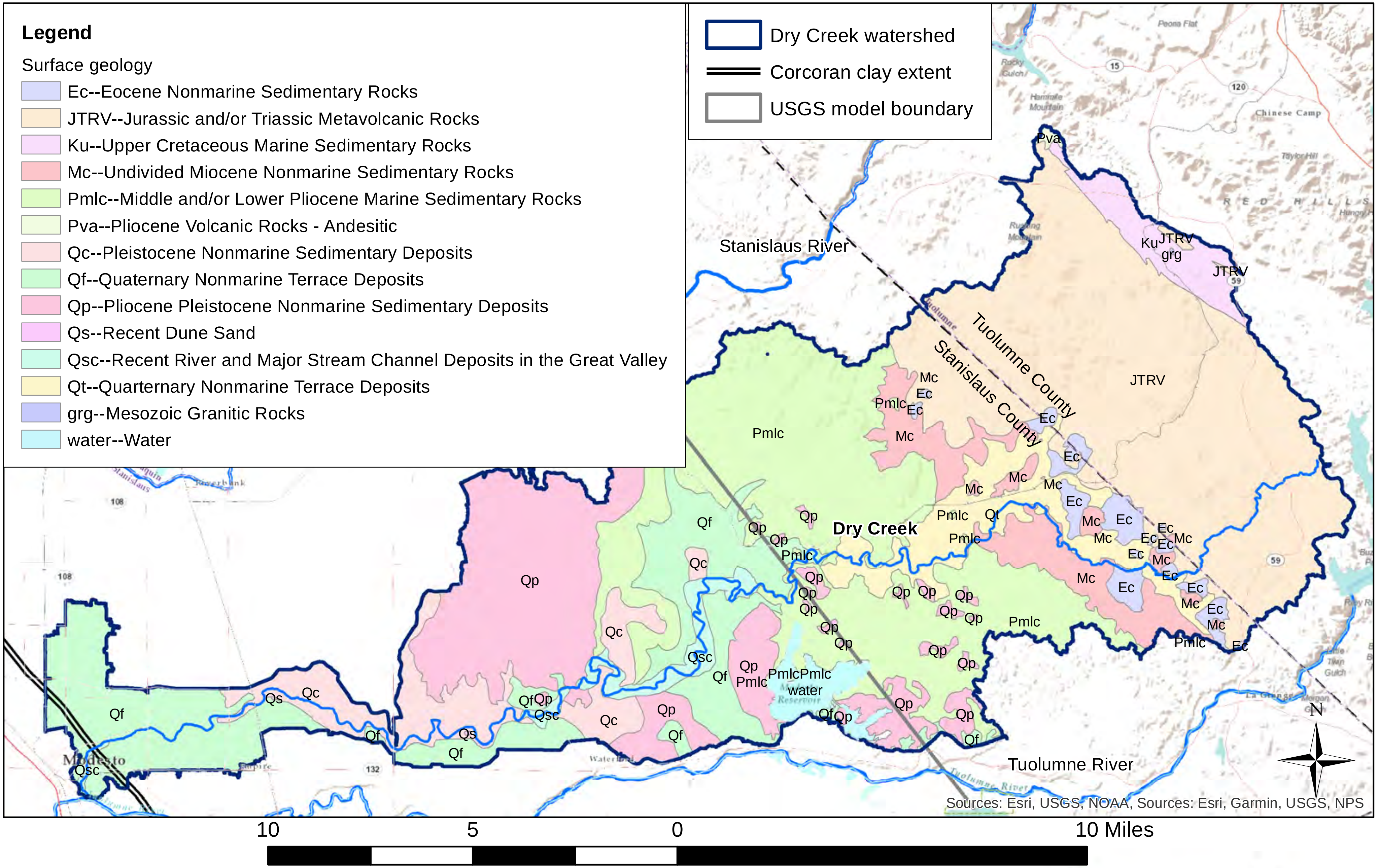
3.2.1 Surface Geologic Map Data

Surface geology data was provided by the USGS (Steve Phillips, personal communication, 8/8/2019) in the form of GIS shapefiles for a modified version of the California Division of Mines and Geology (1966) mapping. Figure 6 shows the surface geology map units within the watershed boundary, the USGS hydrogeologic model domain (USGS, 2015), and the northeastern limit of a notable local groundwater confining layer (i.e. aquitard), the Corcoran Clay.

3.2.2 Sub-surface Geologic Conditions

The geologic formations that make up the freshwater-bearing groundwater system underlying the DCW include (from youngest to oldest): the Modesto Formation, Riverbank Formation, Turlock Lake Formation, Mehrten Formation, Valley Springs Formation, and Ione Formation. The surface exposures of each of these formations are shown in Figure 6. Older consolidated units/bedrock formations in the eastern portion of the DCW, primarily in Tuolumne County (e.g. the Gopher Ridge Volcanics, JTRV, Figure 6), are either considered non-water bearing or are disconnected from the alluvial basin of the DCW and the Modesto groundwater subbasin. The water bearing alluvial geologic formations are unconsolidated or semi-consolidated. The Modesto Formation, Riverbank Formation, and Turlock Lake Formation are unconsolidated. The Mehrten Formation, Valley Springs Formation, and Ione Formation are semi-consolidated.

Within the DCW, the structural orientation of the semi-consolidated formations has the strike northwest to southeast (Figure 6) at an angle of roughly 37 degrees west of north (i.e. N 37W). The dip is perpendicular to the strike (i.e. N 127W) and the angle of dip decreases to the southwest from a high of 3 degrees in the uplifted semi-consolidated deposits of the Mehrten to Ione sequence in the east, to a low of 1 degree near and beneath the City of Modesto. The land surface slope is typically about 0.5 degrees lower than the structural slope and as a result of this difference between land surface slope versus the depositional/structural slope, the geologic formations form a wedge-shaped geometry that increases in thickness to the west. The youngest unconsolidated units, the Modesto and Riverbank Formations, pinch out quickly to the east whereas the older units, including the unconsolidated Turlock Lake Formation, are exposed in more complete vertical section in outcrops upslope in the DCW. Descriptions of the hydrogeology of these water-bearing units can be found in Phillips et al., 2015.



Geology data modified from: California Division of Mines and Geology, 1966, Geologic map of California, San Jose sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

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Figure 6. Surface geology, USGS model domain, and Corcoran Clay extent

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3.2.3 Modesto Formation

The Modesto Formation (Qf in Figure 6), is of late Pleistocene age, ranging from about 0.3 million years ago (mya) to 10,000 years ago. It consists of mostly sand, gravel, silt, and contains some lower permeability silt and clay units. Most of the Modesto Formation is observed to outcrop to the west of the community of Empire. The thickness of the Modesto Formation is limited within the DCW to perhaps 50 feet and is a thin (generally less than 6 foot) layer, developed on channel banks or sand dunes, overlying or interspersed with the Riverbank Formation (Burow et al., 2004).

3.2.4 Riverbank Formation

The Riverbank Formation (Qc in Figure 6), underlies the extent of the Modesto Formation, as it is older, of late Pleistocene age (about 0.5 mya to 0.3 mya). Its thickness increases westward from its outcrop near Claribel toward the City of Modesto with a thickness of generally less than 120 feet. Most of the Riverbank Formation outcrops between the Oakdale-Waterford Highway and Santa Fe Avenue. However, smaller portions of the Riverbank Formation are observed to outcrop along low-lying meanders in the Dry Creek river channels. There is a relatively large wedge of up to 120 feet of unsaturated thickness of the Riverbank Formation between its eastern extent and the City of Modesto at the western edge of the DCW. The Riverbank Formation has experienced enough uplift post-deposition that it does not pinch out completely to the east but has a somewhat limited section of exposure at the surface over a relatively large surface area due to the smaller variation between depositional slope and land surface slope. The formation contains silt, sand and gravel fluvial deposits (Hall, 1960) and typically has a hardpan layer at 3 to 6 feet bgs (Burow et al., 2004).

3.2.5 Turlock Lake Formation

The Turlock Lake Formation (Qp in Figure 6), which is of mid- and late Pleistocene age (0.5 mya to ~3 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 and in places clay at the base (Marchand and Allwardt, 1981). Marchand and Allwardt, 1981 also note that the Turlock Lake Formation beds grade upward to coarse and occasional pebbly sand or gravel; these deposits are typically massive cross-bedded and difficult to trace laterally (i.e. probably discontinuous lenticular deposits). The finer-grained sand and silt beds are well stratified and laterally continuous. The Turlock Lake Formation is the primary aquifer for water-supply wells within the DCW. 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. The Turlock Lake Formation has been uplifted such that a large portion of its type section is exposed at land surface as one moves upslope. Notably the Turlock Lake Formation is layered in a coarsening upward sequence with gravel beds near the top of the lower Turlock Lake Formation in its type section. Situating projects near lower Turlock Lake Formation outcrops may directly result in groundwater recharge to the principal aquifer.

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; the extent of the Corcoran Clay is limited to the subsurface in the lowermost reaches of the DCW. It is incised by erosion near surface and thus is of little consequence to opportunities for groundwater recharge either within the upper Turlock Lake Formation or the overlying Riverbank or Modesto Formations.

3.2.6 Mehrten Formation

The Mehrten Formation, Pmlc in Figure 6, was deposited over an extended period of time, perhaps 10 million years. It dates from mid-Miocene to late Pliocene in age (13 mya to 3 mya) and consists of a sequence of volcaniclastic and volcanic rocks. The Mehrten is much thicker at approximately 650 feet than the older Tertiary units, the Valley Springs and Ione, and consequently it outcrops much more extensively.

The Mehrten Formation in this area is a layered sequence of conglomerate, sandstone, siltstone, and claystone derived from andesitic source material (Marchand and Allwardt, 1981). A general decrease in mean grain size within the Mehrten can be seen southward from the Stanislaus to the Fresno River, where Mehrten exposures cease. Thus, it can be inferred from this description and the proximity of Dry Creek to the Tuolumne River just south of the Stanislaus River that the Mehrten Formation alluvial deposits will be quite coarse-grained in the area of Dry Creek. The Mehrten is comprised of two distinct geologic units: the Upper Mehrten Formation of alluvially-derived andesitic material (sands and gravels) and the Lower Mehrten Formation with welded volcaniclastic deposits interbedded with coarse grained alluvial deposits (medium to coarse sands without true gravel sized particles).

The more permeable Upper Mehrten may only surface outcrop along a line of strike through the western tip of Modesto Reservoir. Detailed study of Well Completion Reports for irrigation wells completed into the Merhrten Formation south of the Tuolumne River indicates that the hydraulic conductivity of the black sand and gravel beds is high (100 feet/day, (John Lambie E-PUR LLC, personal communication, 1/20/2020). Consequently, situating flood control/stormwater capture projects near Mehrten Formation outcrops may directly benefit groundwater recharge.

3.2.7 Valley Springs Formation

The Valley Springs Formation (Oligocene and Miocene, Mc in Figure 6), is a sequence of rhyolitic sandstone, siltstone, claystone, and conglomerate that appears to have been deposited by streams flowing in small valleys (Bartow, 1992). The Valley Springs Formation crops out at slightly lower elevations than the underlying Ione Formation. The Valley Springs, in addition to the cemented alluvial deposits noted, also contains thick ledge-forming altered zones that are diagenetically altered greenstones containing low grade metamorphic minerals. It is not likely that groundwater recharge can be accomplished into the Valley Springs Formation but in local areas it may be suitable for flood water detention.

3.2.8 Ione Formation

The Ione Formation (Eocene, Ec in Figure 6), consists primarily of light-brown, tan, and gray to pinkish or yellowish quartz sandstone with interbedded kaolinitic clay, usually near the base (Bartow, 1992). The sandstone becomes conglomeratic and very strongly cemented near the top, where it locally contains marine fossils. In many places these cemented beds form weather resistant westward-sloping cuestas over basement outcrops in the westernmost foothills of the Sierra Nevada. The Ione appears to have been deposited in a fluctuating swamp and deltaic environment close to the marine shoreline (Bartow, 1992). Lateritic soils containing crystalline iron oxides and abundant kaolinite (Ely et al., 1977 and Creely, 2007) and some aspects of lateritic crust remnants are found on the buried and exhumed Ione surface in eastern Stanislaus County. Given its locale in the upper portions of the DCW the Ione is predominantly on hillslopes too steep to meaningfully detain water, however if there are locations where water can be impounded at a lower hillslope of the Ione Formation a multi-benefit project could be situated there.

3.3 General Hydrogeology

Prior to development of the Modesto area, recharge was primarily through the alluvial fans in the DCW, with groundwater moving toward Dry Creek and the Tuolumne River with discharge from artesian wells west of Modesto (Burow et al., 2004). Post-development, groundwater recharge is primarily from percolation of irrigation runoff and discharge from pumping out of the unconfined and semi-confined aquifer and water is now percolating from the rivers to recharge those aquifers (Burow et al., 2004).

The lowermost portion of the valley aquifer is saline (electrical conductivity greater than 3,000 mS/cm). This saline fraction occurs at varying depths. There is approximately 600 feet thickness of freshwater under the western end of Modesto shallowing to the north to 400 feet where the Stanislaus River joins the San Joaquin River. There can be as little as 200 feet thickness of fresh-water aquifer before encountering saline water at the eastern edge of the subbasin (Burow et al. ,2004).

In the very westernmost extent of the DCW and westward into the center of the San Joaquin Valley the Corcoran Clay divides the Modesto regional aquifer system into an unconfined to semiconfined unit above it and a confined unit below it. Most of the DCW is east of the mapped edge of the Corcoran Clay (Figure 6), and thus it is not an important hydrogeologic feature for this study. However, it is worth noting that the more permeable layers within the Riverbank, and Upper Turlock Lake formation may be semi-confined by clay lenses within those hydrogeologic units. The confined aquifer below the Corcoran Clay at the far southwestern edge of the DCW is in alluvium of the Lower Turlock Lake Formation and both Upper and Lower Mehrten Formation.

3.3.1 Relative Permeability of Subsurface Materials

Probable ranges of hydraulic conductivity (i.e. permeability) were developed for each of the water bearing geologic units in the DCW. These were developed as initial estimates of the relative permeability for purpose of qualitatively evaluating the potential for groundwater recharge at different potential flood control and stormwater capture sites. Table 1 provides a list of the hydrogeologic units in the DCW with descriptions, along with estimated ranges for their hydraulic conductivity when fully saturated in the horizontal and vertical direction (Ksat). Horizontal Ksat (Kh) values were estimated for the different hydrogeologic units based on Marchand and Allwardt (1981) and Freeze and Cherry (1979), with the exception of the Mehrten Formation black sand and gravel beds which were estimated from specific capacity tests on Well Completion Reports (personal communication from John Lambie). Vertical Ksat (Kv) values were estimated based on calculations from Maasland (1957), assuming a layered lithologic structure of isotropic near horizontal sedimentary bedding; this produces estimated horizontal to vertical anisotropy ratios of 15:1 to 28:1.

Table 1. Surface geology and estimated hydraulic properties

Soil Map Unit ID	Map Unit Description	Local Place Name or Descriptor	Lithology	Estimated Horizontal Saturated Hydraulic Conductivit9 (K_h, ft/day)	Estimated Vertical Saturated Hydraulic Conductivity (K_v, ft/day)
Qs	Recent dune sand	Discontinuous near-surface deposits	Windblown sand derived from Pleistocene alluvial fan deposits	28	1.1 to 1.9
Qsc	Recent river and major stream channel deposits in the Great Valley	Narrow locality along current streams	Sediments along river channels and major streams, including natural levees	10	0.4 to 0.6
Qb	Flood Basin Deposits	Lateral extensive near surface deposits	Mix of sand and silts with clay areas	5	0.2 to 0.3
Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	brown to gray sand and silt, with a relatively uniform westward-sloping surface	22	0.8 to 1.4
Qt	Quaternary nonmarine terrace deposits	Recent Structural Terrace	Stream terrace deposits of cobble and pebble gravel, sand, and silt, locally cemented	20	0.7 to 1.3
Qc	Pleistocene nonmarine sedimentary deposits	Riverbank Formation	Brown to gray sand, locally pebbly, minor silt and clay; terraced deposits exposed in areas along stream banks	72	2.6 to 4.5
Qp	Pliocene-Pleistocene nonmarine sedimentary deposits	Turlock Lake Formation	fluvial pebbly sand and gravel, interbedded silt and lacustrine clay	118	4.2 to 7.4
		Turlock Lake Formation Upper Unit	Sand zones with silt units dominant	22	0.8 to 1.4
		Turlock Lake Formation Middle Unit	Eroded member, virtually absent	28	1.0 to 1.8
		Turlock Lake Formation Lower Unit	Coarsening upward sequence, silt clay basal layer, sand zones and gravel unit typical	237	8.5 to 14.8
Pmlc	Middle and/or Lower Pliocene nomarine sedimentary rocks	Mehrten Formation	Fluvial, andesitic sand, sandstone, gravel, conglomerate, siltstone, claystone, and interbedded altered rhyolitic ash near base, locally includes hornblende andesite, basaltic agglomerate, tuff, and tuff breccia	100	3.6 to 6.3
Mc	Undivided Miocene nonmarine sedimentary rocks	Valley Springs Formation	Dominantly fluvial sequence of white tuffaceous sand, sandy clay, siliceous gravel; interbedded rhyolitic tuff partially altered to bentonitic clay	0.1	~0
Ec	Eocene nonmarine sedimentary rocks	Ione Formation	Pink, yellow, red, and gray, quartzose, anauxite-bearing sandstone and conglomerate, white sandy clay at base	10	0.4 to 0.6
Ku	Upper Cretaceous marine sedimentary rocks	No local place name in this locality	Potential for interbedded massive concretionary sandstone and siltstone, local sandstone dikes, organic shale with limestone concretions	NA[4]	NA
grg	Mesozoic granitic rocks	No local place name in this locality	Various granitic rocks, including grandiorite, quartz diorite, diorite, pegmatite, aplite, and some gabbro	NA	NA
JTRV	Jurassic and/or Triassic metavolcanic rocks	Gopher Ridge Volcanics	Metamorphosed mafic pyroclastic rocks, metamorphosed pillow lava and massive felsic flows	NA	NA

[1] Data modified from: California Division of Mines and Geology, 1966
[2] Type Section Data taken from USGS Bulletin 1470
[3] Estimates made from either local specific capacity tests in supply wells or estimates from material texture in USGS Bulletin 1470 and Table X from Groundwater (p. 29, Freeze & Cherry, 1979) and following Maasland,M., 1957. “Soil anisotropy and land drainage”. Drainage of Agricultural Lands ed. J.N. Luthin. American Society of Agronomy, Madison, Wisconsin, pp. 216-246
[4] NA=Not Analyzed

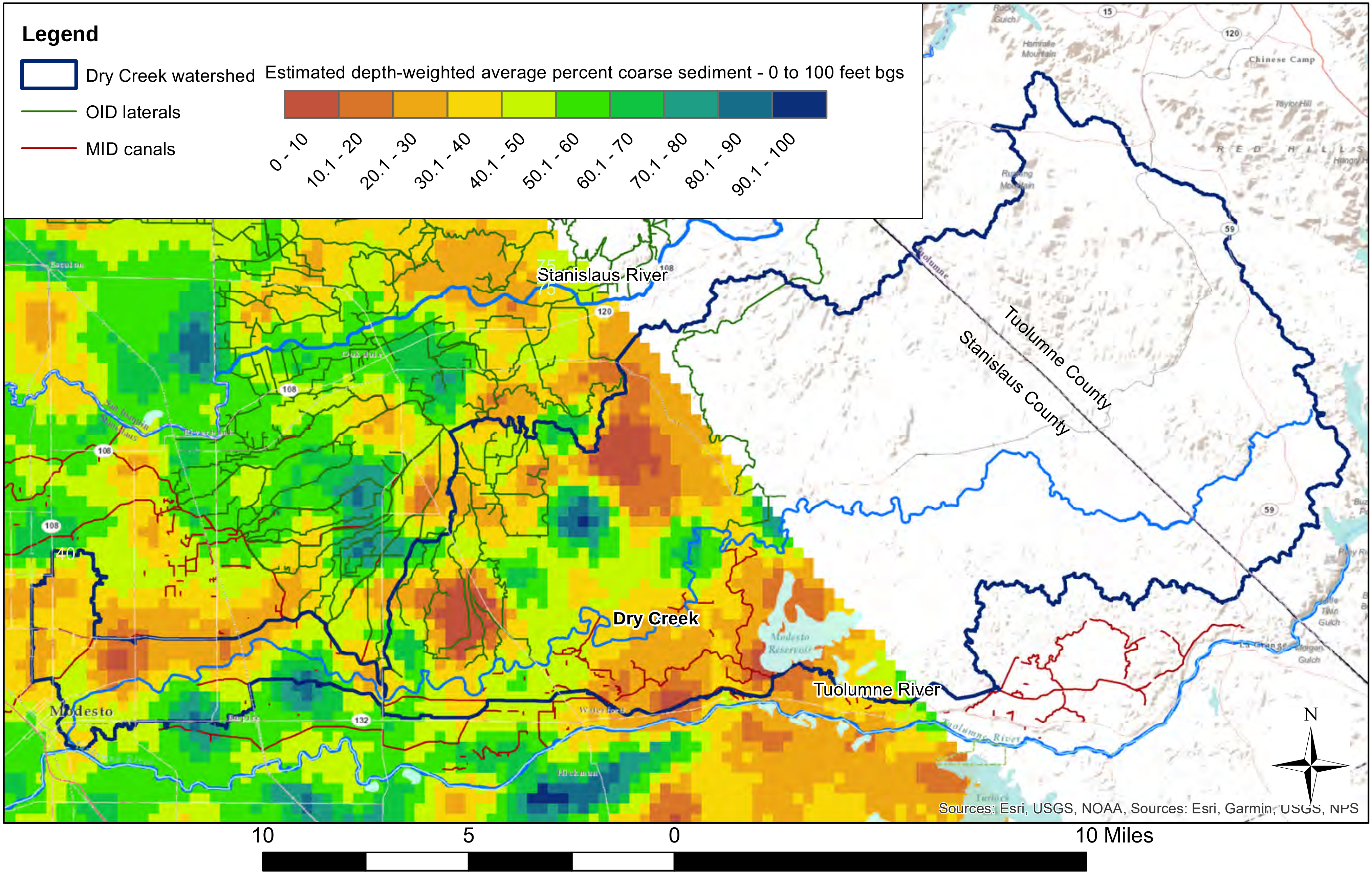
3.3.2 Subsurface Sediment Texture Data

In general, groundwater recharge is facilitated by the presence of coarse sediments (i.e. sand and gravel) in the subsurface, and restricted by the presence of fine-grained sediments (i.e. silt and clay). Therefore, the ratio of coarse-grained sediments to fine-grained sediments is a useful proxy for the ability of the vadose zone to recharge groundwater.

Collecting and analyzing borehole geologic log data within the proximity of Dry Creek was beyond the scope of this Phase I study. However, the USGS developed a binary classification method to describe sediment texture in terms of percent coarse for the purposes of numerical modeling in the Central Valley Hydrologic Model studies (Faunt, C.C. ed., 2009). That binary method was subsequently used in Phillips, 2015 for the more localized MERSTAN model of the Modesto and Turlock region to provide low resolution estimates of the lateral and vertical percentage of coarse sediments over the MERSTAN model layers.

MERSTAN coarse sediment data files were acquired from USGS (Steve Phillips, personal communication, 8/8/2019) for use in estimating the percent coarse sediment for the portion of the model domain that intersects the western portion of the DCW (Figure 6). These data are described by the USGS as well-constrained to 160 feet bgs due to a high density of log data to that depth (Phillips, et al., 2015). Model layer thicknesses are variable; consequently, data from the nine upper-most layers of the model were processed in ArcGIS (ver. 10.7, ESRI), to calculate a depth-weighted average percent coarse sediment to a 100-foot bgs depth.

Figure 7 shows the resulting coarse sediment percent averages for each model cell (1312 feet x 1312 feet). These data indicate there are several areas along Dry Creek that could have higher ratios of coarse to fine-grained sediments; these sediment estimates are insufficient to assess the relative permeability at potential project sites. Detailed analysis of the USGS data, borehole geologic logs and geospatial modeling are recommended for future project phases (See Section 6.0) to assist in identifying coarse sediment layers within the Dry Creek streambed and banks to identify optimum in-channel groundwater recharge areas.



Percent coarse sediment data from: Phillips, Rewis, Traum 2015. Hydrologic Model of the Modesto Region, California, 1960–2004. USGS, Scientific Investigations Report 2015–5045.

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Figure 7. Estimated depth-weighted average percent coarse sediment - 0 to 100 feet bgs

3.4 Depth to Groundwater and Groundwater Elevation Data

Depth to groundwater data from the California Department of Water Resources Water Data Library (CDWR, 2019) were reviewed for use in creating estimates of depth to water and groundwater elevation across the DCW for selected years. The years 1971 and 2015 were selected for their relatively large number of readings compared to other years (1971) and to represent recent (2015) groundwater levels. Data were processed in ArcGIS (ver. 10.7, ESRI) with interpolations made with the natural neighbor function in Spatial Analyst (ESRI). Wells with water level readings are concentrated in the southwestern end of the watershed, constraining the extent of the interpolations to that area.

Figure 8 and Figure 9 show estimated depth to groundwater in spring 1971 and spring 2015, respectively. Figure 10 and Figure 11 show the estimated groundwater elevation contours for spring of the same years, respectively. Figure 12 shows the estimated difference in groundwater elevation between spring of 1971 and spring of 2015.

Depth to groundwater increased from 1971 to 2015 from the southwest of the DCW to the central watershed (at the eastern extent of the well data), with corresponding decreases in groundwater elevation (Figure 8 through Figure 11). The difference in groundwater elevation between 1971-2015 (Figure 12) indicates a smaller (zero to 20 foot) decrease in groundwater elevation in the far southwest portion of the DCW and a greater decrease (60 to 80 feet) in the central watershed. There was insufficient well data in the central eastern portion of the DCW which contain the Mehrten, Valley Springs and Ione Formations (Section 3.2.2) to predict groundwater elevations. These data indicate that significant vadose zone storage has been created within the groundwater bearing units in the central portions of the DCW that can be used for potential groundwater recharge.

