**Attachment 4: Project Description**

# Identification and Evaluation of Groundwater Recharge in Butte County

## A. Purpose

Groundwater resources have long played an important role in the development, growth, and sustainability of Butte County and its residents. Local groundwater management continues to increase in complexity and scope, driven by evolving demands for groundwater resources both within and adjacent to Butte County. Nearly one-third of Butte County's water demand is directly met from groundwater. The county's streams, creeks and ecosystems depend on a healthy groundwater basin. Butte County has recognized the importance of protecting groundwater and groundwater recharge to ensure a healthy water resource system through its Groundwater Management Plan, Integrated Water Resource Plan, and General Plan. Through policies and programs, Butte County incorporates groundwater recharge considerations into its water resource planning efforts. Butte County formalized the linkage between land use and water resource planning through its General Plan process. The proposed project will fulfill objectives of the Butte County Groundwater Management Plan, the Butte County Integrated Water Resource Management Plan, and the Butte County General Plan 2030.

Through three main tasks, the proposed project will provide land use planners, water resource managers, and stakeholders with information on natural groundwater recharge areas in Butte County and areas that may be considered for managed recharge in the future. A revised countywide map of natural groundwater recharge areas will improve decision makers' ability to assess and manage groundwater resources and guide land use decisions. The Butte County Groundwater Management Plan will be amended to replace the existing countywide groundwater recharge map with the revised and updated one developed from this project. Identifying areas where managed recharge may be feasible and beneficial will serve as an important planning tool for potential future projects. Managed recharge in the county could benefit local groundwater levels and/or have flood control benefits. These first two tasks are based on similar projects recently conducted in Tehama County (Tehama County Groundwater Recharge Area Location Study, Project Number 139235) and Glenn County (Glenn County Groundwater Reliability and Recharge Pilot Project). The project will utilize the experience and general approach of these efforts and will foster a regional approach to addressing similar analytical questions regarding groundwater management. In addition to mapping, a site investigation component of this project will use innovative techniques combined with traditional data collection to better characterize natural recharge mechanisms, source and flow paths of recharged water, and interconnectedness of the valley's aquifer systems. This task will investigate groundwater recharge conditions in one or more site locations corresponding to an area identified in task two as showing promise for future managed groundwater recharge. The site investigation will test assumptions concerning groundwater recharge and potentially develop efficient groundwater recharge evaluation techniques for future investigations. It may also be valuable in validating the mapped areas of recharge in tasks one and two.

Throughout the valley, information is needed at the county government level to provide the basis for informed land-use planning in the recharge corridor. As Butte County moves

forward with their General Plan 2030 implementation, this data will provide decision makers the information necessary to take appropriate measures that can be included in the plan to ensure protection of the recharge areas. Improved characterization of groundwater recharge is critical in the overall evaluation of groundwater conditions and the Basin Management Objective program. The project will also enhance public education and outreach regarding groundwater recharge issues since the public will be given the opportunity to keep informed and provide input throughout the duration of the project.

## B. Project Summary

The proposed project will provide a more comprehensive, defendable characterization of groundwater recharge and will employ innovative investigative tools to better characterize groundwater recharge mechanisms. The proposed project will produce a countywide groundwater recharge map, identify locations where future groundwater recharge activities could be beneficial, and investigate groundwater recharge processes at a representative site.

The first task involves preparing a countywide map identifying areas based on their potential to contribute to natural groundwater recharge. The map will be a beneficial resource for local agencies in their efforts to protect groundwater recharge areas and improved the understanding of basin conditions. The task will update and replace the groundwater recharge map currently included in the Groundwater Management Plan. The existing map does not provide the specificity that land and water resource managers need, nor does it incorporate the latest scientific data. The task will build upon the most current datasets to refine and improve the map identifying groundwater recharge areas in Butte County. A methodology to refine the existing groundwater recharge map was developed as part of the Butte County General Plan 2030 update process but was not completed. The effort to update and replace the countywide groundwater recharge map will take into consideration the latest data and information. The approach taken in this task is consistent with regional efforts which have produced viable approaches to categorize areas based on their potential to contribute to groundwater recharge.

A second task will identify and map promising areas in the county where managed groundwater recharge projects (e.g., flood detention basins, storm water or similar facilities) could provide local benefits. The scope of this task will develop criteria to be used to identify areas where managed groundwater recharge could be effective and feasible and areas that could benefit from supplemented groundwater recharge. Planning to augment groundwater recharge will provide additional flexibility for managing water resources within changing climate conditions, inter-annual variability, and increased local demands. Managing surface water and groundwater resources within the county is essential to the long-term economic and environmental health of the county.