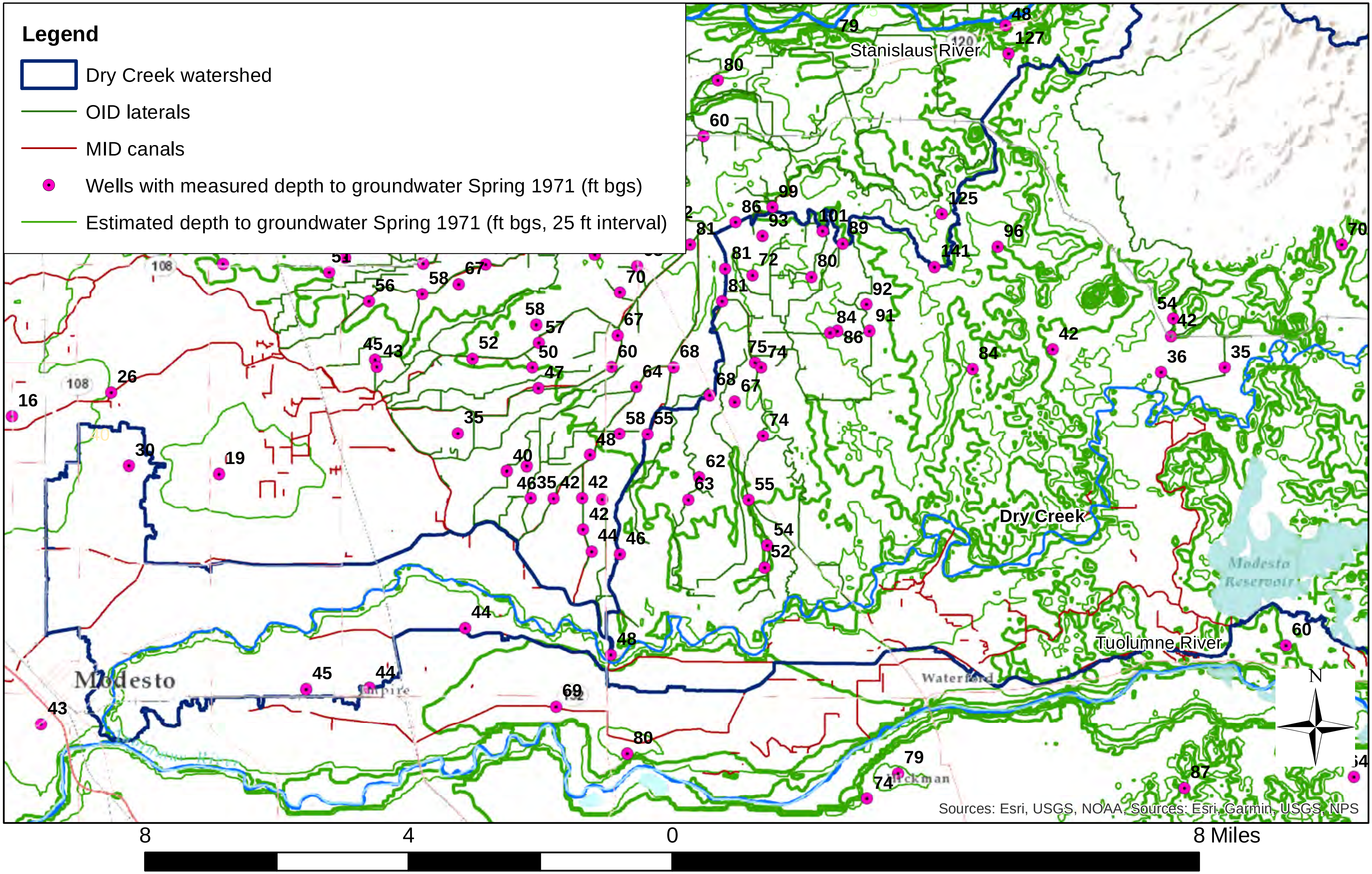

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Figure 8. Estimated depth to groundwater, Spring 1971

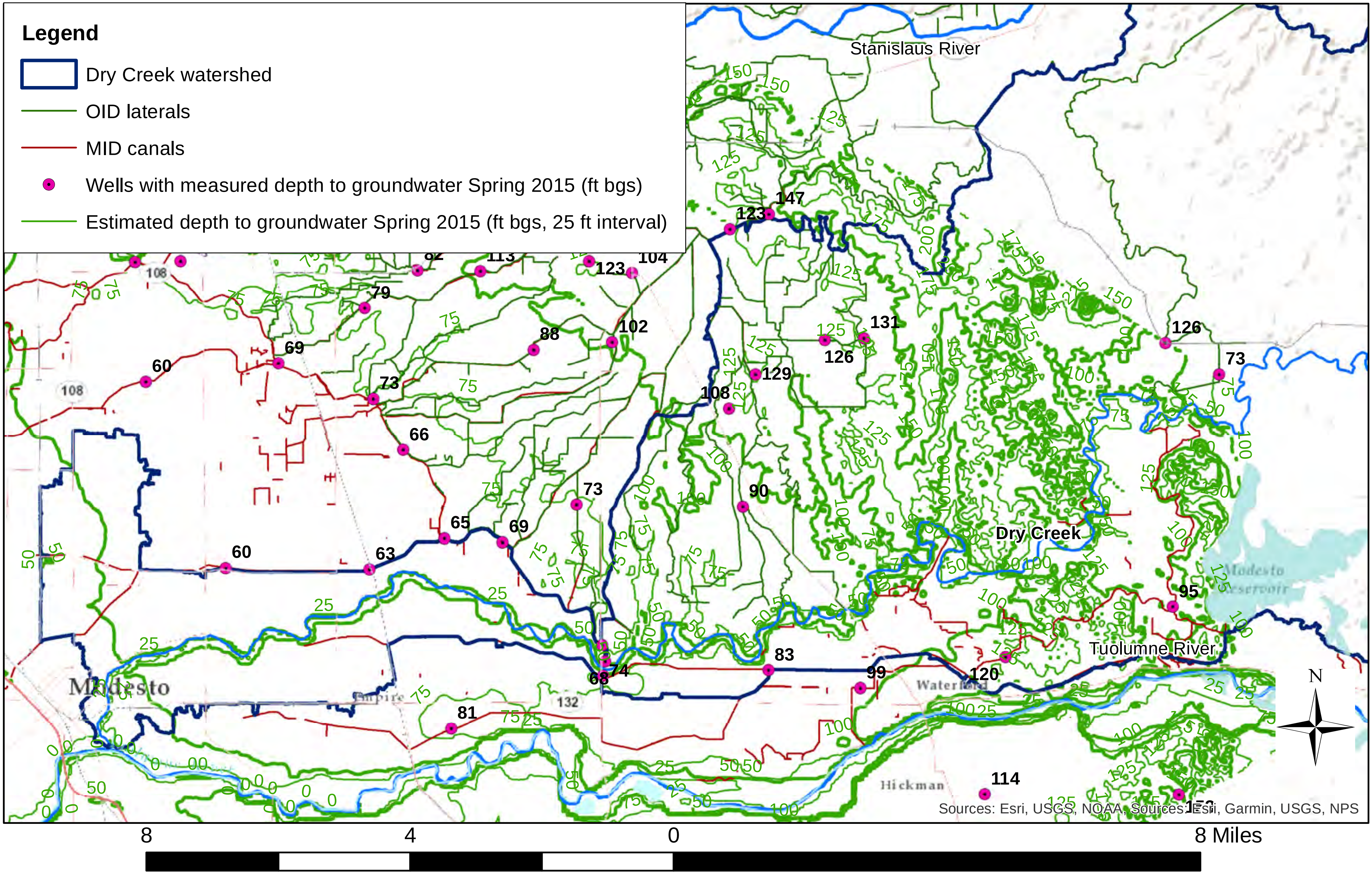

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Figure 9. Estimated depth to groundwater, Spring 2015

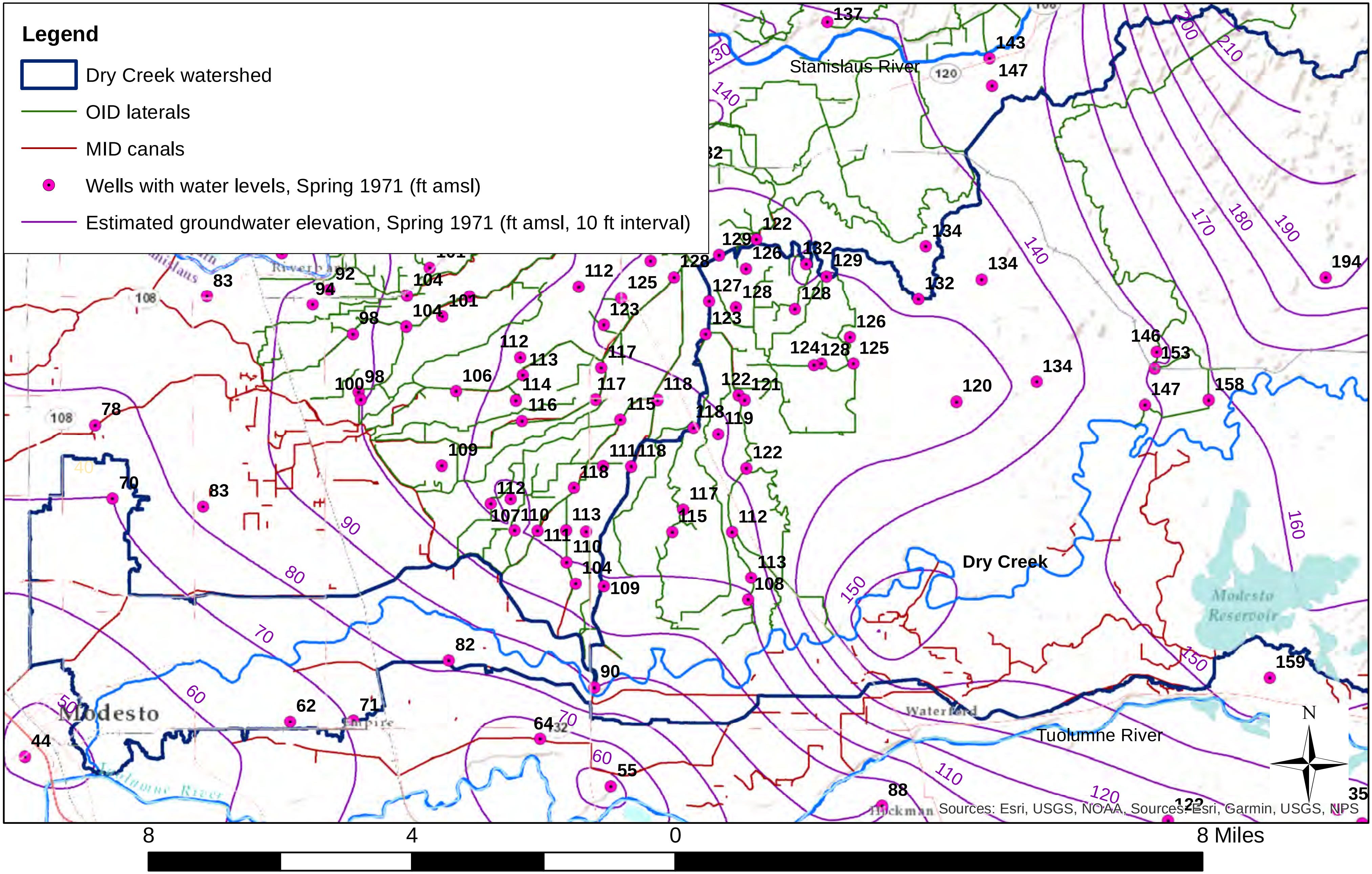

Figure 10. Estimated groundwater elevation, Spring 1971

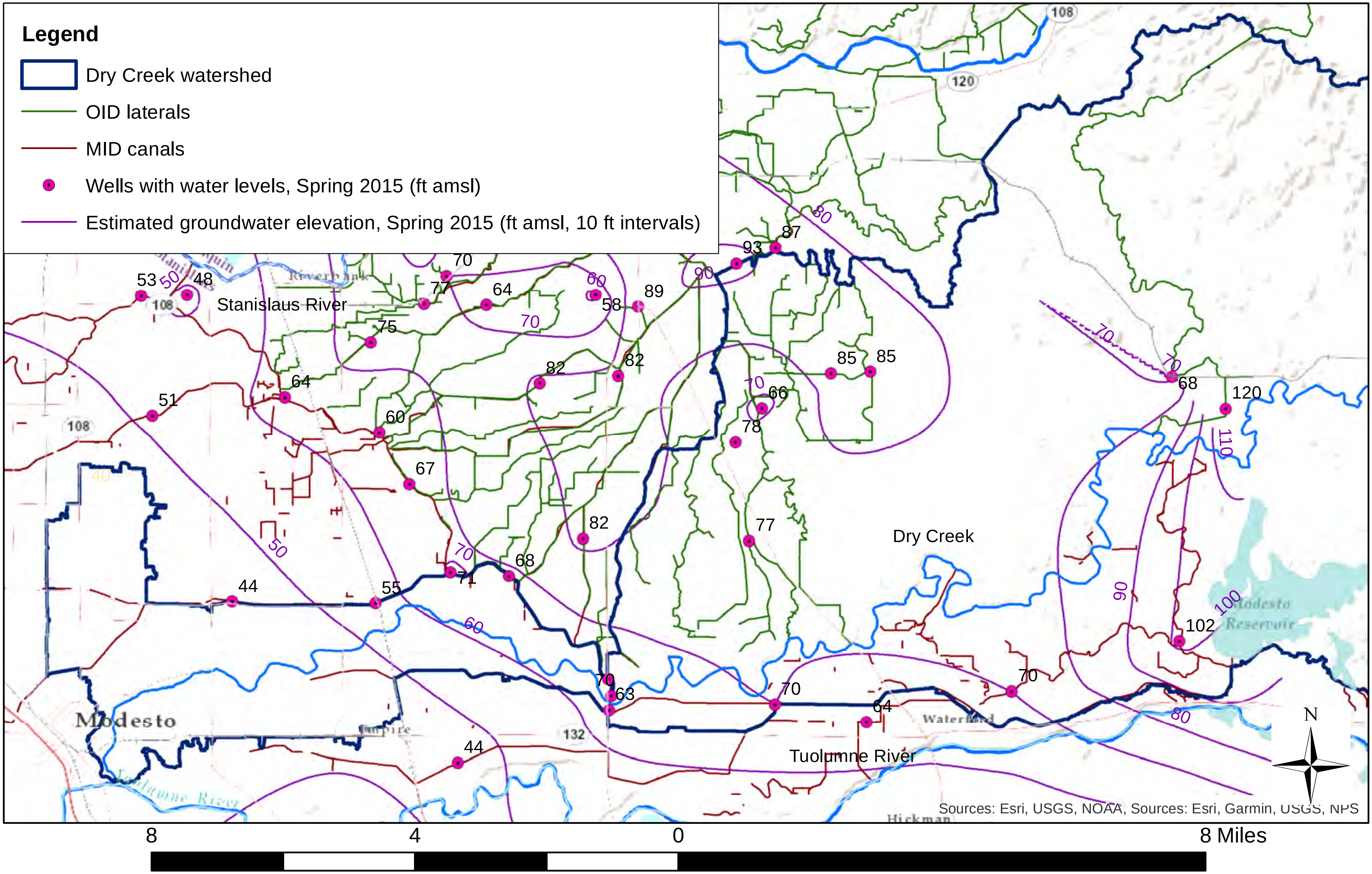

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Figure 11. Estimated groundwater elevation, Spring 2015

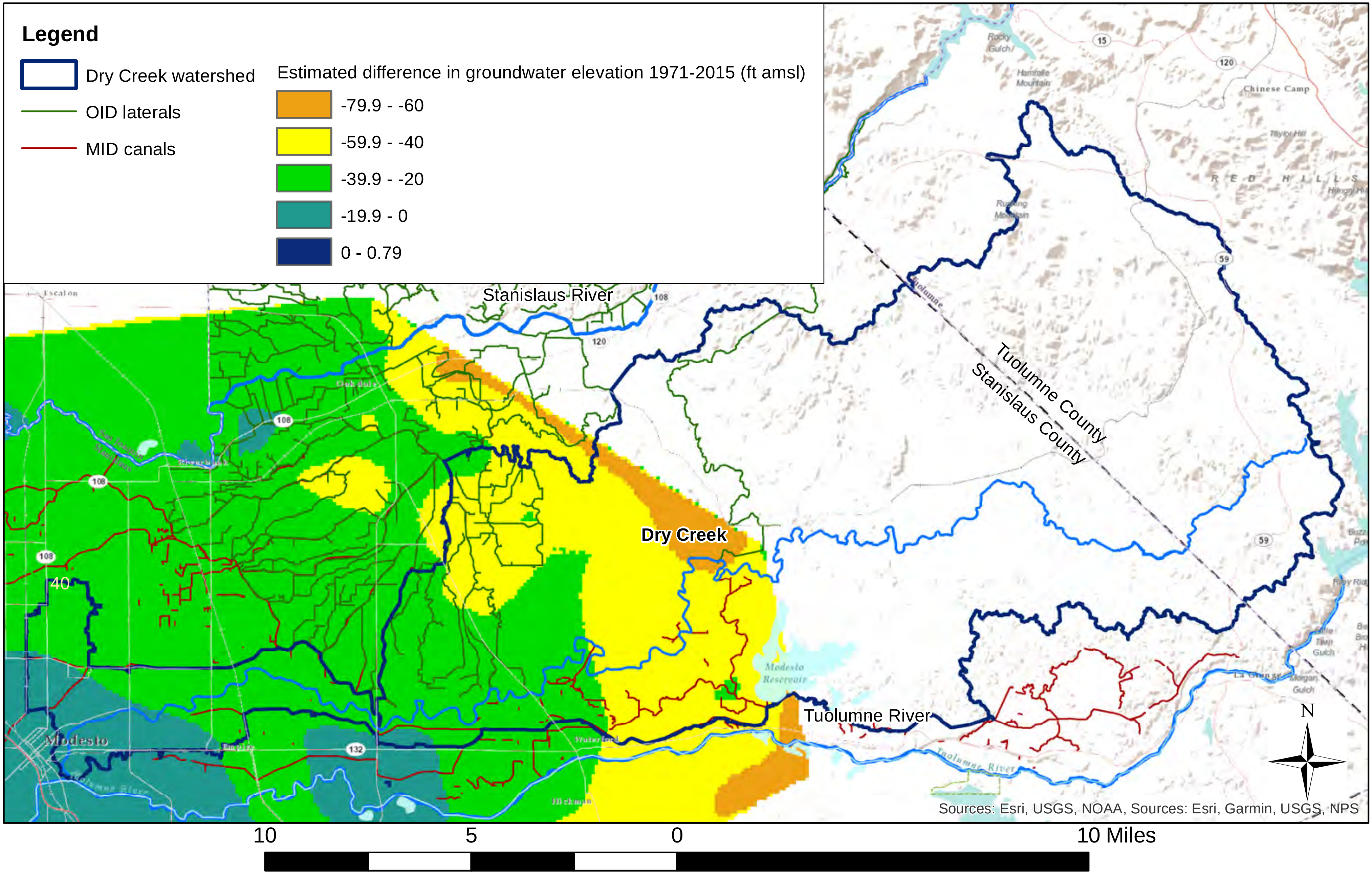

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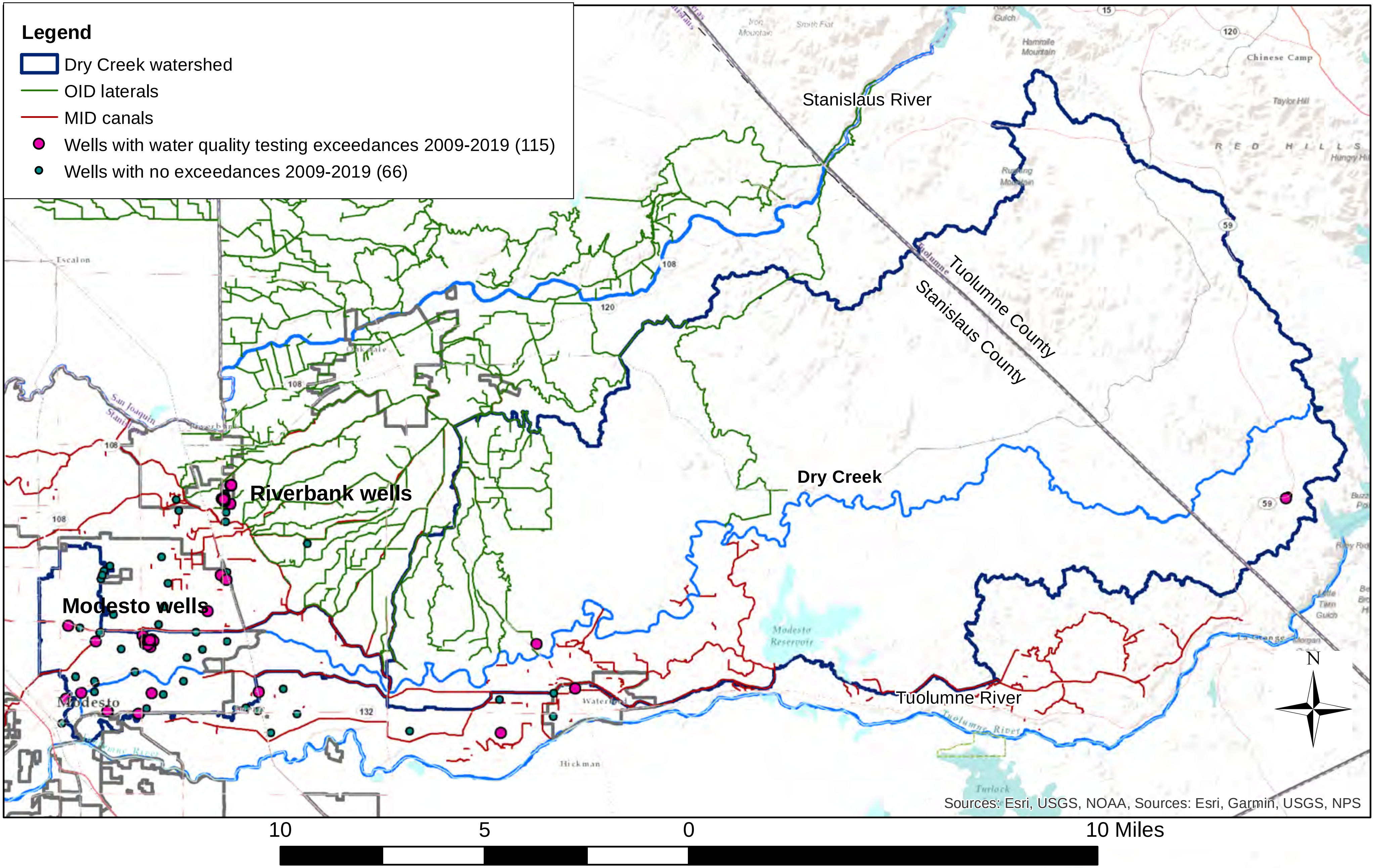
Figure 12. Estimated diference in groundwater elevation Spring 1971 to Spring 2015

3.5 Groundwater Quality

Groundwater quality data within the DCW area were acquired from the California State Water Resources Control Board's Groundwater Ambient Monitoring and Assessment (GAMA) Program Groundwater Information System (CSWRCB, 2019). Groundwater quality data were compiled as discussed in Attachment C.

Figure 13 shows locations for wells with groundwater quality test results from January 2009 to July 2019 exceeding the primary Safe Drinking Water Act Maximum Contaminant Level or secondary MCL for that parameter. Wells without exceedances during the same time period are also shown. Attachment C shows the most recent exceedance for each well and water quality parameter, along with the relevant MCL or SMCL.

Nearly all of wells, with and without exceedances, are clustered within the Modesto and Riverbank city boundaries and along the DCW's southwestern edge (Figure 13). Groundwater quality data is lacking within the vicinity of most of the potential flood control stormwater capture sites (Section 5.0). Consequently, the effect of potential groundwater recharge on existing groundwater quality is indeterminate in most of the DCW.



Groundwater quality test data from: California State Water Resources Control Boards, Groundwater Ambient Monitoring and Assessment Program. GAMA Groundwater Information System. Online: https://gamagroundwater.waterboards.ca.gov/gama/gamamap/public/Default.asp. Accessed 9/3/2019.

For well IDs and test results, see Table 5.

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Figure 13. Wells with groundwater quality testing exceedances, 2009-2019

4.0 SURFACE WATER ANALYSIS

Existing data within the DCW on site topography, soils, land use, precipitation, surface water drainages, canals and storm drain networks, were collected and used to develop an HEC-HMS model for the DCW (Attachment A). The HEC-HMS model was calibrated to a four-day storm event from January 2017 at the California Department of Water Resources stream gage location DCM just downstream of Claus Road. Figure 14 shows the final calibration hydrograph compared to the actual DCM stream gage data or the January 2017 storm event. Attachment A provides a detailed description of the surface water model development and results, a summary is provided below.

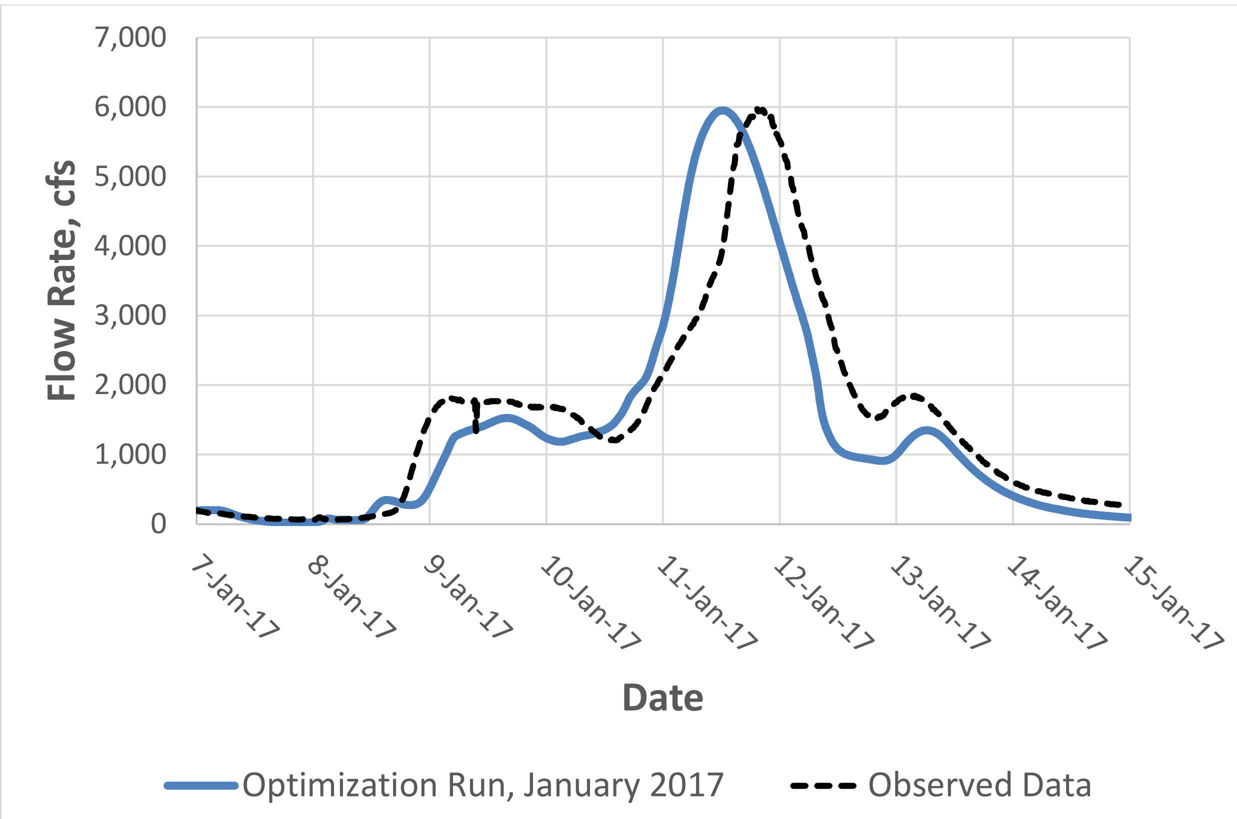

Figure 14. HEC-HMS predicted hydrograph at the DCM gage after model calibration and validation

A frequency analyses of precipitation within the DCW and measured surface water flow rates at the DCM from 1986 to 2019 indicates a 5-year return interval storm (20% exceedance probability) is approximately 4,710 cfs, which is similar to the peak flow rate which occurred in January 2017 which caused known flooding. Consequently, the 5-year and larger design storm events were selected as events that could cause the potential for flooding in downstream DACs. Eight storms occurred between 1986 and 2019 above the 5-year recurrence interval for peak flow rate and precipitation; most of these storms occurred in a similar pattern, with rainfall spread out over a 4-5-day period. Consequently, design storm events for the 2-year through 50-year return interval were developed based on a four-day precipitation event, spatially distributed through the DCW following NOAA guidelines.

Estimated peak surface water flow rates and volumes for various design storm events (i.e. 2-year, 5-year, 10-year, 25-year, and 50-year return intervals) were predicted for 15 potential stormwater capture sites within the DCW. Figure 15 shows the 15 potential stormwater capture sites selected for evaluation. The HEC-HMS model was used to evaluate peak flow rates under existing conditions at each of the 15 sites for each design storm. Table 2 presents the results of the existing condition HEC-HMS model at the 15 sites. The yield per acre of watershed ranges from around 0.09 to 0.12 acre-foot per acre for the 2-year event and up to 0.25 to 0.35 acre-foot per acre for the 50-year event.

The Dry Creek channel is highly incised at most of the 15 locations (20 to 77 feet below the off-channel surface). Consequently, in-channel stormwater detention and recharge will be the most likely conceptual design, due to engineering constraints in pumping stormwater above the channel incision. Attachment A contains conceptual plans for in-channel stormwater capture structures which include:

- A pneumatically operated spillway gate, which would allow for flows less than a 5-year peak flow rate to pass before the gate is lifted to create in-channel storage.
- An in-channel retention structure, with a Con Span Arch at the thalweg elevation to allow lower flows to pass.
- An in-channel retention structure with a reinforced concrete box culvert to allow flows to pass.

The in-channel stormwater capture designs would facilitate groundwater recharge by detaining water upgradient of the structure which would allow increased recharge through permeable sediments in the side-walls of the channel, and by slowly releasing the water to increase recharge in the downstream channel via longer periods of wetting.

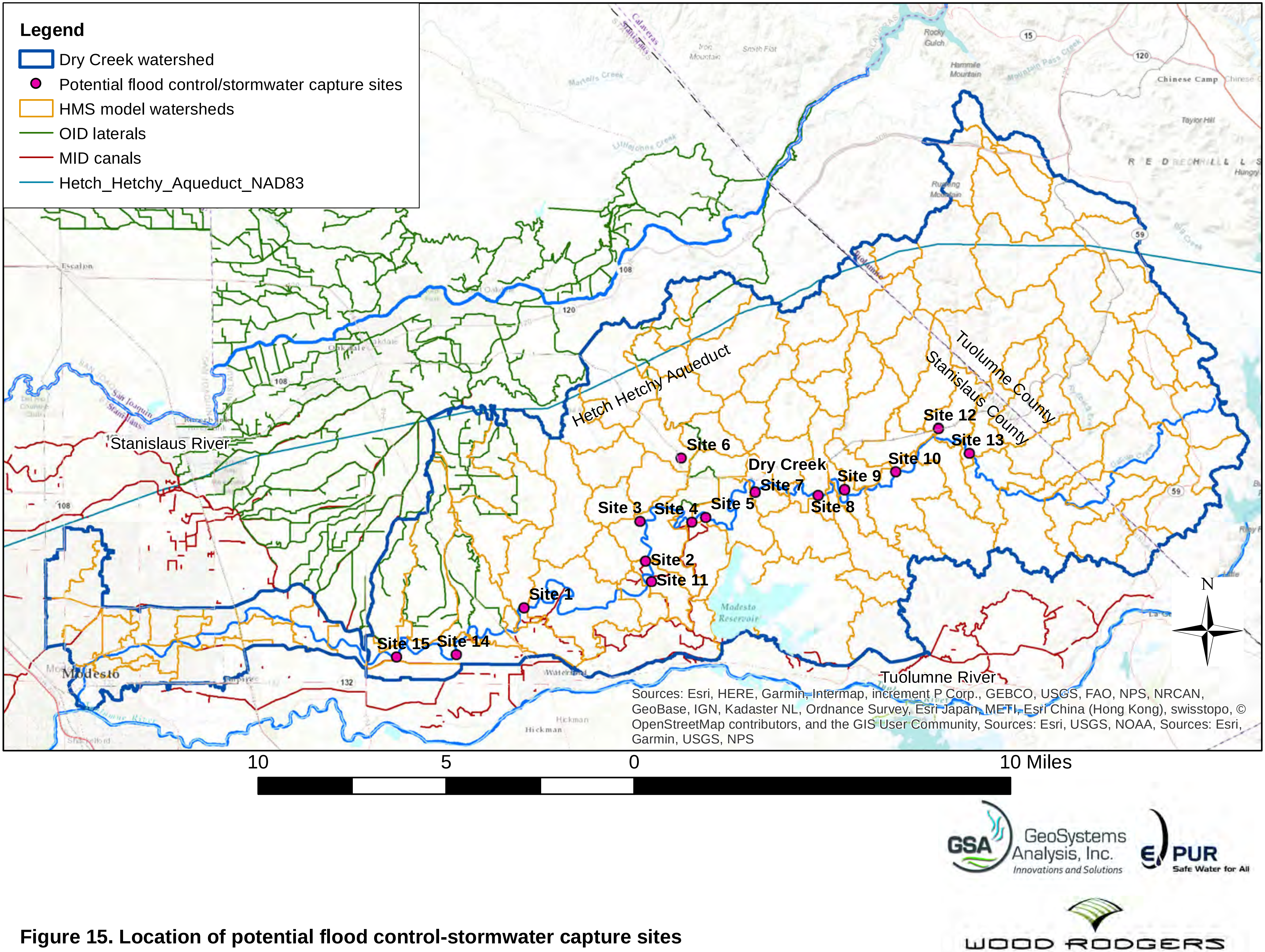

Figure 15. Location of potential flood control-stormwater capture sites

Table 2. Existing Condition HEC-HMS Model Results at 15 Potential Flood Control-Stormwater Capture Sites

Site	DRAIN AREA (Acres)	2-YEAR STORM PRECIP[1] = 2.36 IN		5-YEAR STORM PRECIP[1] = 3.32 IN		10-YEAR STORM PRECIP[1] = 3.92 IN		25-YEAR STORM PRECIP[1] = 4.69 IN		50-YEAR STORM PRECIP[1] = 5.25 IN	
		MAX CFS	TOT VOL (AC-FT)	MAX CFS	TOT VOL (AC-FT)	MAX CFS	TOT VOL (AC-FT)	MAX CFS	TOT VOL (AC-FT)	MAX CFS	TOT VOL (AC-FT)
DCM	135,910	3,200	12,700	5,400	21,900	6,900	28,100	8,900	36,300	10,000	42,800
Site 1	103,700	3,200	10,500	5,300	18,200	6,700	23,200	8,600	30,000	9,900	35,100
Site 2	90,370	3,500	9,990	5,700	17,000	7,100	21,600	8,900	27,700	10,000	32,300
Site 3	16,540	650	1,750	1,100	2,980	1,300	3,780	1,600	4,810	1,900	5,590
Site 4	70,780	2,800	8,020	4,600	13,600	5,800	17,400	7,300	22,200	8,400	25,900
Site 5	70,780	2,800	8,020	4,600	13,600	5,800	17,400	7,300	22,200	8,400	25,900
Site 6	10,250	500	1,170	800	1,960	980	2,470	1,200	3,130	1,400	3,640
Site 7	68,220	3,000	7,850	4,900	13,400	6,000	17,000	7,500	21,800	8,500	25,400
Site 8	63,310	2,800	7,360	4,500	12,500	5,600	16,000	7,100	20,400	8,200	23,900
Site 9	12,280	520	1,340	840	2,290	1,100	2,920	1,400	3,730	1,600	4,350
Site 10	44,500	2,100	5,400	3,600	9,200	4,500	11,700	5,700	15,000	6,600	17,500
Site 11	91,200	3,400	10,000	5,700	17,100	7,100	21,700	8,900	27,800	10,000	32,400
Site 12	43,610	2,100	5,310	3,600	9,050	4,500	11,500	5,700	14,800	6,600	17,300
Site 13	24,690	1,300	2,730	2,100	4,740	2,700	6,080	3,400	7,840	3,900	9,180
Site 14	108,090	3,100	10,700	5,300	18,500	6,600	23,700	8,500	30,600	9,800	36,000
Site 15	110,940	3,100	10,800	5,300	18,800	6,700	24,100	8,500	31,200	9,900	36,700

5.0 POTENTIAL FLOOD CONTROL AND STORMWATER CAPTURE SITES

A full assessment of flood control and recharge benefits at the 15 potential sites (Figure 15) will be addressed in a subsequent phase of this project. An initial assessment of the potential volumes that could be retained by flood control structures and an evaluation of the 10- year storm event at Site 2 are presented in Attachment A.

Figure 16 shows the estimated volume stormwater storage that could be provided based on the height of a conceptual flood control retention structure above the channel thalweg. These initial storage volume estimates indicate that a retention structure would need to be greater than 10 above the thalweg for at least 200 acre-feet of storage at any of the sites. Several sites (i.e. Sites 5-7 and 11-13) show relatively low increases in storage with increasing retention height, whereas storage volumes greater than 1000 acre-feet are achieved at sites 1-4 and 14-15 with retention heights greater than 20 feet. The remaining sites show intermediate storage volumes vs retention height.

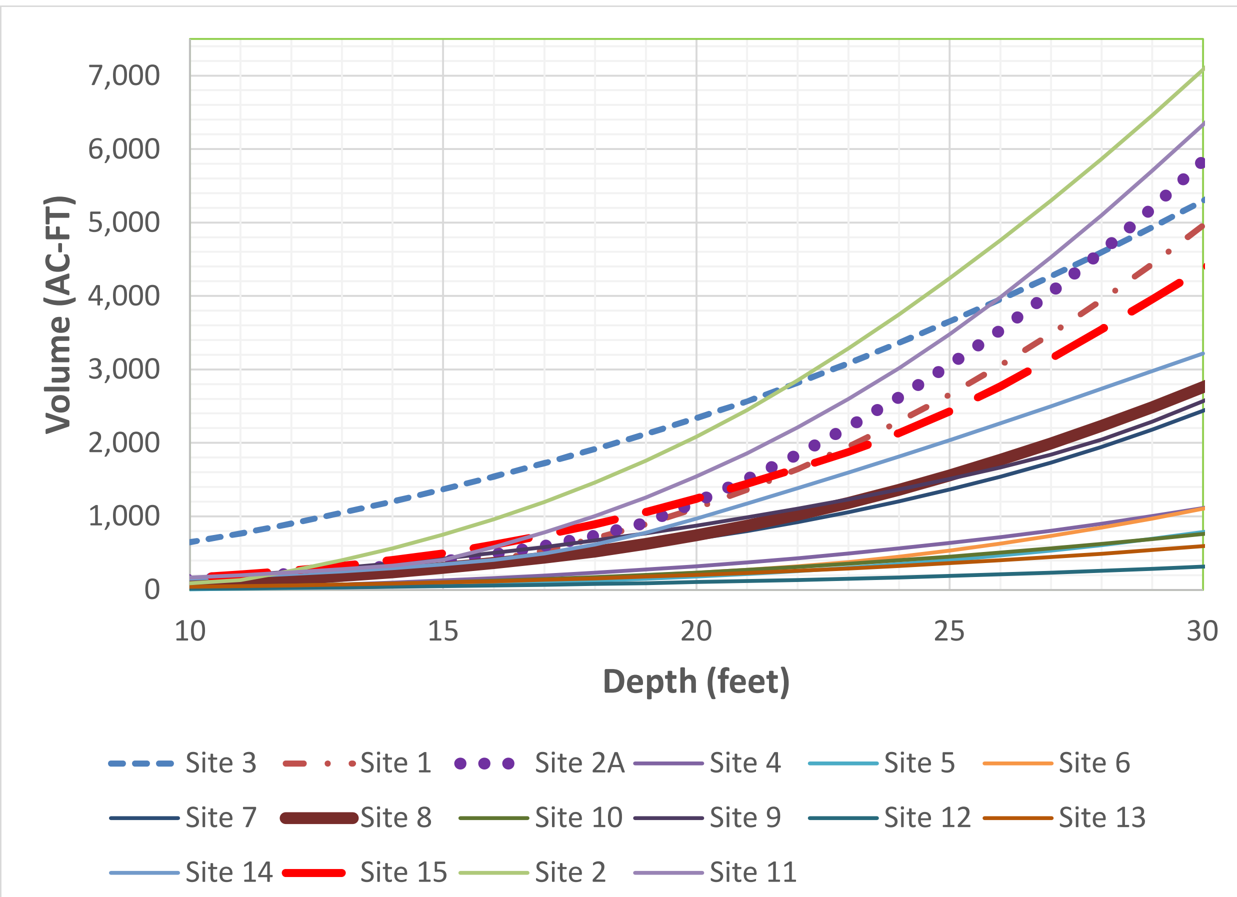

Figure 16. Volume of stormwater storage vs height above the channel thalweg.

A proposed condition HEC-HMS model was developed to evaluate a conceptual flood control design at Site 2 that could capture water up to the total height of the incision while releasing the

5-year flood event flows. Detailed results are shown in Attachment A. Site 2 has some of the greatest peak flow rates and volumes predicted at each of the sites (Table 2). Figure 17 shows the inundation area that would be created by retaining the 10-year storm event to reduce the peak flow rate to a 5-year event. This estimate indicates that most of the inundation would be contained within the Dry Creek channel, but that some agricultural field areas would be inundated (i.e. between sites 3 and 4).

To provide an initial estimate of the potential for groundwater recharge, the near-surface and subsurface hydrogeologic characteristics within 2,500 feet of each site was compiled as an initial approximation of the minimum upgradient channel distance that would be inundated under flood conditions; the downgradient channel distance that would receive the highest duration of stormwater release, and area proximal to Dry Creek for off-channel recharge.

Table 3 shows the surface geologic units present at each of the sites, depth to water was estimated using the 2015 data set presented in Figure 9, and the estimated depth of incision from the ground surface to the thalweg was estimated as discussed in Appendix A. These data indicate that sufficient vadose zone storage (i.e. greater than 50 feet) is probably available at sites 1-6 and 11. Sites 14 and 15 may have limited vadose zone storage, depending on the size of the storm event. Insufficient data is currently available for the other sites. With the exception of Site 6, all of the sites show greater than 29 feet of channel incision.

Figure 18 shows the estimated relative surface permeability for soils; with the exception of sites 1, 11, 4 and 15, the surficial soils proximal to the sites show generally low relative permeability (Figure 18). Figure 19 shows surficial geology data provided in Table 3. Higher permeability hydrogeologic units (Turlock Lake, Riverbank and Mehrten) are present in-channel at sites 4-8, 14 and 15. Of note, these units are also surficially present proximal to several sites and therefore may be encountered due to the Dry Creek channel incision. However, the hydrogeologic units exposed within the channel at each of these sites is currently unknown.

As discussed in Section 2.2.2, groundwater recharge enhancement features (i.e. drywells and infiltration galleries) could be used in areas that have low near-surface permeability, but are proximal to higher permeability subsurface hydrogeologic units. These features will be evaluated in subsequent phases of the project.

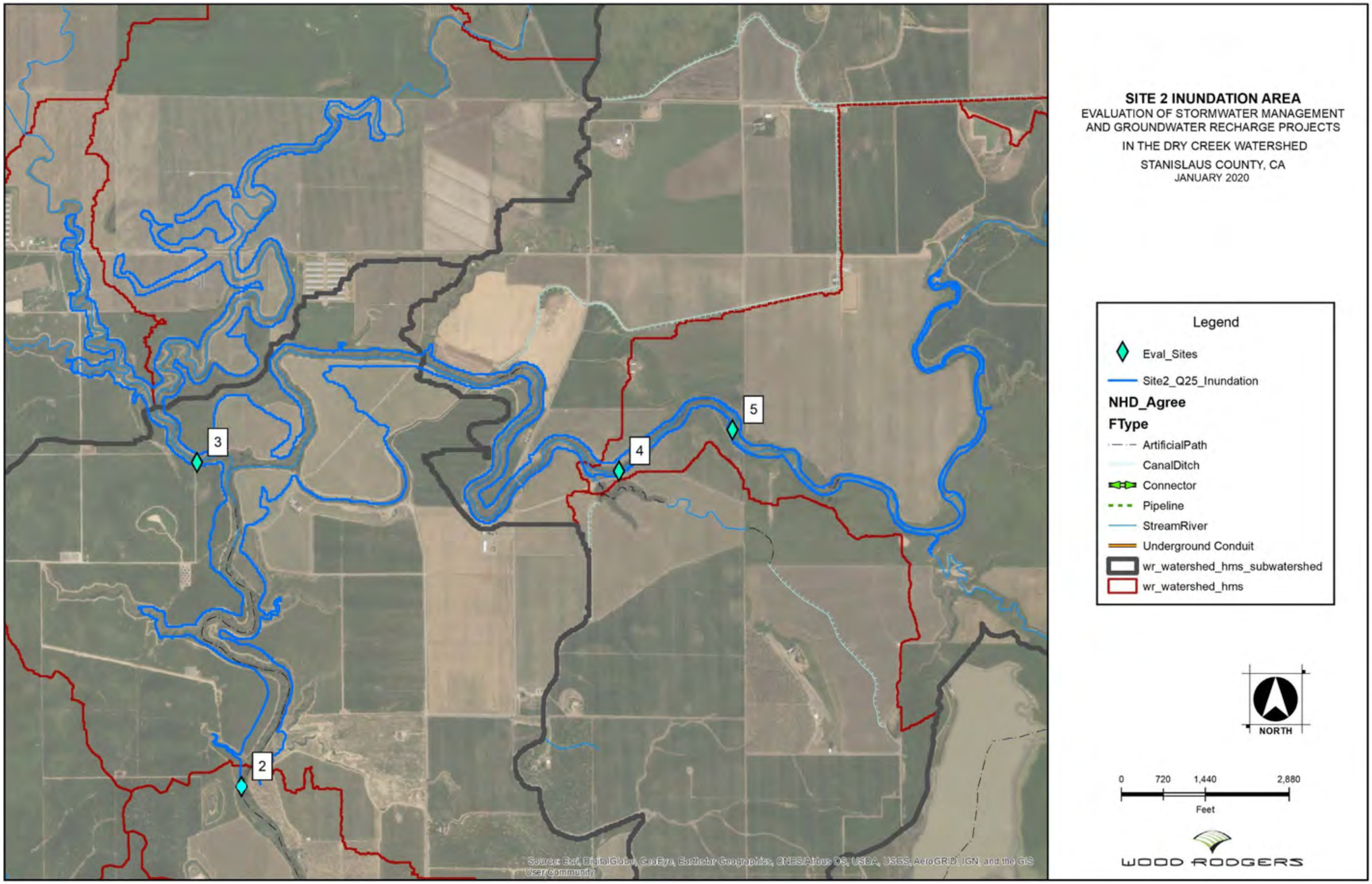

Figure 17. Site 2 Inundation Area, 10-year Storm Event

Table 3. Hydrogeologic units within 2,500 ft of potential flood control-stormwater capture sites

Site ID	Map Unit	Name	Hydrogeologic Unit	Proximity to Channel	Estimated vertical Ksat (ft/day)	Estimated depth to water at site (ft)	Depth of Channel Incision, Surface to Thalweg at Site (ft)	Geologic Formation at Depth of Incision
1	Qc	Pleistocene nonmarine sedimentary deposits	Riverbank Formation	130 ft	2.6 to 4.5	66	39	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	In channel	0.8 to 1.4			
	Qp	Pliocene-Pleistocene nonmarine sedimentary deposits	Turlock Lake Formation	In channel	4.2 to 7.4			
	Qsc	Recent river and major stream channel deposits in the Great Valley	Narrow locality along current streams	In channel	0.4 to 0.6			
2	Pmlc	Middle and or Lower Pliocene nonmarine sedimentary rocks	Mehrten Formation	2,300 ft	3.6 to 6.3	132	45	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	250 ft	0.8 to 1.4			
	Qsc	Recent river and major stream channel deposits in the Great Valley	Narrow locality along current streams	In channel	0.4 to 0.6			
3	Qc	Pleistocene nonmarine sedimentary deposits	Riverbank Formation	80 ft	2.6 to 4.5	74	33	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	In channel	0.8 to 1.4			
	Qsc	Recent river and major stream channel deposits in the Great Valley	Narrow locality along current streams	In channel	0.4 to 0.6			
4	Pmlc	Middle and or Lower Pliocene nonmarine sedimentary rocks	Mehrten Formation	In channel	3.6 to 6.3	74	55	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	In channel	0.8 to 1.4			
	Qp	Pliocene-Pleistocene nonmarine sedimentary deposits	Turlock Lake Formation	1,800 ft	4.2 to 7.4			
	Qsc	Recent river and major stream channel deposits in the Great Valley	Narrow locality along current streams	In channel	0.4 to 0.6			
5	Pmlc	Middle and or Lower Pliocene nonmarine sedimentary rocks	Mehrten Formation	In channel	3.6 to 6.3	48	35	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	In channel	0.8 to 1.4			
	Qp	Pliocene-Pleistocene nonmarine sedimentary deposits	Turlock Lake Formation	1,400 ft	4.2 to 7.4			
	Qsc	Recent river and major stream channel deposits in the Great Valley	Narrow locality along current streams	In channel	0.4 to 0.6			
6	Pmlc	Middle and or Lower Pliocene nonmarine sedimentary rocks	Mehrten Formation	In channel	3.6 to 6.3	Unknown	20	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	In channel	0.8 to 1.4			
	Qp	Pliocene-Pleistocene nonmarine sedimentary deposits	Turlock Lake Formation	1,800 ft	4.2 to 7.4			
7	Pmlc	Middle and or Lower Pliocene nonmarine sedimentary rocks	Mehrten Formation	In channel	3.6 to 6.3	Unknown	60	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	In channel	0.8 to 1.4			
	Qp	Pliocene-Pleistocene nonmarine sedimentary deposits	Turlock Lake Formation	300 ft	4.2 to 7.4			
	Qt	Quaternary nonmarine terrace deposits	Recent Structural Terrace	350 ft	0.7 to 1.3			
8	Pmlc	Middle and or Lower Pliocene nonmarine sedimentary rocks	Mehrten Formation	In channel	3.6 to 6.3	Unknown	36	??
	Qt	Quaternary nonmarine terrace deposits	Recent Structural Terrace	In channel	0.7 to 1.3			
9	Pmlc	Middle and or Lower Pliocene nonmarine sedimentary rocks	Mehrten Formation	1,100 ft	3.6 to 6.3	Unknown		??
	Qt	Quaternary nonmarine terrace deposits	Recent Structural Terrace	In channel	0.7 to 1.3			
10	Mc	Undivided Miocene nonmarine sedimentary rocks	Valley Springs Formation	In channel	approx 0	Unknown	46	??
	Pmlc	Middle and or Lower Pliocene nonmarine sedimentary rocks	Mehrten Formation	75 ft	3.6 to 6.3			
	Qt	Quaternary nonmarine terrace deposits	Recent Structural Terrace	In channel	0.7 to 1.3			

Table 5. Hydrogeologic units within 2,500 ft of potential flood control-stormwater capture sites (continued)

Site ID	Map Unit	Name	Hydrogeologic Unit	Proximity to Channel	Estimated vertical Ksat (ft/day)	Estimated depth to water at site (ft)	Depth of Channel Incision, Surface to Thalweg at Site (ft)	Geologic Formation at Depth of Incision
11	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	700 ft	0.8 to 1.4	53	48	??
	Qsc	Recent river and major stream channel deposits in the Great Valley	Narrow locality along current streams	In channel	0.4 to 0.6			
12	Qt	Quaternary nonmarine terrace deposits	Recent Structural Terrace	In channel	0.7 to 1.3	Unknown	45	??
	Mc	Undivided Miocene nonmarine sedimentary rocks	Valley Springs Formation	In channel	approx 0			
13	Ec	Eocene nonmarine sedimentary rocks	Ione Formation	1,600 ft	0.4 to 0.6	Unknown	77	??
	Mc	Undivided Miocene nonmarine sedimentary rocks	Valley Springs Formation	In channel	approx 0			
	Qt	Quaternary nonmarine terrace deposits	Recent Structural Terrace	In channel	0.7 to 1.3			
14	Qc	Pleistocene nonmarine sedimentary deposits	Riverbank Formation	In channel	2.6 to 4.5	30	30	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	300 ft	0.8 to 1.4			
15	Qc	Pleistocene nonmarine sedimentary deposits	Riverbank Formation	In channel	2.6 to 4.5	42	29	??
	Qf	Recent alluvial fan deposits in the Great Valley	Modesto Formation	120 ft	0.8 to 1.4			

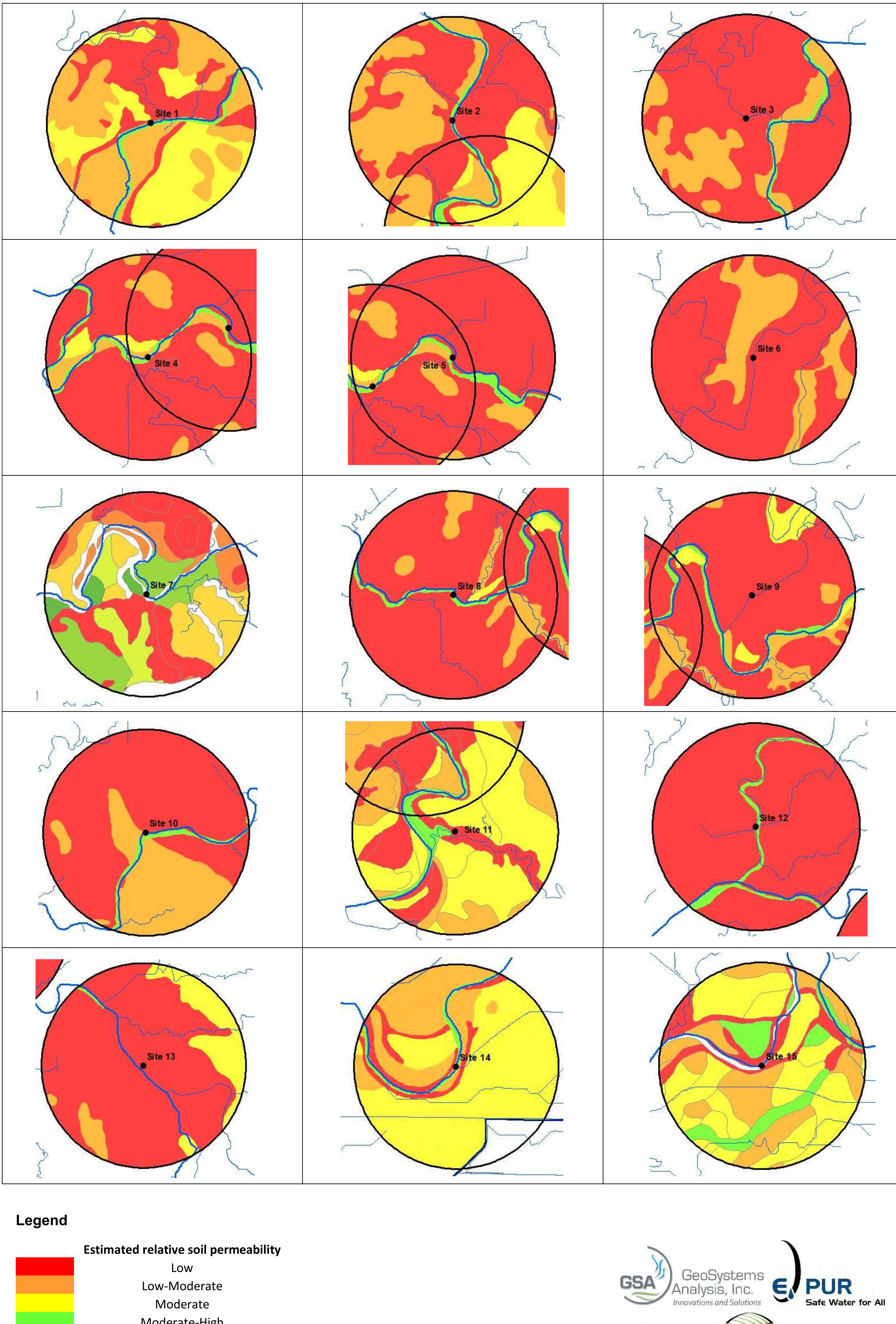

Figure 18. Relative soil permeability within 2500 feet of proposed sites

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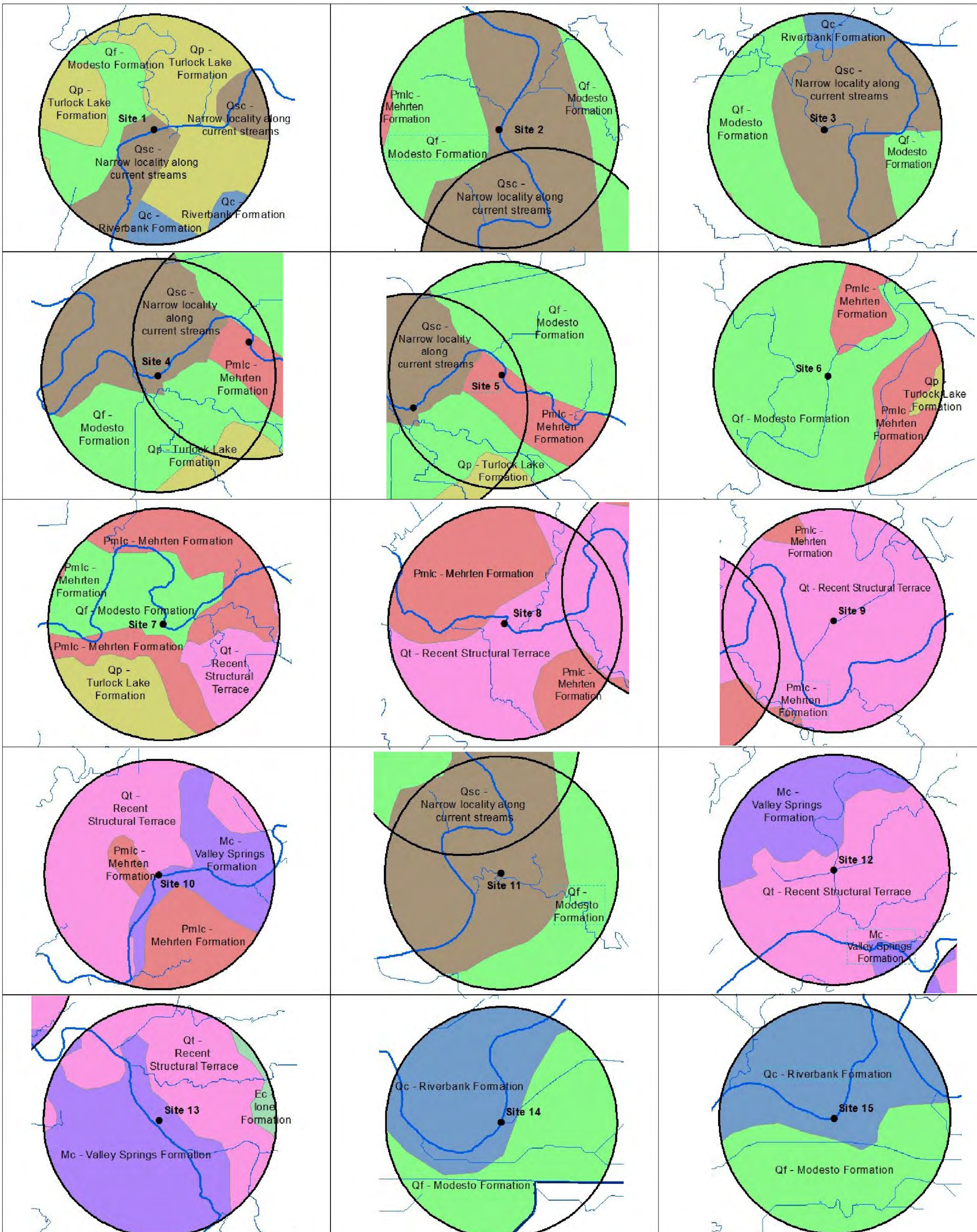

Legend

Map Unit ID	Hydrogeologic Unit	Est. Kv (ft/day)
Ec	Ione Formation	0 .4 - 0.6
Mc	Valley Springs Formation	approx. 0
Pmlc	Mehrten Formation	3.6 - 6.3
Qc	Riverbank Formation	2.6 - 4.5
Qf	Modesto Formation	0.8 - 1.4
Qp	Turlock Lake Formation	0.8 - 14.8
Qsc	Narrow locality along current streams	0.4 - 0.6
Qt	Recent Structural Terrace	0.7 - 1.3

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Figure 19. Hydrogeology within 2500 feet of proposed sites

6.0 RECOMMENDATIONS FOR SUBSEQUENT PHASES

Based on the Phase I findings and datasets available, the following recommendations are made for Phase II of the Stormwater Management and Groundwater Recharge program to assist in site evaluation and selection of at least three high priority projects:

- Evaluate reducing the 15 initial prospective project sites herein to a smaller number of sites using a range of criteria developed by the Stanislaus County Project Development Team:
  - Conduct initial meetings with landowners and water use authorities within the STRGBA GSA
  - Conduct a community outreach event to gain further input on the potential project sites
- Surface water modeling to predict the peak flow reduction and changes in the area of inundation at each site for the 10-, 25- and 50-year return interval storm event
- Gather data from consultants for the SGMA groundwater sustainability plan development
  - Any additional groundwater elevation data for historic periods, particularly 2015
  - Geologic datasets and cross section information in and near the DCW
- Evaluate and map hydrostratigraphic units in detail at potential project locations
  - Convert high quality borehole well logs to sediment texture data
  - Develop more detailed geologic cross-sections in order to estimate hydrogeologic suitability
  - Develop a sediment-texture model within the DCW and potential project locations.
  - Evaluating data in the vicinity of potential sites to develop estimates of vertical lithologies and relative subsurface permeabilities
- Select and contact various well owners to obtain depth to water data within the central and eastern portion of the DCW to improve understanding of groundwater elevations.
- Subsequent to the Multiple Accounts Analysis (MAA) evaluation to identify high priority projects/project sites:
  - Conduct field site reconnaissance work to provide needed information for conceptual designs of the prospective project.
  - perform further hydraulic modeling as needed.
  - perform data and modeling analyses to assess project benefits and risks.

    - prepare preliminary project designs and estimated costs.
    - Conduct additional DAC community and land owner/water-user stakeholder outreach to describe and discuss the Priority Projects.
- Document these analyses in sufficient detail to provide the basis for a Phase III of site characterization and project designs for the Priority Projects.

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ATTACHMENT A

Technical Memo #1: Surface Water Portion of Phase I Evaluation of Stormwater Management and Groundwater Recharge Projects in The Dry Creek Watershed

TECHNICAL MEMORANDUM

TO: Michael Milczarek, Program Director, GSA

FROM: David Mueller, Wood Rodgers Inc.

DATE: March 11, 2020

SUBJECT: Technical Memo #1: Surface Water Portion of Phase I Evaluation of Stormwater Management and Groundwater Recharge Projects in The Dry Creek Watershed

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INTRODUCTION

The purpose of this memo is to provide technical information regarding the surface water analysis performed by Wood Rodgers, Inc. (WRI) for the Phase I Evaluation of Stormwater Management and Groundwater Recharge (SMGR) Projects in The Dry Creek Watershed (Project).

SURFACE WATER MODELING APPROACH AND CALIBRATION

WRI developed a HEC-HMS hydrologic model to serve as the basis for comparison for up to 15 potential detention/ground water recharge sites within the watershed. WRI collected existing data within the watershed and developed a Project geodatabase containing site topography, soils data, land use data, precipitation data, and canals and storm drain linework, which was subsequently used to develop a HEC-HMS model for the Dry Creek watershed.

Digital Elevation Model (DEM)

WRI obtained ground elevation data from several sources, including digital elevation models (DEM) ranging from 1/9 Arc-Second to 1-meter resolution from the United States Geological Survey (USGS), National Elevation Data; and DEMs generated from LiDAR data from the California Department of Water Resources Central Valley Floodplain Evaluation and Delineation Program (CVFED). WRI developed a DEM of the Dry Creek Watershed at a resolution of 10 feet for the purposes of watershed delineation, and developed a DEM at a resolution of 3 feet for the purposes of specific site analysis for this and for future analyses.

Model Development

WRI collected Geographic Information System (GIS) data from Stanislaus County, the City of Modesto, Oakdale Irrigation District (OID), Modesto Irrigation District (MID), National Oceanic and Atmospheric Administration (NOAA), Federal Emergency Management Association (FEMA), and United States Geological Survey (USGS). The DEM was modified by burning in selected irrigation canals, creeks, and pipe networks within the watershed in order to create flow paths consistent with drainage patterns within the watersheds. WRI used ESRI's Arc Hydro Tools and Python scripts written by Wood Rodgers to create a hydrologically accurate DEM for the purposes of watershed delineation.

Data were obtained from three stream gauges:

1) Location DCM on Dry Creek is operated by the California Department of Water Resources and is located just downstream of Claus Road. The period of record extracted from the CDEC (https://cdec.water.ca.gov/dynamicapp/wsSensorData) and the California Department of Water Resources Library (http://wdl.water.ca.gov/waterdatalibrary/docs/Hydstra/index.cfm?site=B04130) for Gage DCM extends from 1987 to current.

2) Stream gauge data was obtained from MID for a stream gauge at Dry Creek near Crabtree Road from 1996 to 2019. Based on communication with MID, the data at this gage is questionable and was not utilized in the analysis.

3) Station MOD on the Tuolumne river is located near the confluence with Dry Creek and is operated by the USGS. Rain gauge data was obtained from six precipitation gauges within the Dry Creek watershed. **Table 1** presents stream flow and precipitation gauge data used in the surface water analysis.

Stream flow and precipitation data were collected and stored in a DSS file storage for use in model calibration efforts.

Table 1. Streamflow and Precipitation Stations

Name	X	Y	Agency Name	Elevation	Station Name	Data Frequency	Type
DCM	-120.92	37.66	CA Dept of Water Resources	88	DRY CREEK AT MODESTO AT CLAUS ROAD	15 Minute	Stream flow
DCC	-120.31	37.65	Merced Irrigation District	728	DRY CREEK NEAR COULTERVILLE	15 Minute	Precipitation
CWS	-120.60	37.72	Modesto Irrigation District	226	CRABTREE WEATHER STATION	Hourly	Precipitation
GTO	-120.68	37.85	US Army Corps of Engineers	600	GOODWIN TUNNEL OUTLET	15 Minute	Precipitation
RCF	-120.96	37.92	US Army Corps of Engineers	100	ROCK CK BLW FARMINGTON DAM	15 Minute	Precipitation
OKW	-120.85	37.73	Stanislaus County	186	OAKDALE WEATHER STATION	Hourly	Precipitation

MBN	-120.61	37.45	Merced Irrigation District	117	MERCED R AT SHAFFER BRIDGE NR CRESSY	15 Minute	Precipitation
CRB			Turlock Irrigation District		DRY CREEK AT CRABTREE ROAD	Hourly	Stream flow
MOD	-120.99	37.63	US Geological Survey	90	TUOLUMNE RIVER AT MODESTO	15 Minute	Stream flow

Arc hydro tools were used to create a HEC-HMS model (HEC-HMS; U.S. Army Corps of Engineers, Version 4.3, September 2018). The Soil Conservation Service (SCS) Curve Number method (United States Department of Agriculture, Natural Resources Conservation Service, National Engineering Handbook, Part 630 Hydrology, Chapter 9, U.S. Department of Agriculture, July 2004) was used to determine losses. A curve number grid was developed for the entire watershed, using GIS tools. Land use values were extracted from the 2011 USGS land use database, with land uses assumed to remain in existing condition, as significant future development is not expected in the watershed. Soils data used to develop the curve number estimates were obtained from USGS. Lag times were determined using the Basin "N" lag equation originally developed by the US Army Corps of Engineers and used in Sacramento County and other areas in the Central Valley (Sacramento City/County Drainage Manual, 1996):

$$L_g = Cn\left(\frac{L\,L_c}{S^{0.5}}\right)^{0.33}$$

Where:

$$C = 1560$$

$L_g =$ Lag time, min

$L =$ Length of longest watercourse, measured as approximately 80% of the distance from the point of interest to the headwater divide of the basin, miles (“headwater divide” is defined as the furthermost downstream point in each individual drainage basin)

$L_c =$ Length along the longest watercourse measured upstream from the point of interest to a point close to the centroid of the basin, miles (m) (The centroid of the basin is defined as the location of the point within the drainage basin that represents the weighted center of the basin. It is the first moment of the area about the origin)

$S =$ Overall slope of the longest watercourse between the headwaters and concentration point, ft/mile

$n =$ Basin “n”

Routing was accomplished using the Muskingum-Cunge routing method in HEC-HMS, with channel slopes and widths determined through inspection of the Project DEM. Aerial photos were used to determine Manning's 'n' parameters, which typically were set to 0.05.

Storm Event Selection and Model Calibration

Based on WRI's review of documentation from the Regional Flood Management Plan for the Mid-San Joaquin River Region (California Department of Water Resources, 2014) and from discussions with Stanislaus County Staff during a meeting on October 30, 2019; flooding occurs in Dry Creek when flows above 5,000 – 6,000 cfs in Dry Creek occur concurrently with releases from Don Pedro Dam of 9,000 cfs.

WRI reviewed stream flow data from station DCM from 1986 – 2019 and performed a log-Pearson III analysis of the data using the NRCS Frequency Curve Determination spreadsheet, which uses procedures developed with Bulletin 17B by USGS (U.S. Department of the Interior, Geological Survey, March 1982). **Figure 1** presents the results of the statistical analysis for station DCM.

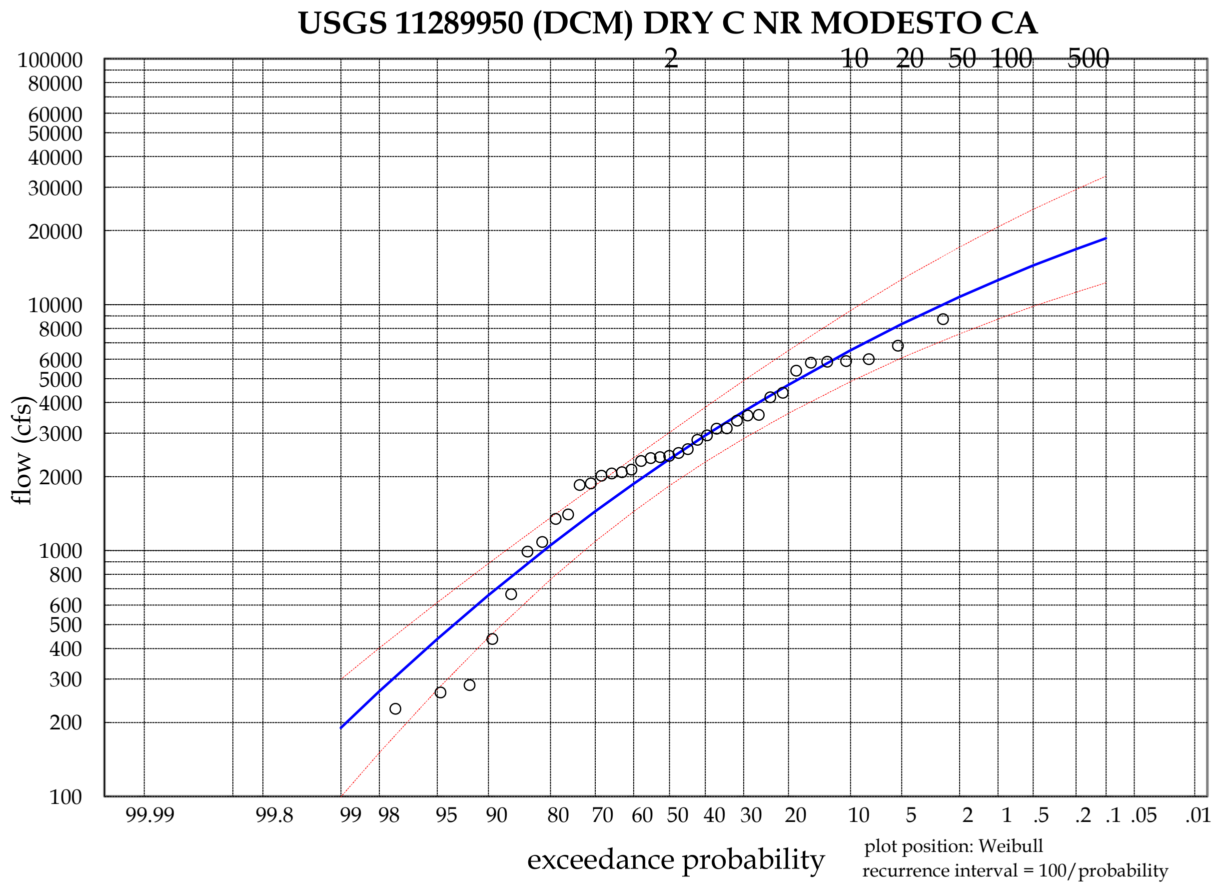

Figure 1, NRCS Frequency Curve Determination Spreadsheet

The frequency analysis shows a 5-year recurrence interval storm (20% exceedance probability) is approximately 4,710 cfs, which is similar to the peak flow rate which occurred in January 2017 which caused known flooding. Based on our review of data from Station DCM, WRI found eight (8) storms occurring between 1986 and 2019 above the 5-year recurrence interval for peak flow rate and precipitation. **Figure 2** presents the stream gauge record for Station DCM.

The majority of these storms occurred in a similar pattern, with rainfall spread out over a 4-5-day period. Therefore, WRI developed a design storm with a rainfall pattern based off the January 2017 storm event.

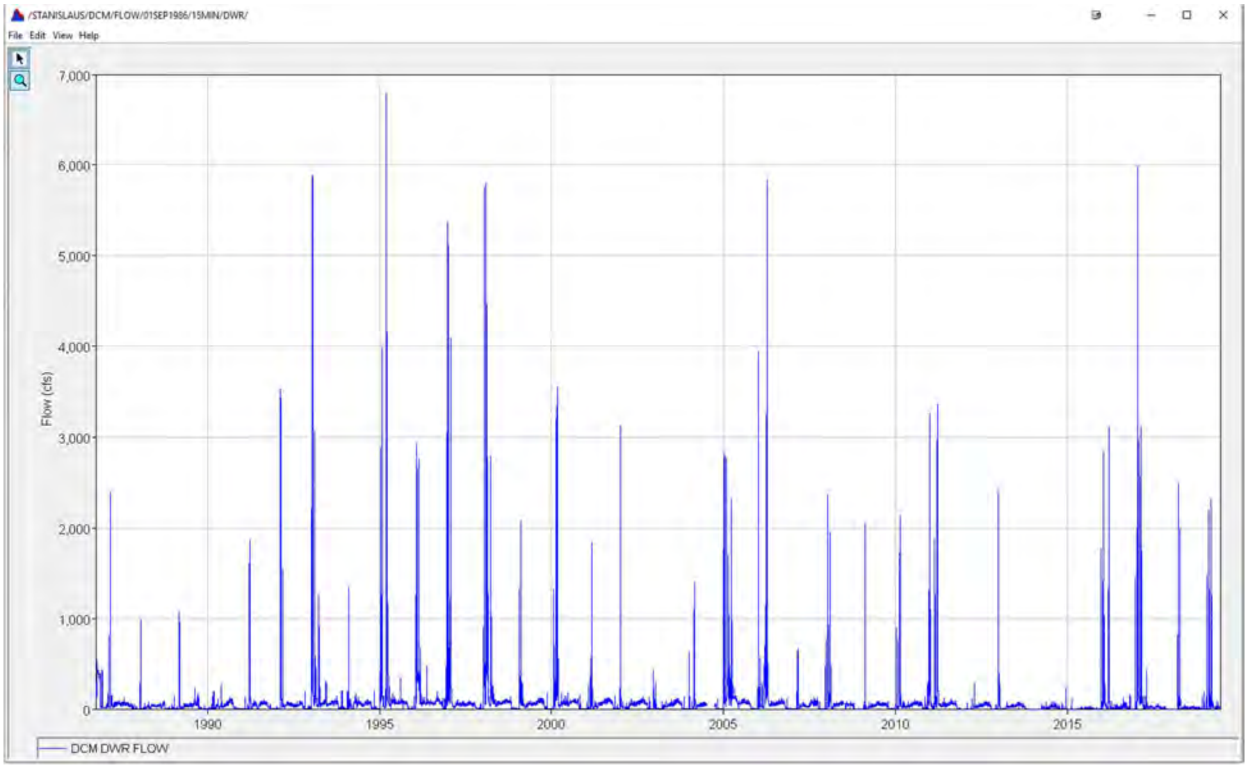

Figure 2, DCM Stream Gauge Record

The HEC-HMS model was calibrated to the January 2017 storm event, and verified using the March 2016 storm event using the Inverse Distance method, with indexing precipitation gauges to annual rainfall. The resultant hydrograph at HEC-HMS Junction J7631-DCM was compared with data from the station DCM. Basin lag times were adjusted using the optimization feature within HEC-HMS. Manning's 'n' values throughout the model were revised to attempt to match the time to peak. A value of 0.07 was selected for the Muskingum-Cunge routing parameters. After optimization, the peak flow data at Junction J7631-DCM closely matched observed data at Station DCM, but the time to peak was slightly off by approximately 6 hours. Further revisions to Manning's 'n' values resulted in peak flows which were not acceptable, therefore no further changes were done. **Figure 3** shows the final calibration hydrograph at Station DCM and Junction J7631-DCM for the January 2017 storm event. **Figure 4** presents the HEC-HMS model extent, watersheds, and precipitation gauges used in calibration efforts.

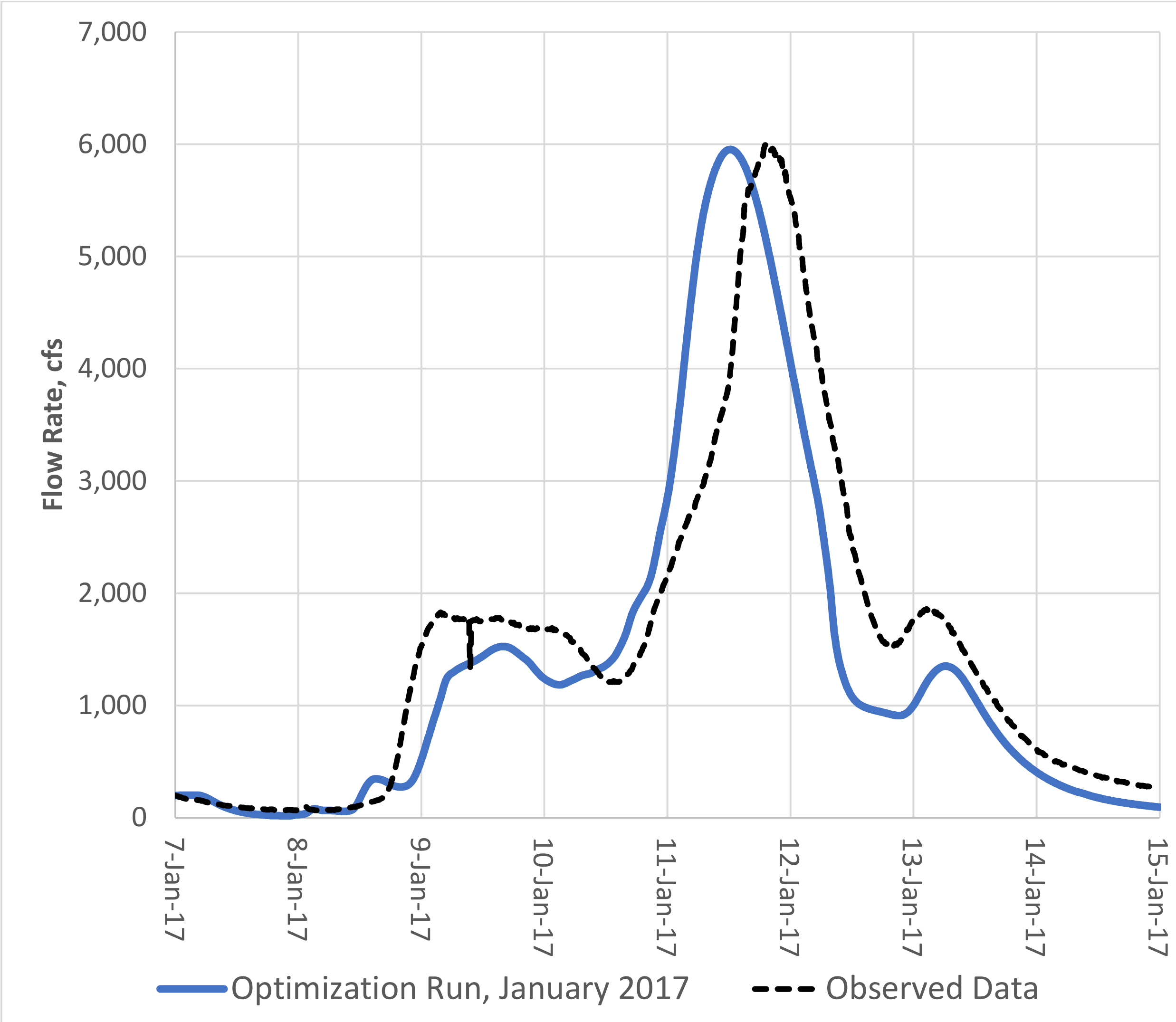

Figure 3, Hydrograph at DCM after Model Calibration and Validation

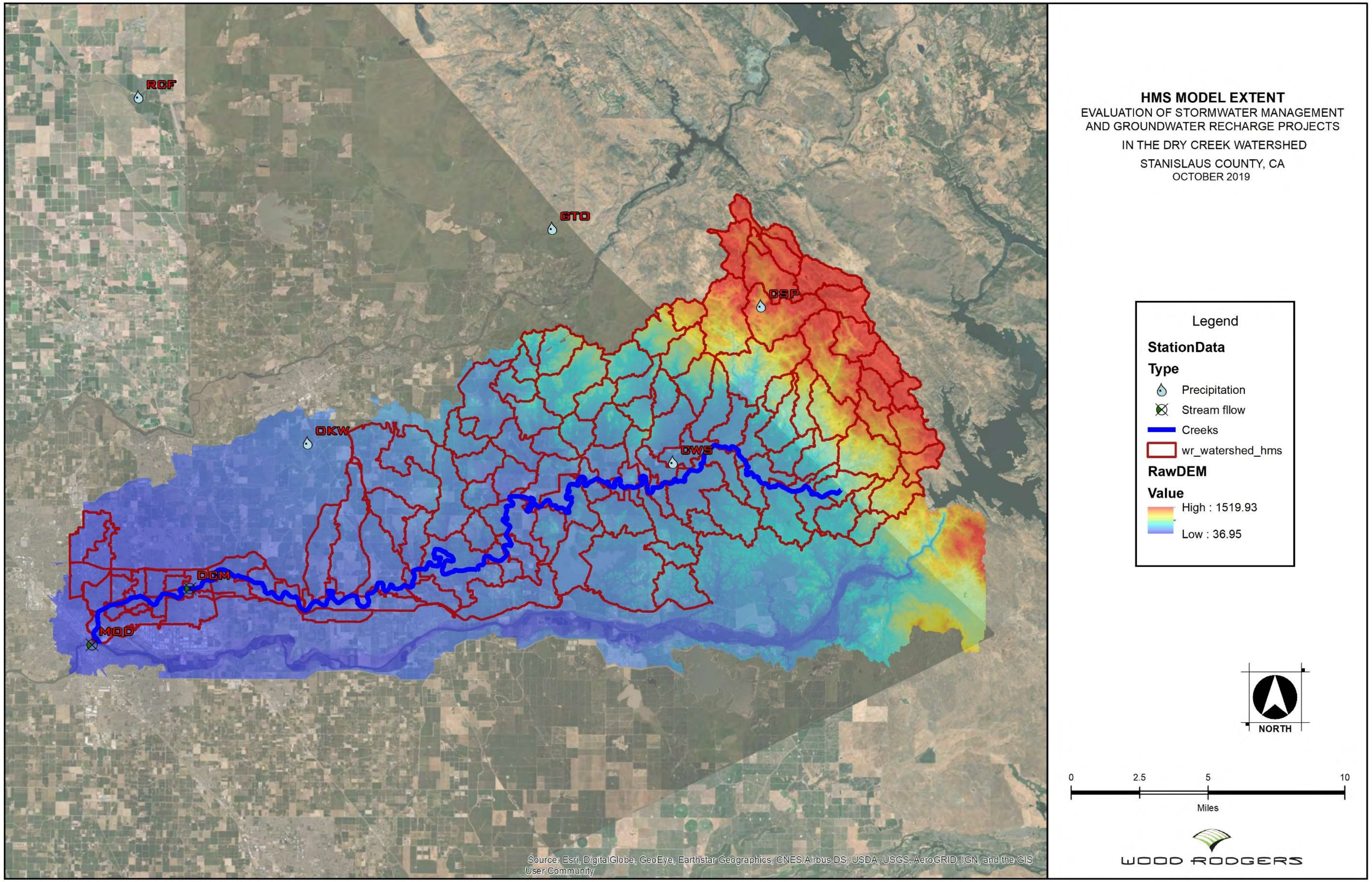

Figure 4, HEC-HMS Model Extent

SURFACE WATER MODELING RESULTS AT 15 POTENTIAL STORMWATER CAPTURE SITES

WRI and GSA reviewed watershed maps and soils maps to determine 15 potential storage sites for evaluation. WRI developed design storms for the 2-year through 50-year recurrence interval based on the rainfall distribution form the January 2017 rain event and total precipitation within the watershed, spatially distributed, for the corresponding 4-day storm event for the 2-year through 50-year recurrence interval from NOAA GIS data: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html

Existing Condition HEC-HMS Model Results

The HMS model was used to evaluate peak flow rates under existing conditions at each of the 15 sites for each design storm. **Figure 5** presents the location of potential sites, and **Table 2** presents the results of the existing condition HEC-HMS model at the 15 sites.

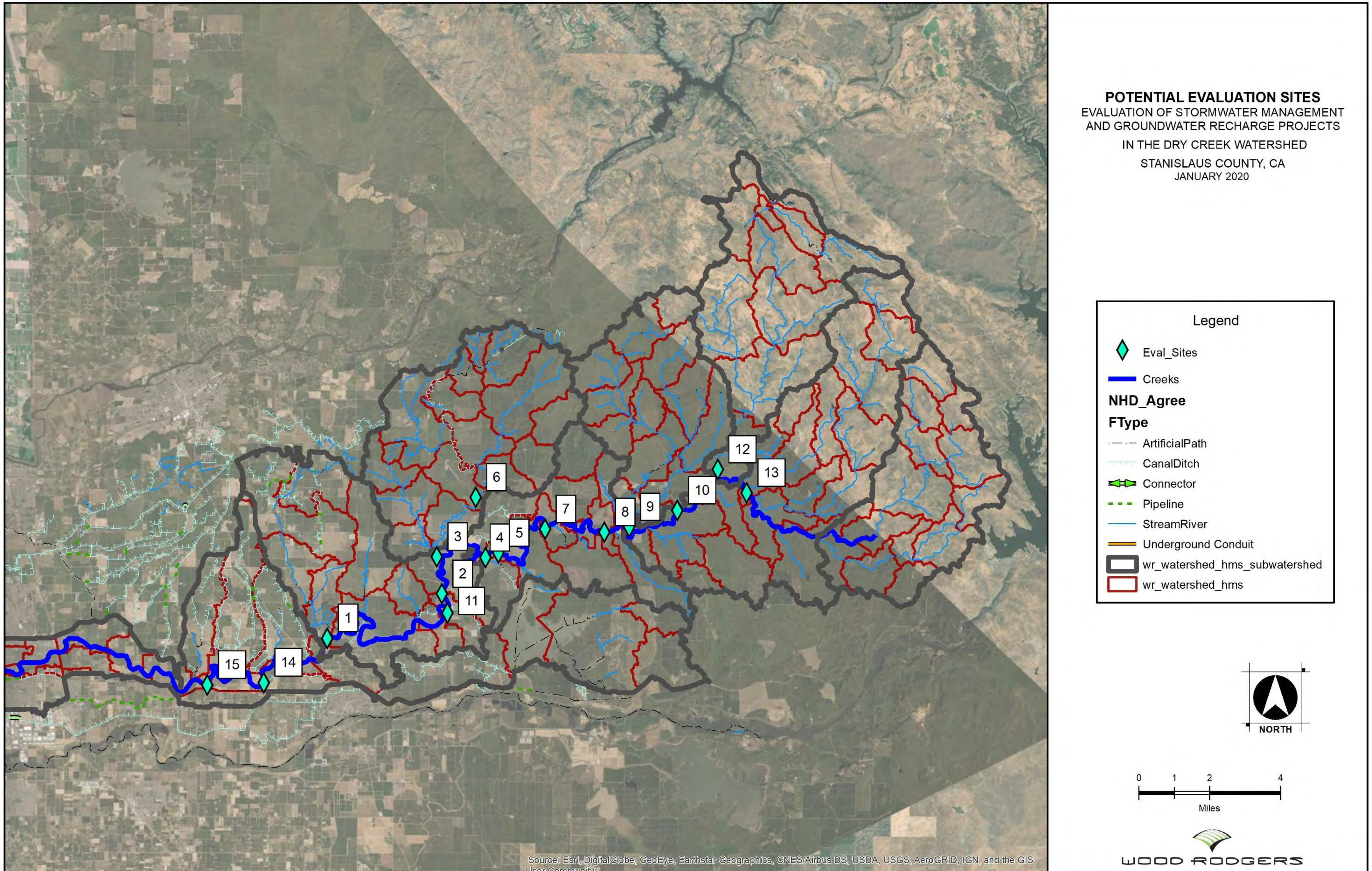

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Figure 5, Potential Evaluation Sites

Table 2, Existing Condition Model Results at 15 Potential Sites

Site	HMS Node	DRAIN AREA (SM)	2-YEAR STORM PRECIP = 2.36 IN		5-YEAR STORM PRECIP = 3.32 IN		10-YEAR STORM PRECIP = 3.92 IN		25-YEAR STORM PRECIP = 4.69 IN		50-YEAR STORM PRECIP = 5.25 IN	
			MAX CFS	TOT VOL (AC-FT)	MAX CFS	TOT VOL (AC-FT)	MAX CFS	TOT VOL (AC-FT)	MAX CFS	TOT VOL (AC-FT)	MAX CFS	TOT VOL (AC-FT)
DCM	J7631_DCM	212.4	3,200	12,700	5,400	21,900	6,900	28,100	8,900	36,300	10,000	42,800
Site01	J6478	162.0	3,200	10,500	5,300	18,200	6,700	23,200	8,600	30,000	9,900	35,100
Site02	J6751	141.2	3,500	9,990	5,700	17,000	7,100	21,600	8,900	27,700	10,000	32,300
Site03	J6583	25.8	650	1,750	1,100	2,980	1,300	3,780	1,600	4,810	1,900	5,590
Site04	J6565	110.6	2,800	8,020	4,600	13,600	5,800	17,400	7,300	22,200	8,400	25,900
Site05	J6565	110.6	2,800	8,020	4,600	13,600	5,800	17,400	7,300	22,200	8,400	25,900
Site06	J6845	16.0	500	1,170	800	1,960	980	2,470	1,200	3,130	1,400	3,640
Site07	J6595	106.6	3,000	7,850	4,900	13,400	6,000	17,000	7,500	21,800	8,500	25,400
Site08	J6618	98.9	2,800	7,360	4,500	12,500	5,600	16,000	7,100	20,400	8,200	23,900
Site09	J6517	19.2	520	1,340	840	2,290	1,100	2,920	1,400	3,730	1,600	4,350
Site10	J6795	69.5	2,100	5,400	3,600	9,200	4,500	11,700	5,700	15,000	6,600	17,500
Site11	J6821	142.5	3,400	10,000	5,700	17,100	7,100	21,700	8,900	27,800	10,000	32,400
Site12	J6586	68.1	2,100	5,310	3,600	9,050	4,500	11,500	5,700	14,800	6,600	17,300
Site13	J6724	38.6	1,300	2,730	2,100	4,740	2,700	6,080	3,400	7,840	3,900	9,180
Site14	J6493	168.9	3,100	10,700	5,300	18,500	6,600	23,700	8,500	30,600	9,800	36,000
Site15	J7639	173.3	3,100	10,800	5,300	18,800	6,700	24,100	8,500	31,200	9,900	36,700

Site-Specific Topographic Data

Review of topographic data within the watershed shows Dry Creek to be incised up to 80 feet from thalweg elevation. WRI utilized ESRI's 3d Analyst extension and topographic data to cut cross sections in the vicinity of each of the 15 sites, and **Table 3** presents site-specific data extracted from each site, including approximate thalweg elevations, bankfull elevations (2-year flood event), and depth of channel incision (where available).

Table 3, Site-Specific Topography

Site	HMS Node	DRAIN AREA (Acres)	Thalweg elevation[1] (ft)	Bank elevation[2] (ft)	Incision elevation[3] (ft)	Depth of Thalweg to Bank Elevation (ft)	Depth of Total Incision (ft)
Site1	J6478	103,680	107	124	146	17	39
Site2	J6751	90,368	131	147	185	16	45
Site3	J6583	16,512	143	176	176	33	33
Site4	J6565	70,784	145	190	200	45	55
Site5	J6565	70,784	145	180	180	35	35
Site6	J6845	10,240	180	190	200	10	20
Site7	J6595	68,224	160	177	220	17	60
Site8	J6618	63,296	170	180	206	10	36
Site9	J6517	12,288	187	212	N/A	25	25
Site10	J6795	44,480	184	230	230	46	46
Site11	J6821	91,200	128	143	176	15	48
Site12	J6586	43,584	207	242	252	35	45
Site13	J6724	24,704	213	250	290	37	77
Site14	J6493	108,096	100	115	130	15	30
Site15	J7639	110,912	93	107	122	14	29

[1]Thalweg elevation is defined as the line of lowest elevation within a valley or watercourse

[2]Bank is defined as the terrain edge of the adjacent river or stream

[2]Incision elevation refers to the top of the incised section of Dry Creek. The project topography indicates that over thousands of years, due to erosion and extreme flood events, Dry Creek has incised a channel in some areas up to 50 feet deep below adjacent topography.

CONCEPTUAL FLOOD CONTROL DESIGN DEVELOPMENT

WRI and GSA reviewed the Existing Condition Model results, and site-specific topography data to develop Conceptual Site Designs. Because the Dry Creek channel is highly incised at most locations, in-channel recharge will be the most likely conceptual design, as it would likely not be feasible to pump stormwater above a 60-foot channel incision. **Appendix A** contains a conceptual plan for an in-channel recharge basin with a pneumatically operated spillway gate, which would allow for flows less than a 5-year peak flow rate to pass through before the gate is automatically lifted to create in-channel storage. **Figure 6** presents a typical cross section of a structure at Site 1.

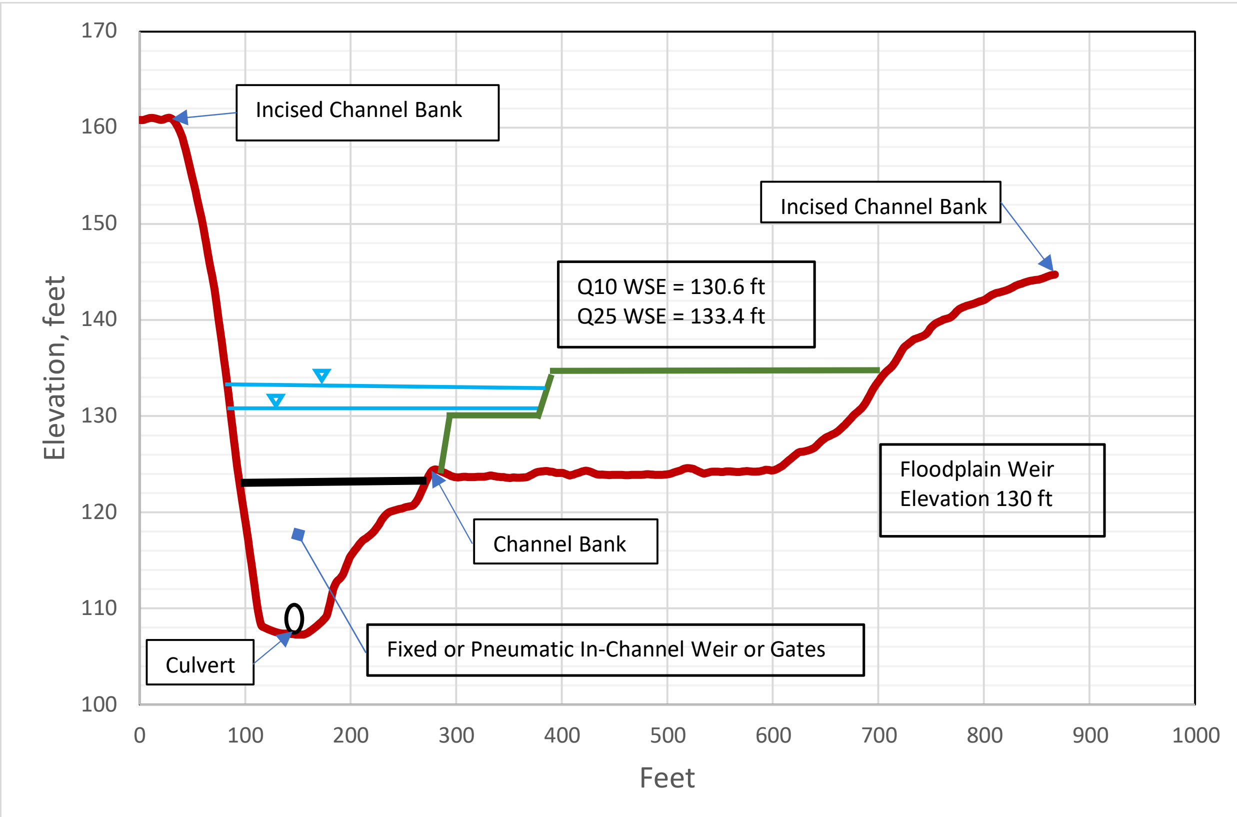

Figure 6, Conceptual Cross-Section, Site 1

Another potential conceptual plan consists of an in-channel flow control structure, with either a Con Span Arch or a reinforced concrete box culvert at the thalweg elevation, allowing for smaller flows to pass underneath the structure (See Appendix A). In this configuration the Spillway would only be activated in large events, such as the 50-year or 100-year event, or as needed to prevent flooding of upstream areas. Future design phases will determine the required spillway designs and design storm events. **Figure 7** presents this flow control concept at Site 2.

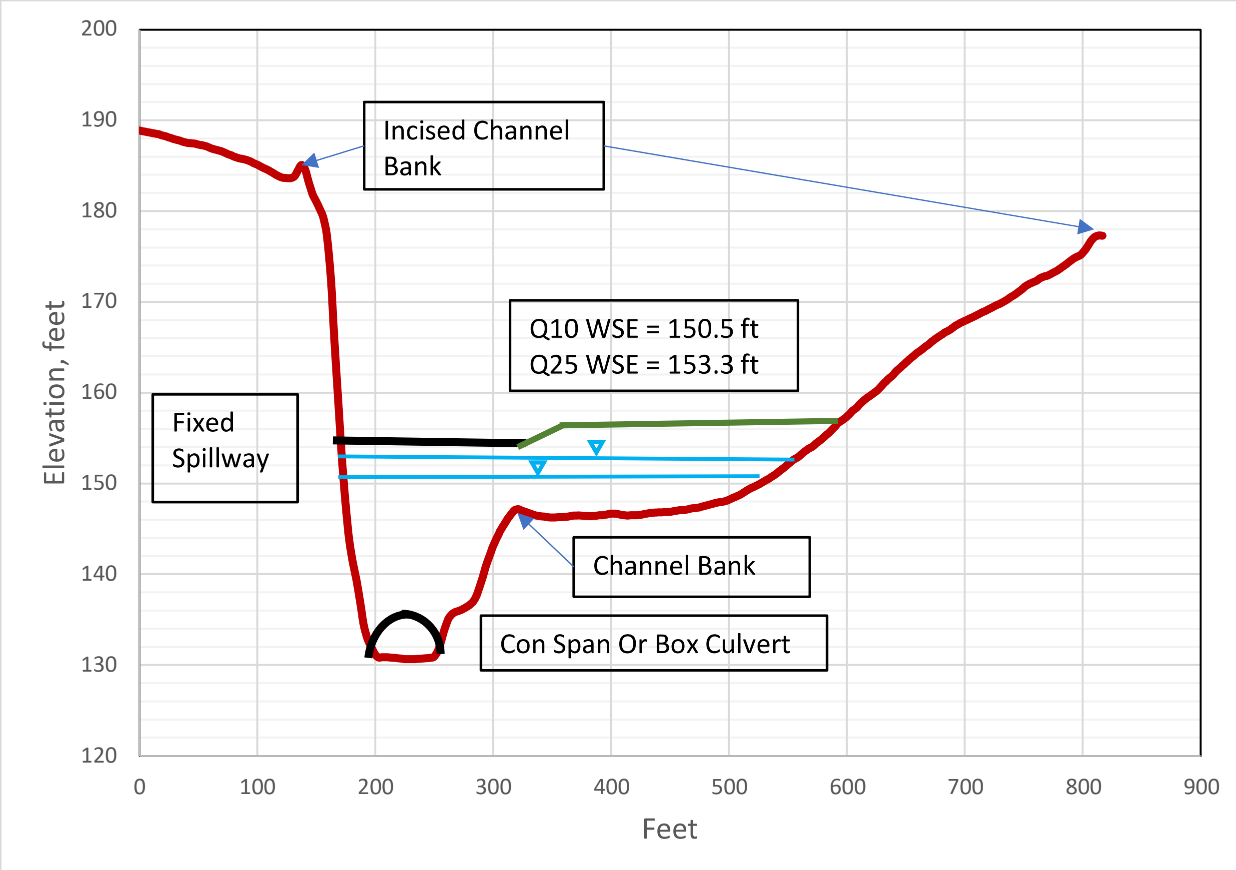

Figure 7, Flow Control Conceptual Cross Section, Site 2

<u>Depth Vs. Storage Curves</u>

WRI developed stage-storage data for each of the 15 sites using site topography from the 3-foot DEM and GIS, and compared depth vs. storage volume at each site. **Figure 8** presents the depth vs. storage curve for the 15 sites. For the purpose of discussion, Site 2 was chosen for a detailed analysis as this site contained a significant drainage area, and because Site 2 was presented to the Project team as a potential site in the October 2019 meeting.

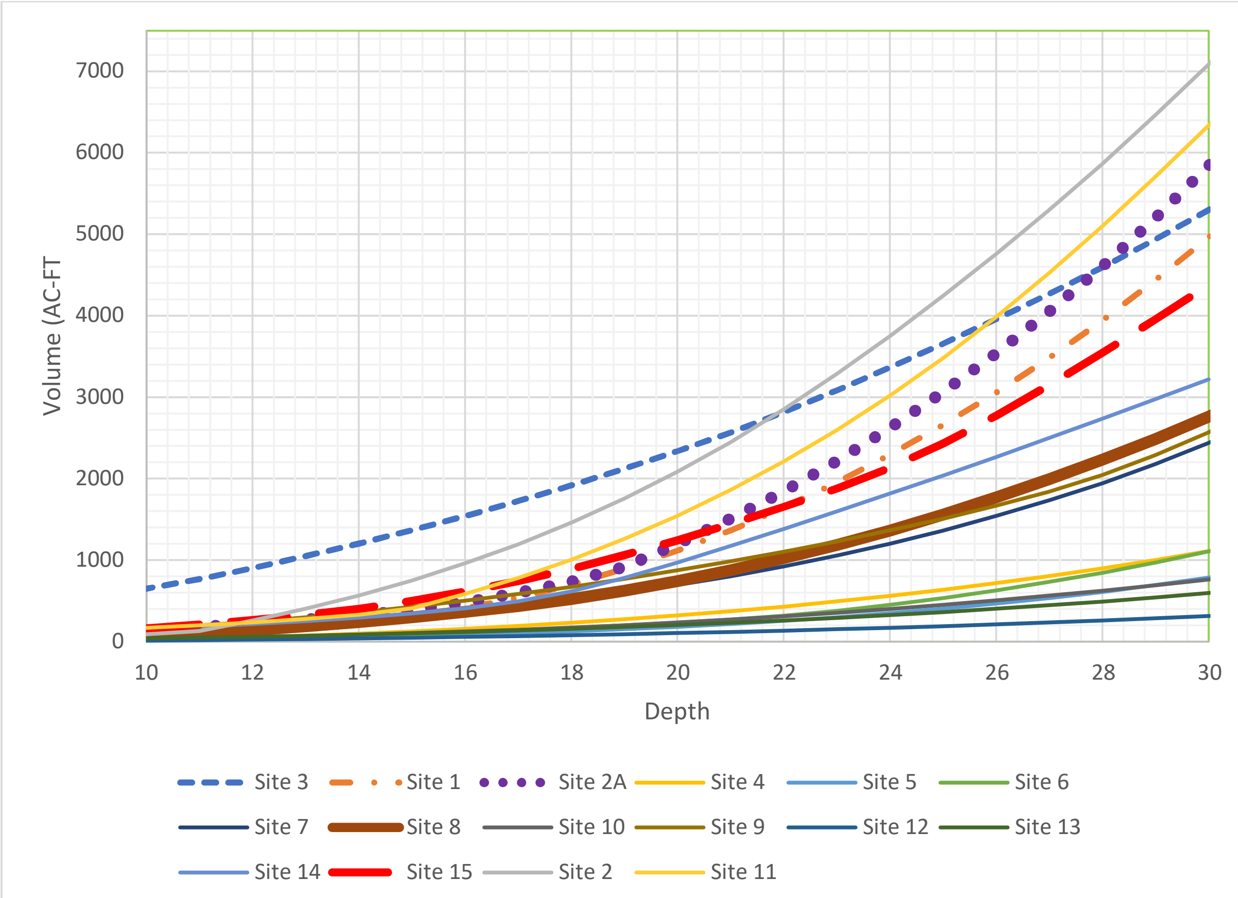

Figure 8, Height of Conceptual Flow Control Structure vs. Storage

Proposed Condition HEC-HMS Model Results and Phase II Recommendations

WRI developed a proposed condition HEC-HMS model to develop detailed results at Site 2 using the conceptual flood control design that could capture water beyond the total height of the incision while releasing the 5-year flood event flows.

The proposed conditions HEC-HMS model shows a 22-foot high flow control structure at Site 2 has the potential to reduce the 10-year peak flow rate at Site 2 to 4,100 cfs from a 10-year peak flow of 7,100 cfs, as shown in **Figure 9**. The proposed condition flow rate at Station DCM is 5,000 cfs in the 10-year event, which means construction of Site 2 alone may have the potential to reduce flood risks from the 10-year return interval event (and when peak flows in the Tuolumne River are at 9,000 cfs), as shown in **Figure 10**. The predicted inundation area corresponding to a ponding elevation of 153 feet resulting from the flood control storage for Site 2 in the 10-year storm event is presented in **Figure 11**.

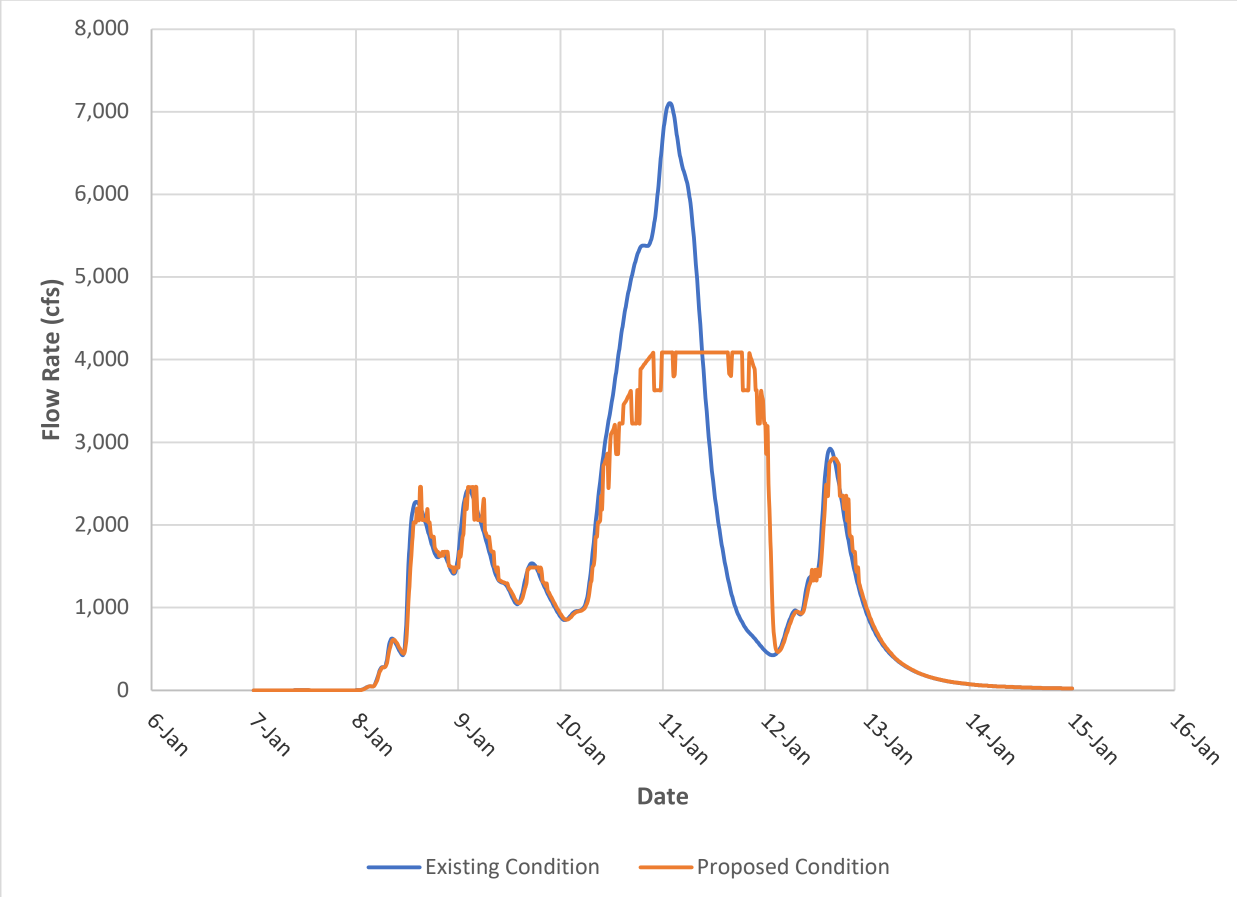

Figure 9, 10-year, 4-day HEC-HMS Existing vs Proposed Condition Results at Site 2

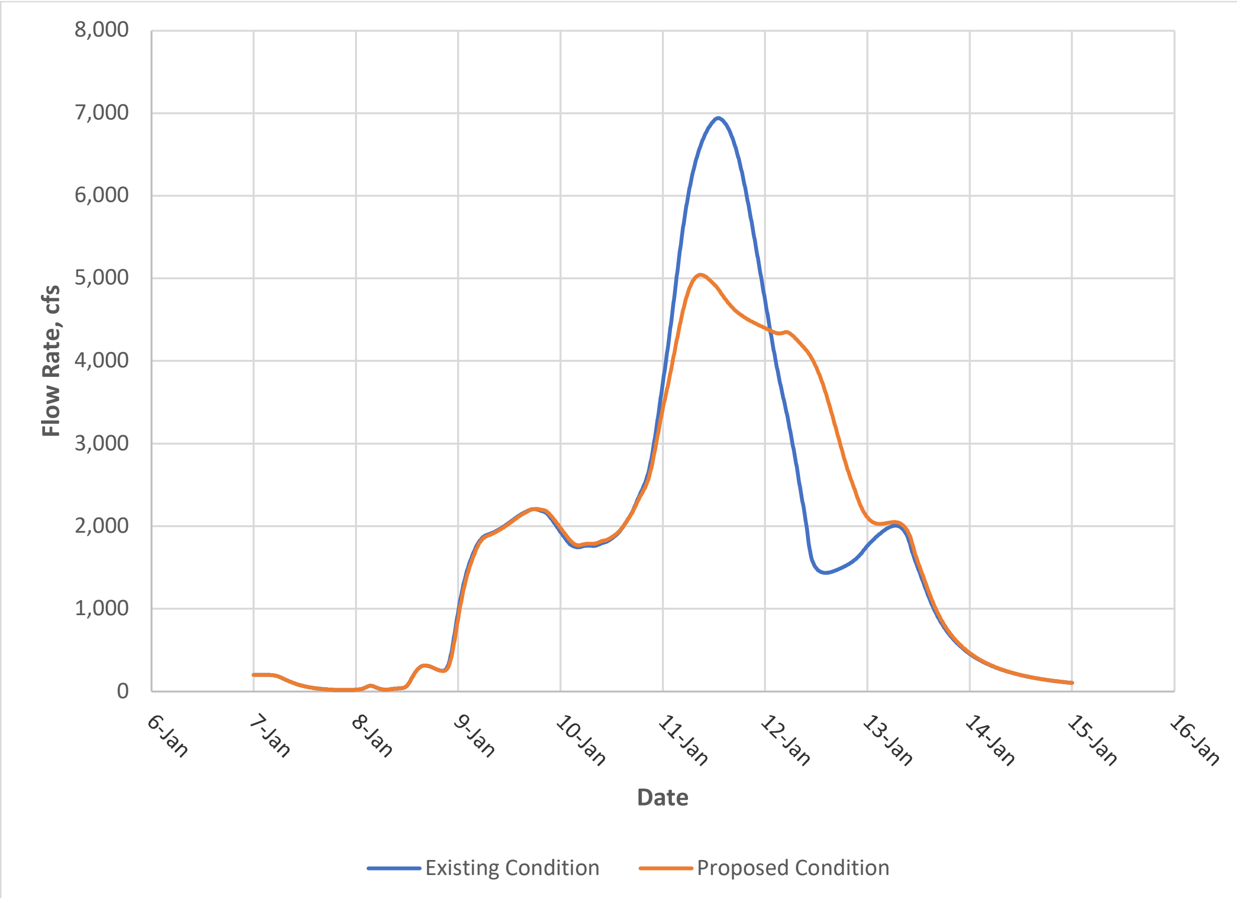

Figure 10, Existing vs proposed condition hydrograph comparison at DCM, 10-year Storm Event

The proposed condition HEC-HMS model was constructed to predict flow rates and storage volumes at selected, individual sites. Based on the preliminary proposed condition modeling results, to reduce flood risks in events greater than the 10-year storm event, several sites may be required to be constructed in series. Therefore, in subsequent phases of the project, the proposed condition model should be used to both evaluate the feasibility of individual sites and to evaluate the highest-ranking sites in combination, to determine the order in which future projects may be constructed.

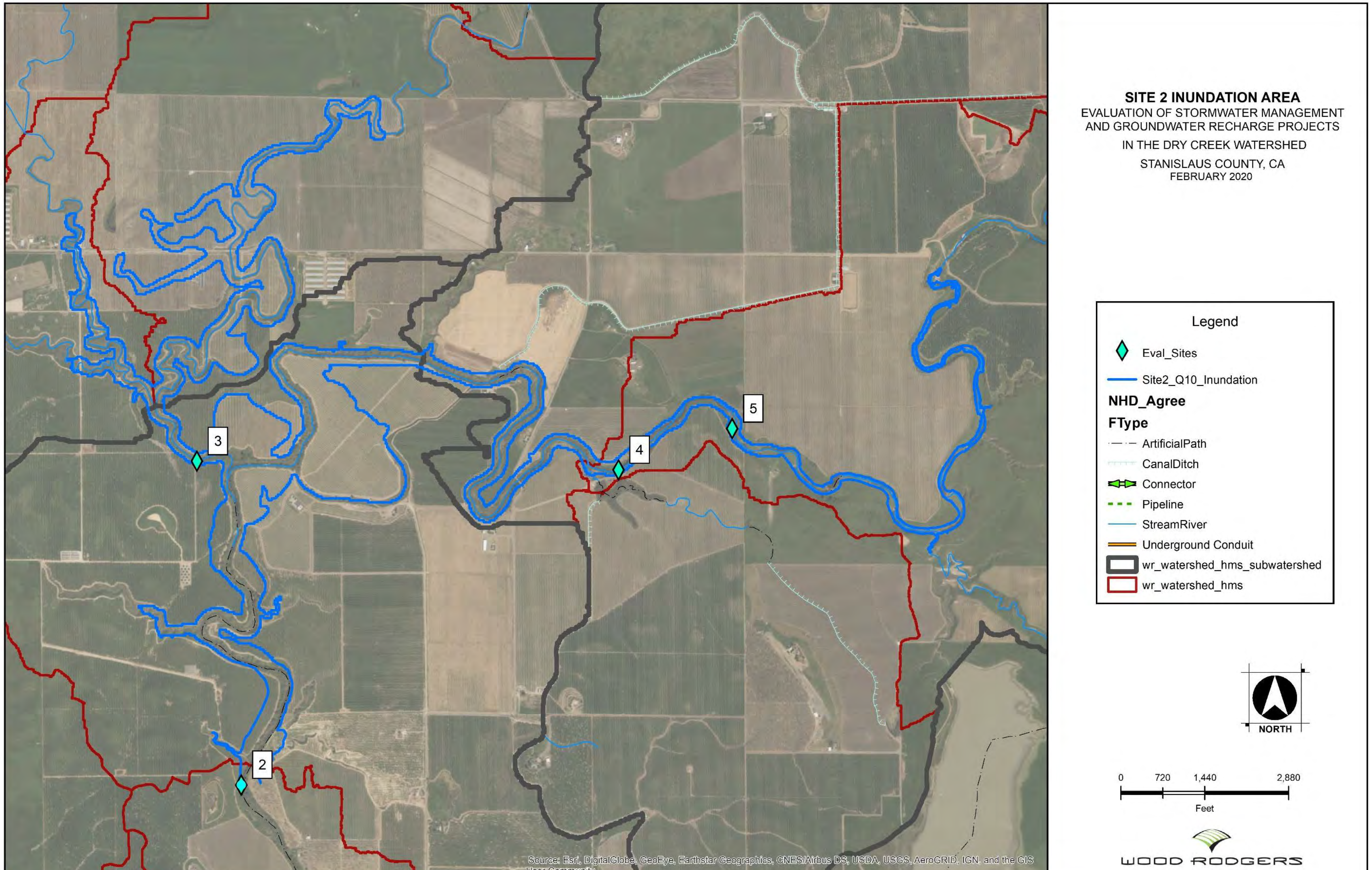

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Figure 11, Site 2 Inundation Area, 10-year Storm Event

References:

United States Department of Agriculture, Natural Resources Conservation Service, National Engineering Handbook, Part 630 Hydrology, Chapter 9, (July 2004, U.S. Department of Agriculture)

Sacramento City/County Drainage Manual (1996)

California Data Exchange Center (CDEC) (https://cdec.water.ca.gov/dynamicapp/wsSensorData)

National Land Cover Database (2016, United States Geological Survey, accessed from https://www.mrlc.gov/data

Web Soil Survey, United States Department of Agriculture, National Resources Conservation Service, accessed from https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

HEC-HMS, United States Army Corps of Engineers, Version 4.3, September 2018

The National Map, United States Geological Survey, accessed from https://viewer.nationalmap.gov/basic/

Water Data Library, California Department of Water Resources, accessed from http://wdl.water.ca.gov/waterdatalibrary/docs/Hydstra/index.cfm?site=B04130

Storm Drain Master Plan (March 2008, City of Modesto)

Addendum Final Hydraulic Analyses and Results for Tuolumne River and Dry Creek in Stanislaus County (May 2014, California Department of Water Resources and Federal Emergency Management Agency)

Regional Flood Management Plan for the Mid-San Joaquin River Region (2014, California Department of Water Resources)

Atlas 14 Precipitation Frequency Estimates in GIS format, (National Oceanic and Atmospheric Administration, Precipitation Frequency Data Center, accessed at https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html)

Topographic data from Central Valley Flood Evaluation & Delineation Program (California Department of Water Resources, 2011)

Guidelines for Determining Flow Frequency, Bulletin 17B (March 1982, United States Geological Survey)

ENCLOSURES

Appendix A: Conceptual Design: In-Channel Recharge Basin, Pneumatically Actuated Gates

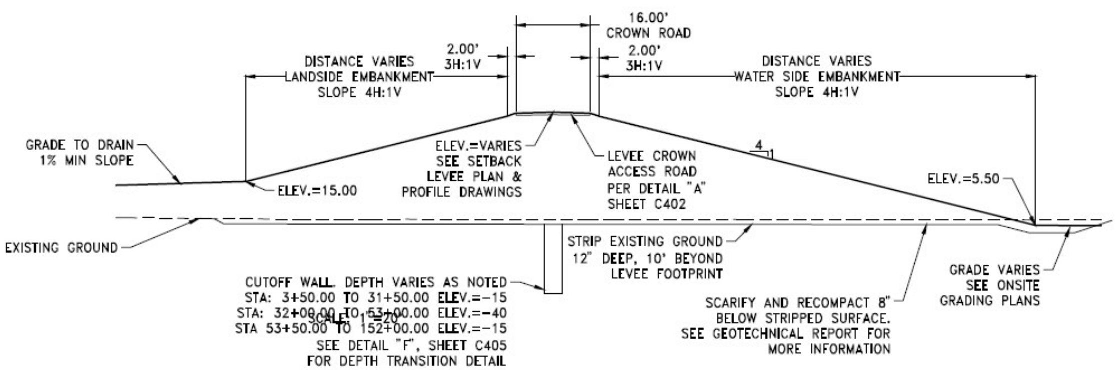
Appendix B: Conceptual Design: ConSpan Arch Bridge and Dam

Appendix C: Conceptual Design: In-Channel Structure, Bypass Culvert, Auxiliary Storage and/or Recharge Basin

Appendix A – Conceptual Design #1: In-Channel Recharge Basin, Pneumatically Actuated Gates

Conceptual Design #1 consists of a pneumatically actuated gate made by Obermayer, and a floodplain/setback levee. Design #1 allows flows to pass through the system until the desired flow rate is achieved, at which time the gate is engaged and inflated to a height of up to 7 feet. The gate operates automatically by communication with an inclinometer transducer and upstream depth transducer, allowing the gate to operate in either upstream level control (i.e. hold set elevation) or downstream flow control (i.e. pass set flow) modes. When not engaged, the gate can lay back to a near flat position, allowing for sediments to pass. The installation requires electrical power, an air compressor, and a control building.

The setback levee may require a cutoff wall constructed of clay or sheet piling to prevent seepage. Subsequent phases of work will include a preliminary levee cross section, including consideration of seepage mitigation.

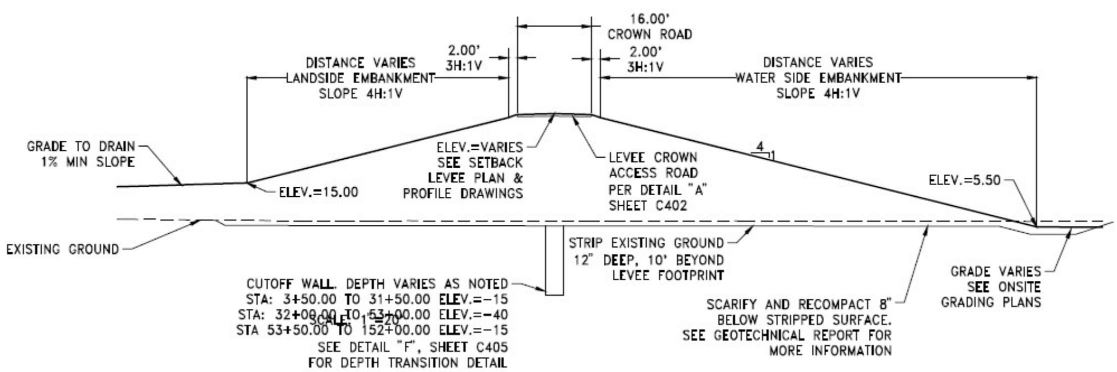


TYPICAL SETBACK LEVEE SECTION 4/–
STA. 100+44.31 TO 104+52.65

Appendix B – Conceptual Design #2: ConSpan Arch Bridge and Dam

Conceptual Design #2 consists of a ConSpan arch culvert, an earthen dam above the arch, a levee, and an emergency spillway. Design #2 allows for most flows to pass through the ConSpan arch culvert, with larger flows ponding up behind the culvert and spilling onto the upstream floodplain. The spillway would only be activated in very large storm events well beyond the design storm.

The precast arch structure allows for quicker construction, and minimizes impacts to wetlands and waters of the U.S. Per documentation provided by Contech, allowable fill material is only sands and silts (i.e. no clayey impervious materials) so attention must be made to seepage concerns.



TYPICAL SETBACK LEVEE SECTION (4/–)

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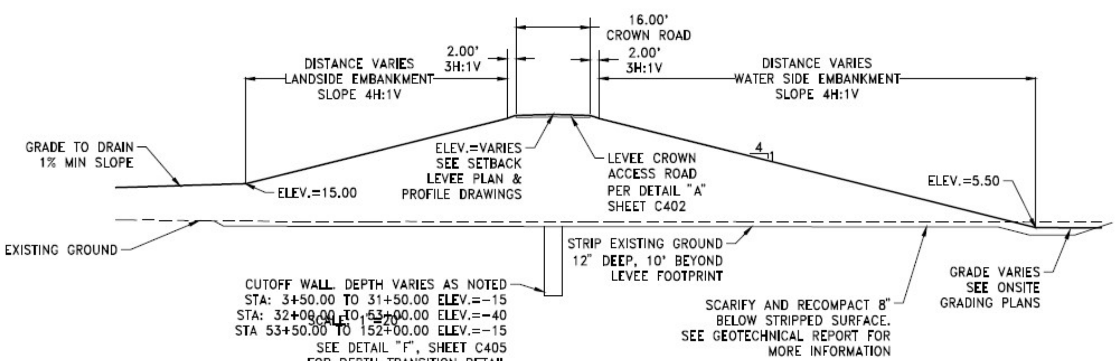
Appendix C – Conceptual Design #3: In-Channel Structure, Bypass Culvert, Auxiliary Storage and/or Recharge Basin

Conceptual Design #3 consists of an in-channel structure with a diversion to an auxiliary detention and groundwater recharge basin. The in-channel structure may be either a pneumatic gate or a culvert with an earthen weir. This conceptual design may also include a floodplain levee, depending on the depth of flows in the upstream floodplain. The bypass culvert would serve primarily to convey flows to an auxiliary storage and/or groundwater recharge basin. The bypass culvert may also potentially convey flows to adjacent irrigation canals. The auxiliary storage and/or detention basin may be an above ground basins, or a below ground basin.



TYPICAL SETBACK LEVEE SECTION (4/–)

STA. 100+44.31 TO 104+52.65

ATTACHMENT B
Soil Survey Data

Soil property data were retrieved from the U.S. Natural Resources Conservation Service Web Soil Survey (NRCS, 2019). Three properties directly related to soil permeability and water storage capacity, saturated hydraulic conductivity (Ksat), clay percentage, and depth to a restrictive soil or rock layer, were mapped and analyzed in order to assign an estimated relative permeability category to each soil map unit in the watershed. In the data set (NRCS, 2019), estimates of the percent clay, Ksat, and depth to a restrictive contact were made for several distinct soil horizons, with differing properties, to a depth of not more than approximately 6.5 feet (200 cm) below ground surface (bgs) for each map unit. Table 1 summarizes the collected data and estimated properties for each of the soil map units.

Figure 1, Figure 2, Figure 3 and Figure 4 show, respectively, spatial distribution of estimated soil Ksat, clay percentage, depth to a paralithic/lithic (restrictive) contact, and relative soil permeability. For Ksat (Figure 1), map units were aggregated into value ranges based on percent composition in their profiles. Based on our experience, the NRCS estimates of Ksat were reduced by a factor of 10 to approximate achievable infiltration rates for groundwater recharge. Figure 1 shows the largest continuous areas of higher Ksat (0.51 – 1 ft/day) in soils along the southwest edge of the watershed, with smaller areas in the same range in the central and eastern portions of Stanislaus County.

For clay percentage (Figure 2), a weighted average of the component horizon values was selected as representative of each map unit. Figure 5 generally shows the largest areas of lower clay percentages (10.1 to 15 percent), as with Ksat, in soils along the watershed's southwest edge, and in smaller areas in the central and eastern portions of Stanislaus County. There are small areas of lower (0 to 10 percent) clay percentage not visible at the map scale but present along parts of Dry Creek. For estimated depth to a restrictive layer (Figure 3), map units were aggregated by the percent composition in their profiles into either the presence of a restrictive layer within the 200 cm (the approximately 6.5 ft-depth examined by the soil survey) or somewhere below that depth. Restrictive layers noted in the NRCS Survey (2019) were primarily classified as lithic and paralithic bedrock.

For estimated soil relative permeability (Figure 4), estimated soil Ksat, percent clay, and depth to restrictive contact were considered in assigning each mapped soil to a relative permeability category. Figure 4 shows low to moderate permeability along the southwestern portion of Dry Creek.

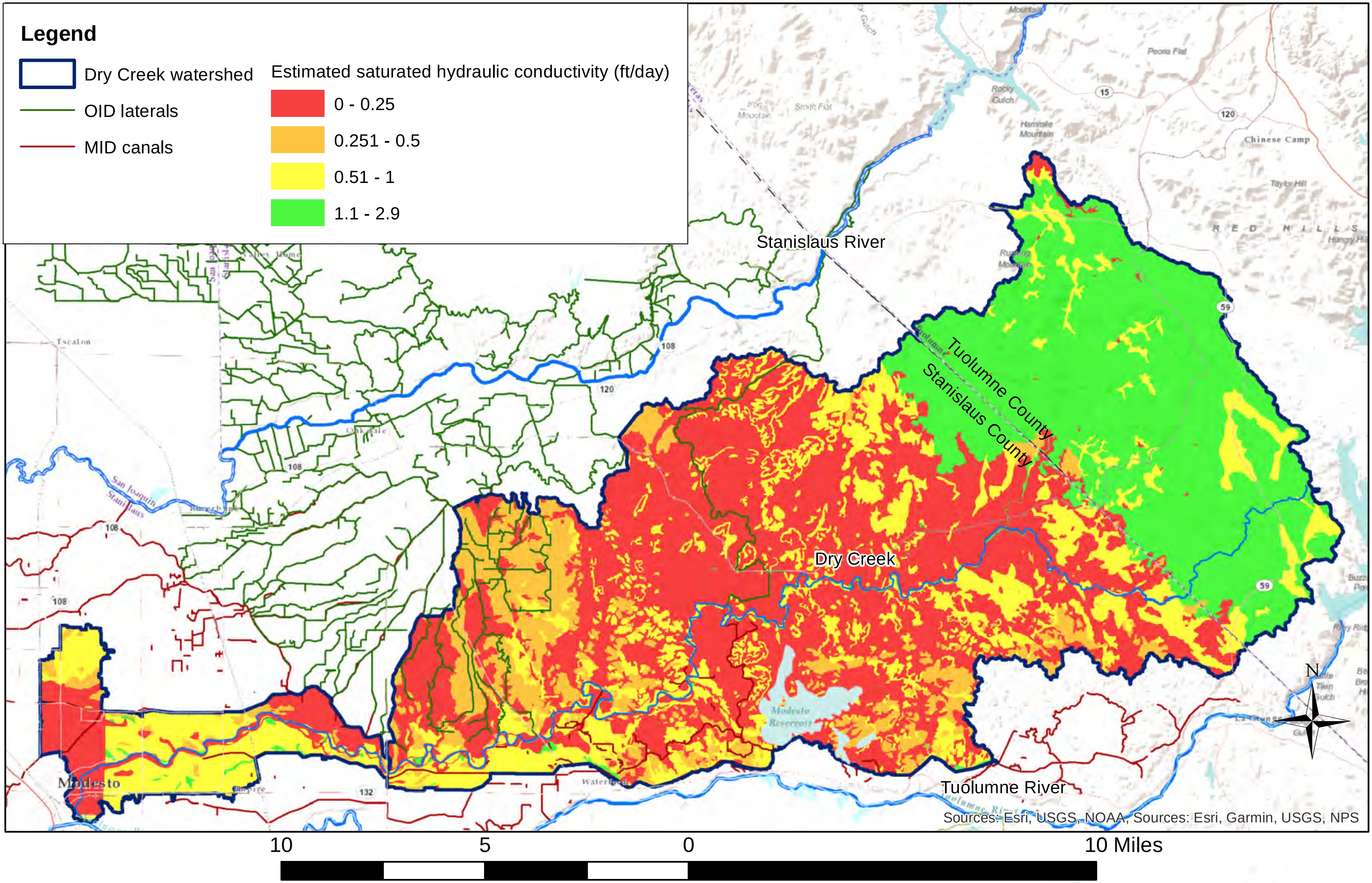
Attachment B - Table 1. Estimated relative permeability of soil map units

Map Unit Name	Stratigraphic Unit (Burows, et al. 2004)	Est. Saturated Hydraulic Conductivity (ft/day)	Est. % Clay	Est. Relative Permeability	Est. Depth to Restrictive Layer (cm bgs)
Alamo clay		0.01	50	Low	0 - 160
Amador loam and gravelly loam	Valley Springs Formation	0.21	20	Low	> 160
Anderson gravelly fine sandy loam		0.79	15	Moderate	0 - 160
Aquic Haploxeralfs-Loafercreek-Dunstone complex		0.62	32.7	Moderate	0 - 160
Archerdale-Hicksville association		0.08	40.8	Low	0 - 160
Auburn clay loam	Basement complex	0.18	28.5	Low	0 - 160
Bear Creek loam, clay loam, and gravelly clay loam		0.13	23.8	Low	> 160
Bonanza-Loafercreek complex		1.63	24.6	Moderate-High	0 - 160
Bonanza-Loafercreek-Gopheridge complex		1.60	19.7	Moderate-High	0 - 160
Chualar sandy loam	Modesto Formation	0.17	17.7	Low	0 - 160
Copperopolis-Whiterock complex		1.63	17.6	Moderate-High	0 - 160
Corning gravelly sandy loam	Laguna Formation	0.18	22.1	Low	0 - 160
Delhi sand and loamy sand	Modesto Formation	2.61	2.5 to 3.1	High	0 - 160
Dinuba sandy loam and fine sandy loam	Modesto Formation	0.33 - 0.41	13.5	Low-Moderate	0 - 160
Dredge and mine tailings		2.61	0.5	High	0 - 160
Exchequer and Auburn soils and rocky soils	Basement complex	0.20	18.5	Low	0 - 160
Goldwall-Toomes-Rock outcrop complex		0.08	10	Low	0 - 160
Greenfield sandy loam and fine sandy loam	Modesto Formation	0.53 - 0.79	12.5	Moderate	0 - 160
Hanford sandy loam, fine sandy loam, and very fine sandy loam	Modesto Formation	0.51 - 0.79	12.5 - 17.5	Moderate	0 - 160
Honcut loam, clay loam, sandy loam, and fine sandy loam	Holocene deposits	0.08 - 0.79	10.8 - 31	Low - Moderate	0 - 160
Hopeton loam, clay loam, and clay		0.05 to 0.10	35.2 - 37.6	Low	> 160

Map Unit Name	Stratigraphic Unit (Burows, et al. 2004)	Est. Saturated Hydraulic Conductivity (ft/day)	Est. % Clay	Est. Relative Permeability	Est. Depth to Restrictive Layer (cm bgs)
Hornitos fine sandy loam and gravelly fine sandy loam	Ione Formation and other undiff. Eocene sediments	0.54	15	Moderate	> 160
Hornitos-Red Bluff-Ultic Haploxeralfs, shallow, complex	Ione Formation and other undiff. Eocene sediments	0.08	18	Low	0 - 160
Jasperpeak-Gopheridge complex		1.60	18.3	Moderate-High	0 - 160
Keyes gravelly clay loam and cobbly clay loam		0.14	15.3	Low	0 - 160
Lava and Sandstone rockland		0.00	0	Low	0 - 160
Madera loam and sandy loam	Riverbank Formation	0.09 - 0.26	20.9 - 22.19	Low-Moderate	0 - 160
Madera-Alamo complex	Riverbank Formation	0.26	20.9	Low-Moderate	0 - 160
Meikle clay		0.12	32.3	Low	0 - 160
Modesto loam, clay loam, and clay loam, slightly saline-alkali	Modesto Formation	0.04	35.5 -37	Low	0 - 160
Montpellier coarse sandy loam and coarse sandy loam, poorly drained variant	Turlock Lake Formation	0.14 - 0.29	18.2 - 18.4	Low-Moderate	0 - 160
Oakdale sandy loam	Modesto Formation	0.79	12.1	Moderate-High	0 - 160
Paulsell clay		0.05	41	Low	0 - 160
Pentz loam, loam, moderately deep,sandy loam, gravelly loam, and cobbly loam, very shallow	Mehrten Formation	0.44 - 0.69	13	Low-Moderate	> 160
Peters clay and cobbly clay	Mehrten Formation	0.04 - 0.05	50	Low	> 160
Peters-Pentz complex	Mehrten Formation	0.04	50	Low	> 160
Psammentic Haploxerolls-Mollic Fluvaquents-Riverwash-complex		2.29	3.6	High	0 - 160
Raynor clay and cobbly clay	Mehrten Formation	0.02	45	Low	> 160

Map Unit Name	Stratigraphic Unit (Burows, et al. 2004)	Est. Saturated Hydraulic Conductivity (ft/day)	Est. % Clay	Est. Relative Permeability	Est. Depth to Restrictive Layer (cm bgs)
Redding cobbly loam, dry	Laguna Formation	0.07 - 0.10	18.4 - 25.3	Low	0 - 160
Riverwash	Holocene deposits	2.61	0.5	High	0 - 160
Rocklin sandy loam	Turlock Lake Formation	0.10	16.1	Low	0 - 160
Ryer loam, clay loam, and clay	Riverbank Formation	0.04 - 0.07	33.2 - 35	Low	0 - 160
San Joaquin and Madera soils	Riverbank Formation	0.26	24.3	Low-Moderate	0 - 160
San Joaquin sandy loam	Riverbank Formation	0.05 -0 .06	20.3 - 24.3	Low	0 - 160
Schist rockland	Riverbank Formation	0.00	0	Low	0 - 160
Shawsflat-Angelscreek complex		0.08	20.4	Low	0 - 160
Snelling sandy loam and sandy loam, poorly drained	Riverbank Formation	0.14 - 0.31	19.6 - 19.9	Low-Moderate	0 - 160
Terrace escarpments		0.00	0	Low	> 160
Tuff rockland		0.00	0	Low	0 - 160
Tujunga sand and loamy sand	Holocene deposits	2.61	2.5	Moderate-High	0 - 160
Ultic Haploxeralfs, moderately deep-Ultic Haploxeralfs, shallow complex		0.08	26.2	Low	> 160
Ultic Haploxeralfs-Typic Palexerults-Aquultic haploxeralfs complex		0.28	16.7	Low-Moderate	0 - 160
Whiterock silt loam and rocky silt loam	Basement complex	0.84	18.5	Moderate	0 - 160
Whitney and Rocklin sandy loams	Turlock Lake Formation	0.34	14.8	Low-Moderate	> 160

Map Unit Name	Stratigraphic Unit (Burows, et al. 2004)	Est. Saturated Hydraulic Conductivity (ft/day)	Est. % Clay	Est. Relative Permeability	Est. Depth to Restrictive Layer (cm bgs)
Whitney sandy loams	Turlock Lake Formation	0.29 to 0.34	14.8 - 14.9	Low-Moderate	> 160
Wyman loam, loam,moderately deep over gravelly, and clay loam		0.15 - 0.93	18.3 - 24.7	Low	0 - 160
Yokohl loam and clay loam	Riverbank Formation	0.05	29.6 - 31	Low	0 - 160
Zaca clay		0.03	45.8 to 46.2	Low	> 160



Soils data from: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey.Online: https://websoilsurvey.sc.egov.usda.gov/. Accessed 8/16/2019.

Appendix B - Figure 1. Estimated soil saturated hydraulic conductivity

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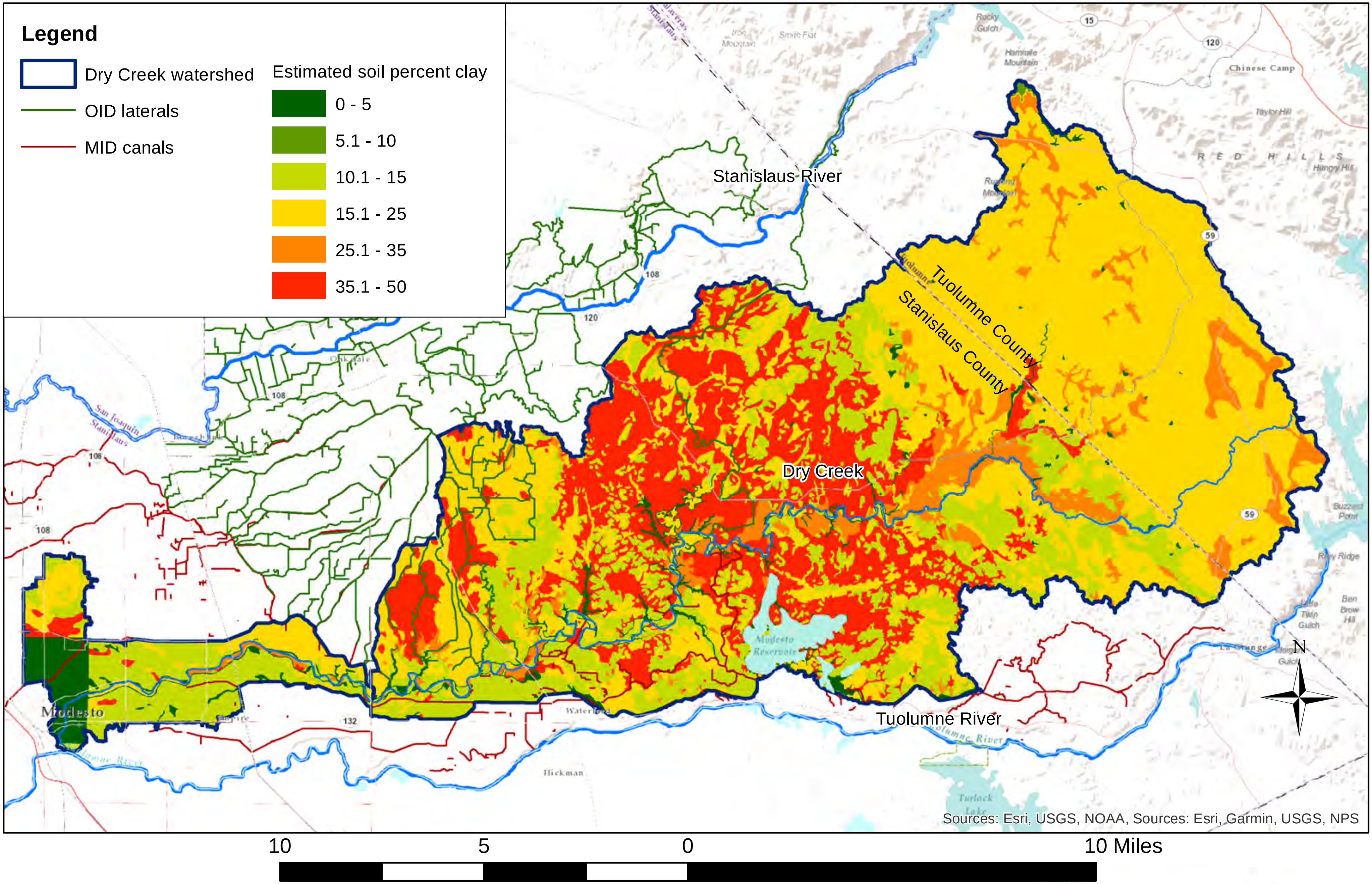

Soils data from: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey.Online: https://websoilsurvey.sc.egov.usda.gov/. Accessed 8/16/2019.

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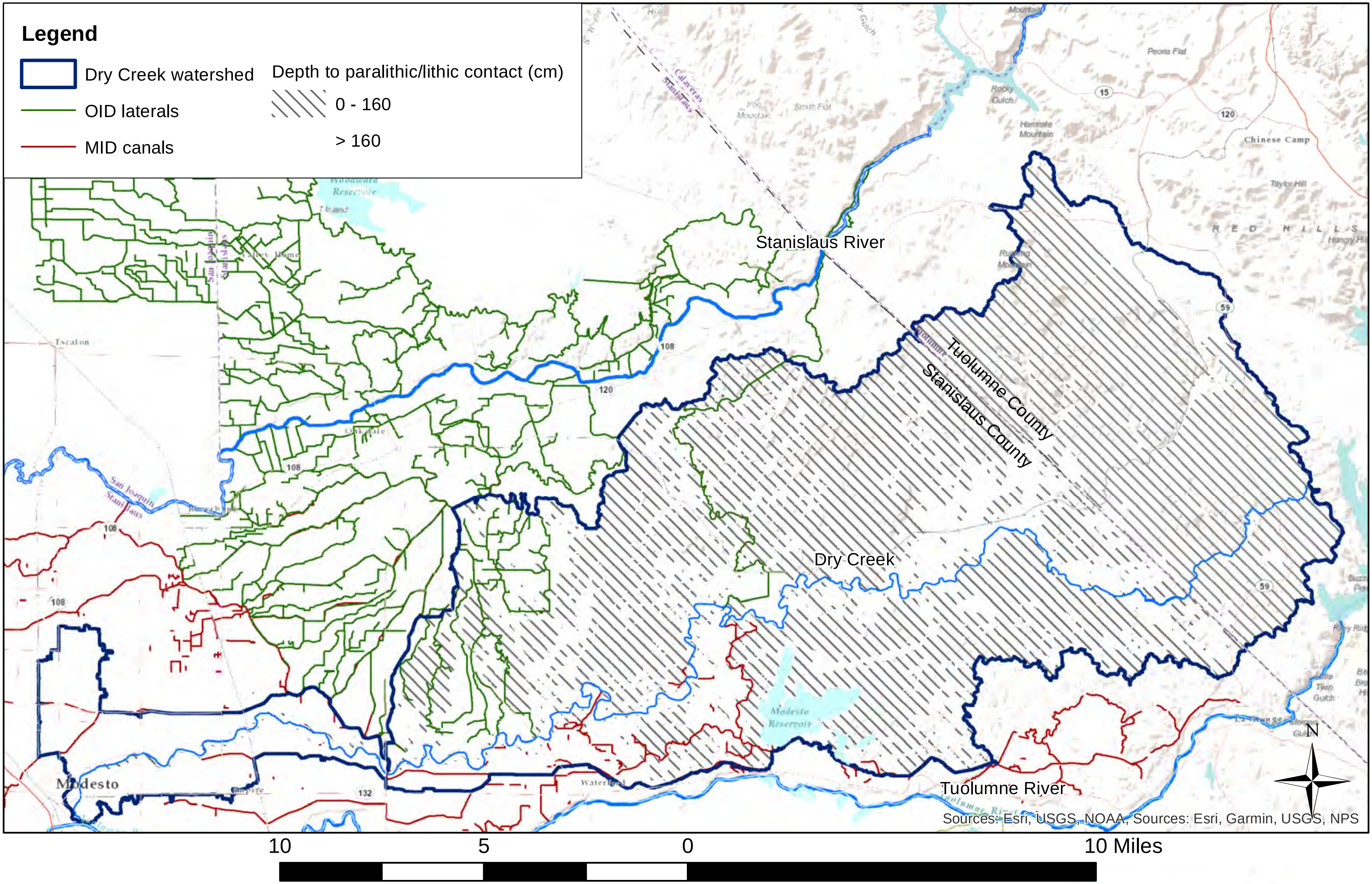
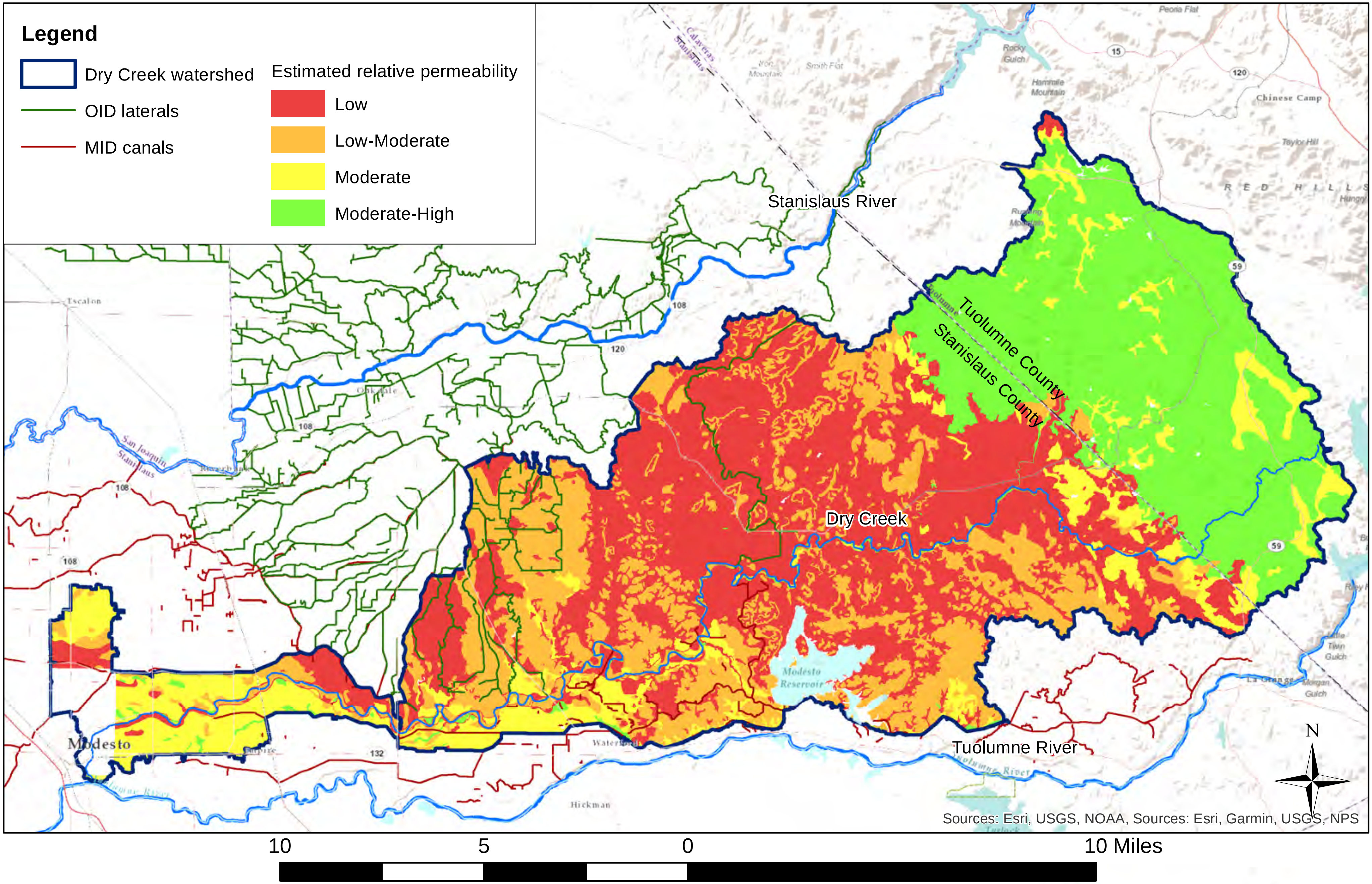
Appendix B Figure 2. Estimated soil clay percentage



Soils data from: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey.Online: https://websoilsurvey.sc.egov.usda.gov/. Accessed 8/16/2019.

Appendix B Figure 3. Estimated depth to restrictive paralithic/lithic contact



Soils data from: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey.Online: https://websoilsurvey.sc.egov.usda.gov/. Accessed 8/16/2019. Data are not available for the Modesto urban area.

Appendix B - Figure 4. Relative soil permeability

ATTACHMENT C
Water Quality Data

Groundwater quality data within the Dry Creek Watershed area were acquired from the California State Water Resources Control Board's Groundwater Ambient Monitoring and Assessment (GAMA) Program Groundwater Information System (CSWRCB, 2019). Data were compiled from the GAMA Domestic Wells, GAMA Priority Basin Project, GAMA Special Studies, and Public Water System Wells databases, as well as data from the Department of Pesticide Regulation, Department of Water Resources, local groundwater projects, Water Board-regulated sites, and the USGS National Water Information System.

Water quality parameters searched included 18 described by Landon et al. (2009), in their eastern San Joaquin Valley (Stanislaus and Merced counties) study, as having relatively moderate to high concentrations relative to human health thresholds or having a relatively high frequency of detection. Their grid-based study involved assessing the relative concentrations of parameters in the primary aquifer (the depth range in the water bearing unit at which most of the wells are perforated). The following parameters were identified.

- Inorganic parameters with primary Maximum Contaminant Levels (MCLs): arsenic, vanadium, and nitrate detected at high relative-concentrations in 15.6, 3.6, and 2.1 percent of the wells, respectively, in the primary aquifer.
- Inorganic parameters with primary MCLs: uranium, nitrate, and total dissolved solids (TDS) - detected in high and moderate relative-concentrations in some wells where perforations are within the upper 200 feet of the aquifer.
- Inorganic parameters with secondary MCLs (SMCLs): manganese, iron, and TDS - detected at high relative-concentrations in 4.5, 2.2, and 1.7 percent, respectively, of the wells in the primary aquifer.
- Organic parameters with primary MCLs: 1,2-dibromo-3-chlororopane (DBCP) and tetrachloroethene (PCE) - detected at high relative-concentrations in 1.0 and 0.2 percent, respectively, of the wells in the primary aquifer.
- Organic parameters with primary MCLs: chloroform, carbon tetrachloride, DBCP, and perchlorate, detected at moderate relative-concentrations.
- Organic or special interest parameters with primary MCLs: chloroform, bromoform, bromodichloromethane, and dibromochloromethane; PCE; atrazine, simazine, metolachlor, and perchlorate.

Exceedances were measured for nine of the 18 parameters:

- In the Modesto area, test results exceeded MCLs for nitrate, tetrachloroethene (PCE), 1,2-dibromo-3-chlororopane (DBCP), and uranium, and SMCLs for total dissolved solids (TDS) and manganese.

- In the Riverbank area, test results exceeded MCLs for nitrate and arsenic and SMCLs for iron, manganese and TDS.

- The Stanislaus County wells outside those two cities exceeded the MCLs for DBCP, nitrate, and PCE and of the SMCL for iron.

- The single Tuolumne County well exceeded the SMCL for manganese.

Table C-1. Wells with water quality test results exceeding maximum contaminant levels, 2009-2019

Map Area[1]	Well ID	Results	Parameter	Category	Date	Units	Limit Type	Limit	Exceed Amount	Lat	Long
										WGS84	WGS84
County	5000481-002	350	Iron	Inorganic	4/25/2019	UG/L	SMCL	300	50	37.662849	-120.781239
County	5010006-006	0	1,2-dibromo-3-chlororopane	Organic	10/5/2011	UG/L	MCL	0	0	37.647270	-120.763910
County	5010010-191	10.6	Nitrate	Inorganic	10/19/2016	MG/L	MCL	10	1	37.6456	-120.90525
County	5010010-192	5.5	Tetrachloroethene	Organic	1/9/2018	UG/L	MCL	5	1	37.63757	-120.95876
County	5500266-001	143	Manganese	Inorganic	7/13/2011	UG/L	SMCL	50	93	37.715014	-120.446743
County	USGS-373753120474602	2,040	Manganese	Inorganic	8/4/2015	UG/L	SMCL	50	1,990	37.631320	-120.797151
Modesto Wells	5000462-001	24.8	Nitrate	Inorganic	5/1/2019	MG/L	MCL	10	15	37.686917	-120.922278
Modesto Wells	5010010-003	24	Uranium	Inorganic	7/11/2018	pCi/L	MCL	20	4	37.642770	-120.991170
Modesto Wells	5010010-038	28	Uranium	Inorganic	7/10/2013	pCi/L	MCL	20	8	37.645030	-120.984410
Modesto Wells	5010010-189	10.6	Nitrate	Inorganic	10/15/2016	MG/L	MCL	10	1	37.663160	-120.978080
Modesto Wells	5010010-193	11.1	Nitrate	Inorganic	10/21/2016	MG/L	MCL	10	1	37.645040	-120.952930
Modesto Wells	5010010-234	1,200	Total dissolved solids	Inorganic	7/15/2015	MG/L	SMCL	1000	200	37.674146	-120.928175
Modesto Wells	SL0609983955-AS-01D	14	Tetrachloroethene	Organic	8/5/2014	UG/L	MCL	5	9	37.663727	-120.955025
Modesto Wells	SL0609983955-AS-01S	86	Tetrachloroethene	Organic	8/5/2014	UG/L	MCL	5	81	37.663727	-120.955025
Modesto Wells	SL0609983955-AS-02D	39	Tetrachloroethene	Organic	8/4/2014	UG/L	MCL	5	34	37.663727	-120.954887
Modesto Wells	SL0609983955-AS-02S	76	Tetrachloroethene	Organic	8/6/2014	UG/L	MCL	5	71	37.663727	-120.954887
Modesto Wells	SL0609983955-AS-03D	48	Tetrachloroethene	Organic	8/4/2014	UG/L	MCL	5	43	37.663726	-120.954749
Modesto Wells	SL0609983955-AS-03S	99	Tetrachloroethene	Organic	8/4/2014	UG/L	MCL	5	94	37.663726	-120.954749
Modesto Wells	SL0609983955-AS-04D	45	Tetrachloroethene	Organic	8/4/2014	UG/L	MCL	5	40	37.663724	-120.954610
Modesto Wells	SL0609983955-AS-04S	69	Tetrachloroethene	Organic	8/4/2014	UG/L	MCL	5	64	37.663724	-120.954610
Modesto Wells	SL0609983955-AS-05D	250	Tetrachloroethene	Organic	8/5/2014	UG/L	MCL	5	245	37.663726	-120.954195
Modesto Wells	SL0609983955-AS-05S	24	Tetrachloroethene	Organic	8/6/2014	UG/L	MCL	5	19	37.663726	-120.954195
Modesto Wells	SL0609983955-AS-06D	11	Tetrachloroethene	Organic	8/5/2014	UG/L	MCL	5	6	37.663726	-120.954064
Modesto Wells	SL0609983955-AS-06S	29	Tetrachloroethene	Organic	8/6/2014	UG/L	MCL	5	24	37.663726	-120.954064
Modesto Wells	SL0609983955-AS-07S	19	Tetrachloroethene	Organic	8/6/2014	UG/L	MCL	5	14	37.663726	-120.953918
Modesto Wells	SL0609983955-AS-08S	37	Tetrachloroethene	Organic	8/6/2014	UG/L	MCL	5	32	37.663722	-120.953781
Modesto Wells	SL0609983955-MW-1	17	Nitrate	Inorganic	10/22/2009	MG/L	MCL	10	7	37.665380	-120.957031
Modesto Wells	SL0609983955-MW-2	210	Manganese	Inorganic	8/5/2014	UG/L	SMCL	50	160	37.664117	-120.953039
Modesto Wells	SL0609983955-MW-3	1,300	Manganese	Inorganic	10/22/2009	UG/L	SMCL	50	1,250	37.663379	-120.952322
Modesto Wells	SL0609983955-MW-4	16	Nitrate	Inorganic	10/22/2009	MG/L	MCL	10	6	37.661371	-120.953595
Modesto Wells	SL0609983955-MW-5	13	Nitrate	Inorganic	11/10/2009	MG/L	MCL	10	3	37.663733	-120.954942
Modesto Wells		66	Tetrachloroethene	Organic	11/10/2009	UG/L	MCL	5	61	37.663733	-120.954942
Modesto Wells	SL0609983955-MW-6	1,700	Manganese	Inorganic	7/24/2015	UG/L	SMCL	50	1,650	37.662776	-120.953788
Modesto Wells		17	Nitrate	Inorganic	7/24/2015	MG/L	MCL	10	7	37.662776	-120.953788

continued

Table C-1. Wells with water quality test results exceeding maximum contaminant levels, 2009-2019 (continued)

Map Area[1]	Well ID	Results	Parameter	Category	Date	Units	Limit Type	Limit	Exceed Amount	Lat	Long
										WGS84	WGS84
Modesto Wells	SL0609983955-MW-7	6,100	Manganese	Inorganic	7/21/2015	UG/L	SMCL	50	6,050	37.663731	-120.953762
Modesto Wells		14	Nitrate	Inorganic	11/10/2009	MG/L	MCL	10	4	37.663731	-120.953762
Modesto Wells		15	Tetrachloroethene	Organic	11/10/2009	UG/L	MCL	5	10	37.663731	-120.953762
Modesto Wells	SL0609983955-MW-8	130	Manganese	Inorganic	11/10/2009	UG/L	SMCL	50	80	37.663130	-120.954756
Modesto Wells		13	Nitrate	Inorganic	11/10/2009	MG/L	MCL	10	3	37.663130	-120.954756
Modesto Wells		65	Tetrachloroethene	Organic	1/13/2016	UG/L	MCL	5	60	37.663130	-120.954756
Modesto Wells	SL0609983955-MW-9A	84	Manganese	Inorganic	8/5/2014	UG/L	SMCL	50	34	37.663725	-120.954404
Modesto Wells		11	Nitrate	Inorganic	8/5/2014	MG/L	MCL	10	1	37.663725	-120.954404
Modesto Wells		78	Tetrachloroethene	Organic	12/16/2014	UG/L	MCL	5	73	37.663725	-120.954404
Modesto Wells	SL0609983955-MW-9B	100	Manganese	Inorganic	7/21/2015	UG/L	SMCL	50	50	37.663723	-120.954419
Modesto Wells		15	Tetrachloroethene	Organic	8/5/2014	UG/L	MCL	5	10	37.663723	-120.954419
Modesto Wells	SL0609983955-TR-6-1	86	Manganese	Inorganic	10/20/2009	UG/L	SMCL	50	36	37.662383	-120.955911
Modesto Wells	SL0609983955-TR-7-1	760	Manganese	Inorganic	7/22/2015	UG/L	SMCL	50	710	37.662082	-120.954814
Modesto Wells	SL0609983955-TR-8	360	Manganese	Inorganic	7/24/2015	UG/L	SMCL	50	310	37.663726	-120.956207
Modesto Wells		12	Nitrate	Inorganic	7/24/2015	MG/L	MCL	10	2	37.663726	-120.956207
Modesto Wells	SL0609983955-TR-9-1	260	Manganese	Inorganic	7/21/2015	UG/L	SMCL	50	210	37.663788	-120.954268
Modesto Wells		490	Nitrate	Inorganic	7/21/2015	MG/L	MCL	10	480	37.663788	-120.954268
Modesto Wells		15	Tetrachloroethene	Organic	12/17/2014	UG/L	MCL	5	10	37.663788	-120.954268
Modesto Wells	SL0609983955-TR-9-2	120	Manganese	Inorganic	7/21/2015	UG/L	SMCL	50	70	37.663788	-120.954268
Modesto Wells		11.0	Nitrate	Inorganic	7/21/2015	MG/L	MCL	10	1	37.663788	-120.954268
Modesto Wells		6.3	Tetrachloroethene	Organic	12/17/2014	UG/L	MCL	5	1	37.663788	-120.954268
Modesto Wells	SL0609983955-TR-9-3	220	Manganese	Inorganic	7/21/2015	UG/L	SMCL	50	170	37.663788	-120.954268
Modesto Wells		12	Nitrate	Inorganic	7/21/2015	MG/L	MCL	10	2	37.663788	-120.954268
Modesto Wells		5.1	Tetrachloroethene	Organic	1/19/2015	UG/L	MCL	5	0	37.663788	-120.954268
Modesto Wells	SL0609983955-VR-02	15	Tetrachloroethene	Organic	12/16/2014	UG/L	MCL	5	10	37.663726	-120.954956
Modesto Wells	SL0609983955-VR-03	6	Tetrachloroethene	Organic	8/18/2015	UG/L	MCL	5	1	37.663727	-120.954817
Modesto Wells	SL0609983955-VR-04	8	Tetrachloroethene	Organic	1/19/2015	UG/L	MCL	5	3	37.663724	-120.954680
Modesto Wells	SL0609983955-VR-05	12	Tetrachloroethene	Organic	1/19/2015	UG/L	MCL	5	7	37.663725	-120.954541
Modesto Wells	SL0609983955-VR-06	61	Tetrachloroethene	Organic	12/16/2014	UG/L	MCL	5	56	37.663726	-120.954387
Modesto Wells	SL0609983955-VR-07	12	Tetrachloroethene	Organic	4/11/2016	UG/L	MCL	5	7	37.663726	-120.954262
Modesto Wells	SL0609983955-VR-08	5.6	Tetrachloroethene	Organic	4/11/2016	UG/L	MCL	5	1	37.663726	-120.954127
Modesto Wells	SL0609983955-VR-09	30	Tetrachloroethene	Organic	8/6/2014	UG/L	MCL	5	25	37.663727	-120.953987
Modesto Wells	SL0609983955-VR-10	10	Tetrachloroethene	Organic	8/6/2014	UG/L	MCL	5	5	37.663726	-120.953849
Modesto Wells	SL205833043-MMW-27A	0	1,2-dibromo-3-chlororopane	Organic	12/19/2015	UG/L	MCL	0	0	37.685170	-120.919718

Continued

Table C-1. Wells with water quality test results exceeding maximum contaminant levels, 2009-2019 (continued)

Map Area[1]	Well ID	Results	Parameter	Category	Date	Units	Limit Type	Limit	Exceed Amount	Lat	Long
										WGS84	WGS84
Modesto Wells	SLT5S1883227-D-3	12	Tetrachloroethene	Organic	3/30/2010	UG/L	MCL	5	7	37.668809	-120.990271
Modesto Wells	T0609900108-MW2	8,720	Tetrachloroethene	Organic	3/2/2018	UG/L	MCL	5	8,715	37.638347	-120.972469
Modesto Wells	T0609900108-MW3	8,860	Tetrachloroethene	Organic	3/2/2018	UG/L	MCL	5	8,855	37.638343	-120.972578
Modesto Wells	T0609900108-MW4	2,300	Tetrachloroethene	Organic	3/2/2018	UG/L	MCL	5	2,295	37.638514	-120.972635
Riverbank Wells	5000211-003	684	Iron	Inorganic	2/19/2009	UG/L	SMCL	300	384	37.712279	-120.918206
Riverbank Wells	DOD100368800-EW54B	21,000	Iron	Inorganic	7/24/2018	UG/L	SMCL	300	20,700	37.713959	-120.921172
Riverbank Wells		61	Manganese	Inorganic	7/24/2018	UG/L	SMCL	50	11	37.713959	-120.921172
Riverbank Wells	DOD100368800-EW54C	15,000	Iron	Inorganic	7/24/2018	UG/L	SMCL	300	14,700	37.713899	-120.921172
Riverbank Wells	DOD100368800-IW127A'	63,000	Iron	Inorganic	10/5/2015	UG/L	SMCL	300	62,700	37.718857	-120.917862
Riverbank Wells		2,000	Manganese	Inorganic	10/5/2015	UG/L	SMCL	50	1,950	37.718857	-120.917862
Riverbank Wells		1,200	Total dissolved solids	Inorganic	11/7/2014	MG/L	SMCL	1000	200	37.718857	-120.917862
Riverbank Wells	DOD100368800-IW128A'	39,000	Iron	Inorganic	10/5/2015	UG/L	SMCL	300	38,700	37.718948	-120.917873
Riverbank Wells		760	Manganese	Inorganic	10/5/2015	UG/L	SMCL	50	710	37.718948	-120.917873
Riverbank Wells		11	Nitrate	Inorganic	7/30/2014	MG/L	MCL	10	1	37.718948	-120.917873
Riverbank Wells		1,100	Total dissolved solids	Inorganic	11/5/2014	MG/L	SMCL	1000	100	37.718948	-120.917873
Riverbank Wells	DOD100368800-IW129A'	740,000	Iron	Inorganic	10/5/2015	UG/L	SMCL	300	739,700	37.719031	-120.917915
Riverbank Wells		2,700	Manganese	Inorganic	10/5/2015	UG/L	SMCL	50	2,650	37.719031	-120.917915
Riverbank Wells	DOD100368800-IW129A'	11	Nitrate	Inorganic	7/30/2014	MG/L	MCL	10	1	37.719031	-120.917915
Riverbank Wells		1,200	Total dissolved solids	Inorganic	11/5/2014	MG/L	SMCL	1000	200	37.719031	-120.917915
Riverbank Wells	DOD100368800-IW130A'	180,000	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	179,700	37.714153	-120.920710
Riverbank Wells		1,800	Manganese	Inorganic	10/7/2015	UG/L	SMCL	50	1,750	37.714153	-120.920710
Riverbank Wells	DOD100368800-IW130B	37,000	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	36,700	37.714169	-120.920713
Riverbank Wells		1,600	Manganese	Inorganic	10/7/2015	UG/L	SMCL	50	1,550	37.714169	-120.920713
Riverbank Wells	DOD100368800-IW130C	3,200	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	2,900	37.714184	-120.920711
Riverbank Wells		150	Manganese	Inorganic	7/9/2015	UG/L	SMCL	50	100	37.714184	-120.920711
Riverbank Wells	DOD100368800-IW131A'	110,000	Iron	Inorganic	7/10/2015	UG/L	SMCL	300	109,700	37.714074	-120.920663
Riverbank Wells		1,300	Manganese	Inorganic	7/10/2015	UG/L	SMCL	50	1,250	37.714074	-120.920663
Riverbank Wells	DOD100368800-IW131B	73,000	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	72,700	37.714073	-120.920685
Riverbank Wells		1,500	Manganese	Inorganic	10/7/2015	UG/L	SMCL	50	1,450	37.714073	-120.920685
Riverbank Wells	DOD100368800-IW131C	16,000	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	15,700	37.714073	-120.920707
Riverbank Wells		1,600	Manganese	Inorganic	10/7/2015	UG/L	SMCL	50	1,550	37.714073	-120.920707
Riverbank Wells	DOD100368800-IW132A'	2,700,000	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	2,699,700	37.713967	-120.920709
Riverbank Wells		3,500	Manganese	Inorganic	10/7/2015	UG/L	SMCL	50	3,450	37.713967	-120.920709
Riverbank Wells	DOD100368800-IW132B	480,000	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	479,700	37.713986	-120.920707
Riverbank Wells		470	Manganese	Inorganic	10/7/2015	UG/L	SMCL	50	420	37.713986	-120.920707

Continued

Table C-1. Wells with water quality test results exceeding maximum contaminant levels, 2009-2019 (continued)

Map Area[1]	Well ID	Results	Parameter	Category	Date	Units	Limit Type	Limit	Exceed Amount	Lat	Long
										WGS84	WGS84
Riverbank Wells	DOD100368800-IW132C	17,000	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	16,700	37.714015	-120.920708
Riverbank Wells		960	Manganese	Inorganic	10/7/2015	UG/L	SMCL	50	910	37.714015	-120.920708
Riverbank Wells	DOD100368800-IW133A'	4,700	Iron	Inorganic	10/8/2015	UG/L	SMCL	300	4,400	37.713901	-120.920708
Riverbank Wells		3,800	Manganese	Inorganic	10/8/2015	UG/L	SMCL	50	3,750	37.713901	-120.920708
Riverbank Wells	DOD100368800-IW133B	22,000	Iron	Inorganic	10/8/2015	UG/L	SMCL	300	21,700	37.713872	-120.920711
Riverbank Wells		120	Manganese	Inorganic	10/8/2015	UG/L	SMCL	50	70	37.713872	-120.920711
Riverbank Wells	DOD100368800-IW133C	5,000	Iron	Inorganic	10/8/2015	UG/L	SMCL	300	4,700	37.713886	-120.920698
Riverbank Wells		450	Manganese	Inorganic	10/8/2015	UG/L	SMCL	50	400	37.713886	-120.920698
Riverbank Wells	DOD100368800-IW134A'	5,400	Iron	Inorganic	10/8/2015	UG/L	SMCL	300	5,100	37.713804	-120.920709
Riverbank Wells		950	Manganese	Inorganic	10/8/2015	UG/L	SMCL	50	900	37.713804	-120.920709
Riverbank Wells	DOD100368800-IW134B	11,000	Iron	Inorganic	10/8/2015	UG/L	SMCL	300	10,700	37.713834	-120.920713
Riverbank Wells		600	Manganese	Inorganic	10/8/2015	UG/L	SMCL	50	550	37.713834	-120.920713
Riverbank Wells	DOD100368800-IW134C	45,000	Iron	Inorganic	10/8/2015	UG/L	SMCL	300	44,700	37.713819	-120.920707
Riverbank Wells		3,100	Manganese	Inorganic	10/8/2015	UG/L	SMCL	50	3,050	37.713819	-120.920707
Riverbank Wells	DOD100368800-IW135A'	16,000	Iron	Inorganic	10/8/2015	UG/L	SMCL	300	15,700	37.713741	-120.920706
Riverbank Wells		2,100	Manganese	Inorganic	10/8/2015	UG/L	SMCL	50	2,050	37.713741	-120.920706
Riverbank Wells	DOD100368800-IW135B	19,000	Iron	Inorganic	10/8/2015	UG/L	SMCL	300	18,700	37.713755	-120.920698
Riverbank Wells		850	Manganese	Inorganic	10/8/2015	UG/L	SMCL	50	800	37.713755	-120.920698
Riverbank Wells	DOD100368800-IW135C	19,000	Iron	Inorganic	10/7/2015	UG/L	SMCL	300	18,700	37.713770	-120.920708
Riverbank Wells		2,400	Manganese	Inorganic	10/7/2015	UG/L	SMCL	50	2,350	37.713770	-120.920708
Riverbank Wells	DOD100368800-IW136A'	1,300,000	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	1,299,700	37.713674	-120.920706
Riverbank Wells		1,300	Manganese	Inorganic	10/6/2015	UG/L	SMCL	50	1,250	37.713674	-120.920706
Riverbank Wells	DOD100368800-IW136B	25,000	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	24,700	37.713691	-120.920705
Riverbank Wells		1,200	Manganese	Inorganic	10/6/2015	UG/L	SMCL	50	1,150	37.713691	-120.920705
Riverbank Wells	DOD100368800-IW136C	2,800	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	2,500	37.713706	-120.920709
Riverbank Wells		970	Manganese	Inorganic	10/6/2015	UG/L	SMCL	50	920	37.713706	-120.920709
Riverbank Wells	DOD100368800-IW137A'	1,700,000	Iron	Inorganic	7/10/2015	UG/L	SMCL	300	1,699,700	37.713639	-120.920707
Riverbank Wells		2,200	Manganese	Inorganic	4/1/2015	UG/L	SMCL	50	2,150	37.713639	-120.920707
Riverbank Wells	DOD100368800-IW137B	130,000	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	129,700	37.713572	-120.920702
Riverbank Wells		85	Manganese	Inorganic	10/6/2015	UG/L	SMCL	50	35	37.713572	-120.920702
Riverbank Wells	DOD100368800-IW137C	160,000	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	159,700	37.713608	-120.920706
Riverbank Wells		2,300	Manganese	Inorganic	10/6/2015	UG/L	SMCL	50	2,250	37.713608	-120.920706
Riverbank Wells	DOD100368800-IW138A'	36,000	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	35,700	37.713507	-120.920704
Riverbank Wells		1,500	Manganese	Inorganic	10/6/2015	UG/L	SMCL	50	1,450	37.713507	-120.920704
Riverbank Wells	DOD100368800-IW138B	3,200	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	2,900	37.713475	-120.920705
Riverbank Wells		130	Manganese	Inorganic	10/6/2015	UG/L	SMCL	50	80	37.713475	-120.920705

Continued

Table C-1. Wells with water quality test results exceeding maximum contaminant levels, 2009-2019 (continued)

Map Area[1]	Well ID	Results	Parameter	Category	Date	Units	Limit Type	Limit	Exceed Amount	Lat	Long
										WGS84	WGS84
Riverbank Wells	DOD100368800-IW138C	24,000	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	23,700	37.713490	-120.920701
Riverbank Wells		1,500	Manganese	Inorganic	10/6/2015	UG/L	SMCL	50	1,450	37.713490	-120.920701
Riverbank Wells	DOD100368800-IW139A'	1,200,000	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	1,199,700	37.713366	-120.920689
Riverbank Wells		490	Manganese	Inorganic	7/23/2018	UG/L	SMCL	50	440	37.713366	-120.920689
Riverbank Wells	DOD100368800-IW139B	69,000	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	68,700	37.713431	-120.920701
Riverbank Wells		3,300	Manganese	Inorganic	7/23/2018	UG/L	SMCL	50	3,250	37.713431	-120.920701
Riverbank Wells	DOD100368800-IW139C	3,700	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	3,400	37.713415	-120.920700
Riverbank Wells		1,000	Manganese	Inorganic	7/23/2018	UG/L	SMCL	50	950	37.713415	-120.920700
Riverbank Wells	DOD100368800-IW140A'	56,000	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	55,700	37.713303	-120.920685
Riverbank Wells		2,400	Manganese	Inorganic	7/23/2018	UG/L	SMCL	50	2,350	37.713303	-120.920685
Riverbank Wells	DOD100368800-IW140B	33,000	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	32,700	37.713281	-120.920677
Riverbank Wells		1,600	Manganese	Inorganic	7/23/2018	UG/L	SMCL	50	1,550	37.713281	-120.920677
Riverbank Wells	DOD100368800-IW140C	5,000	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	4,700	37.713285	-120.920693
Riverbank Wells		920	Manganese	Inorganic	7/23/2018	UG/L	SMCL	50	870	37.713285	-120.920693
Riverbank Wells	DOD100368800-IW141A'	470,000	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	469,700	37.713219	-120.920698
Riverbank Wells		3,200	Manganese	Inorganic	7/23/2018	UG/L	SMCL	50	3,150	37.713219	-120.920698
Riverbank Wells	DOD100368800-IW141B	11,000	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	10,700	37.713239	-120.920697
Riverbank Wells		770	Manganese	Inorganic	7/23/2018	UG/L	SMCL	50	720	37.713239	-120.920697
Riverbank Wells	DOD100368800-IW141C	5,400	Iron	Inorganic	7/23/2018	UG/L	SMCL	300	5,100	37.713214	-120.920674
Riverbank Wells		470	Manganese	Inorganic	9/14/2017	UG/L	SMCL	50	420	37.713214	-120.920674
Riverbank Wells	DOD100368800-IW142A'	57,000	Iron	Inorganic	7/24/2018	UG/L	SMCL	300	56,700	37.714473	-120.920700
Riverbank Wells		3,500	Manganese	Inorganic	7/24/2018	UG/L	SMCL	50	3,450	37.714473	-120.920700
Riverbank Wells	DOD100368800-IW142B	2,000	Iron	Inorganic	7/24/2018	UG/L	SMCL	300	1,700	37.714457	-120.920699
Riverbank Wells		930	Manganese	Inorganic	7/24/2018	UG/L	SMCL	50	880	37.714457	-120.920699
Riverbank Wells	DOD100368800-IW142C	31,000	Iron	Inorganic	7/24/2018	UG/L	SMCL	300	30,700	37.714441	-120.920699
Riverbank Wells		2,300	Manganese	Inorganic	7/24/2018	UG/L	SMCL	50	2,250	37.714441	-120.920699
Riverbank Wells	DOD100368800-MW118B	930	Iron	Inorganic	1/29/2018	UG/L	SMCL	300	630	37.714024	-120.922068
Riverbank Wells	DOD100368800-MW124A'	1,000	Iron	Inorganic	10/6/2015	UG/L	SMCL	300	700	37.718912	-120.918267
Riverbank Wells		11	Nitrate	Inorganic	10/6/2015	MG/L	MCL	10	1	37.718912	-120.918267
Riverbank Wells	DOD100368800-MW125A'	1,800	Iron	Inorganic	7/24/2018	UG/L	SMCL	300	1,500	37.713616	-120.921149
Riverbank Wells		52	Manganese	Inorganic	4/2/2015	UG/L	SMCL	50	2	37.713616	-120.921149
Riverbank Wells		11	Nitrate	Inorganic	7/8/2015	MG/L	MCL	10	1	37.713616	-120.921149
Riverbank Wells	DOD100368800-MW125C	420	Iron	Inorganic	4/24/2018	UG/L	SMCL	300	120	37.713662	-120.921149
Riverbank Wells		73	Manganese	Inorganic	7/29/2014	UG/L	SMCL	50	23	37.713662	-120.921149
Riverbank Wells	DOD100368800-MW126A'	800	Iron	Inorganic	4/23/2018	UG/L	SMCL	300	500	37.714180	-120.921158

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Table C-1. Wells with water quality test results exceeding maximum contaminant levels, 2009-2019 (continued)

Map Area[1]	Well ID	Results	Parameter	Category	Date	Units	Limit Type	Limit	Exceed Amount	Lat	Long
										WGS84	WGS84
Riverbank Wells	DOD100368800-MW126B	12	Arsenic	Inorganic	1/29/2018	UG/L	MCL	10	2	37.714205	-120.921158
Riverbank Wells		440	Iron	Inorganic	4/23/2018	UG/L	SMCL	300	140	37.714205	-120.921158
Riverbank Wells		200	Manganese	Inorganic	12/4/2014	UG/L	SMCL	50	150	37.714205	-120.921158
Riverbank Wells	DOD100368800-MW126C	12	Arsenic	Inorganic	7/24/2018	UG/L	MCL	10	2	37.714225	-120.921156
Riverbank Wells		330	Iron	Inorganic	7/24/2018	UG/L	SMCL	300	30	37.714225	-120.921156
Riverbank Wells	DOD100368800-MW143A'	5,000	Iron	Inorganic	7/24/2018	UG/L	SMCL	300	4,700	37.713324	-120.921154
Riverbank Wells	DOD100368800-MW143B	620	Iron	Inorganic	1/30/2018	UG/L	SMCL	300	320	37.713339	-120.921154
Riverbank Wells		68	Manganese	Inorganic	11/21/2017	UG/L	SMCL	50	18	37.713339	-120.921154
Riverbank Wells	DOD100368800-MW143C	810	Iron	Inorganic	4/24/2018	UG/L	SMCL	300	510	37.713353	-120.921154
Riverbank Wells		77	Manganese	Inorganic	1/29/2018	UG/L	SMCL	50	27	37.713353	-120.921154
Riverbank Wells	DOD100368800-MW65A'	1,500	Iron	Inorganic	10/5/2015	UG/L	SMCL	300	1,200	37.718942	-120.917928
Riverbank Wells		180	Manganese	Inorganic	10/5/2015	UG/L	SMCL	50	130	37.718942	-120.917928
Riverbank Wells		11	Nitrate	Inorganic	10/5/2015	MG/L	MCL	10	1	37.718942	-120.917928
Riverbank Wells	DOD100368800-PT01	4,600	Iron	Inorganic	5/15/2013	UG/L	SMCL	300	4,300	37.713922	-120.921146
Riverbank Wells		160	Manganese	Inorganic	5/15/2013	UG/L	SMCL	50	110	37.713922	-120.921146
Riverbank Wells	DOD100368800-PT02	3,500	Iron	Inorganic	5/15/2013	UG/L	SMCL	300	3,200	37.713918	-120.921230
Riverbank Wells		92	Manganese	Inorganic	5/15/2013	UG/L	SMCL	50	42	37.713918	-120.921230
Riverbank Wells	DOD100368800-PT03	470	Iron	Inorganic	5/15/2013	UG/L	SMCL	300	170	37.713913	-120.921316