A third task will involve an investigation of groundwater recharge processes in a defined study area. The location will be chosen based on results from task one and two, availability of existing data, and site accessibility. Although data exists to reasonably characterize recharge conditions in some areas of Butte County, uncertainty exists in specific locations due to complex hydrology and geology. Therefore, the site investigation will use a suite of data types and analyses, including a geophysical investigation to better characterize the subsurface and possibly quantify recharge. The investigation will employ techniques that

could serve as a template for future investigations. The template could be useful for conducting site specific evaluations when presented with future land use project proposals or potentially for a managed recharge pilot project. The results of the investigation will be used to modify, if necessary, the draft countywide groundwater recharge map (Task1) and the identification of potential managed recharge locations (Task 2).

## C. Location

Butte County is located in the Sacramento River Hydrological Region, which covers approximately 17 million acres (27,000 square miles) and extends south from the Modoc Plateau and Cascade Range at the Oregon border to the Sacramento-San Joaquin Delta. In addition to Butte County, the region includes all or large portions of Modoc, Siskiyou, Lassen, Shasta, Tehama, Glenn, Plumas, Colusa, Sutter, Yuba, Sierra, Nevada, Placer, Sacramento, El Dorado, Yolo, Solano, Lake, and Napa counties. The region includes the Sacramento River, the longest river system in the State of California, and its tributaries including the Pit, Feather, Yuba, Bear, and American rivers as its major tributaries.

Annual runoff in the region averages about 22.4 million acre-feet (MAF), which is nearly one-third of the State's total natural runoff. Surface water flows in Butte County and the Sacramento Basin are extremely variable, both seasonally and annually, although their partial dependence on annual snowmelt tends to mitigate the seasonal variability. Butte County includes the geographic provinces of the Sacramento Valley, and the foothill and mountain areas of the Sierra and Cascade ranges. The mountainous portions of the county comprise approximately a third of the county's land area and function as the major water bearing area, though the foothill areas also receive considerable precipitation. Higher-altitude portions of the county receive abundant snowfall. Most of the annual precipitation occurs during the winter and spring. Conversely, the highest water usage is during the hot, dry summer months when agricultural irrigation occurs mostly on the valley floor.

### *a. Groundwater*

In Butte County, reserves of groundwater are found in the thick sedimentary deposits of the Sacramento Valley. Groundwater can also be found in more limited amounts in mountainous areas of the county within volcanic, metamorphic, and granitic rock. Figure 1 shows the groundwater basins found within Butte County.

**Figure 1: Butte County Groundwater Basins**

Groundwater is stored in the pore spaces between particles of granular soil and rock materials, and in the joints and fractures of consolidated rocks. In coarse-grained material, such as sand and gravel, pores are more interconnected than those of clay or silt, facilitating the free movement of water. Fine-grained materials, such as clay and silt deposits, impede groundwater movement and do not readily yield water. Consolidated rocks provide storage space in their joint and fracture systems, which allow for groundwater movement and water yield. Only where wells directly intercept major joints or fractures do these aquifers provide dependable water sources.

Butte County is composed of three primary geomorphic provinces in two categories: the mountain provinces (consisting of the Cascade and Sierra Nevada Geomorphic Provinces) and the great valley province (consisting of four subareas). The four great valley province subareas are:

- Dissected alluvial uplands;
- Low alluvial plains and fans;
- Floodplain and natural levees; and
- Flood basins.

Butte County has two primary groundwater resource areas: the groundwater-rich Sacramento Valley aquifer and the mountainous areas to the east and north, which have restricted groundwater resources. In the mountain areas, weathered and open fractured rock can extend to several hundred feet deep. Shallow wells in perched zones typically yield only a few gallons per minute and can go dry during drought years. Volcanic capped ridge areas having inter-volcanic sand and gravel deposits produce the most productive wells.

Groundwater also occurs to a lesser extent in the soil mantle and weathered surface developed on the Tuscan rocks. Deeper groundwater flows westward toward the Sacramento Valley and recharges the Tuscan sedimentary rocks beneath the younger valley deposits.

The Sacramento Valley aquifer systems are the focus of this study and therefore are described in greater detail below.

### i. Sacramento Valley Aquifer Systems

The main water bearing units in the Sacramento Valley portion of Butte County are the Tuscan, Laguna, Riverbank and Modesto Formations. Although relative amounts of coarse-grained and fine-grained material in the alluvial deposits of the Sacramento Valley vary greatly in both vertical and horizontal extent, in general, clay and fine-grained deposits far exceed those of coarse-grained materials. Coarser materials are deposited in foothill areas. Finer materials are transported further into the valley and are more gradually deposited onto the floodplain. This provides context for the heterogeneity characterizing the basin's deposits. Of the freshwater aquifer systems in the valley, the younger and shallower alluvial deposits comprise the upper portions while the Tuscan and Laguna Formations make up a deeper aquifer.

The Alluvial aquifer system is the uppermost groundwater bearing unit, with a maximum depth of about 200 feet. Four subgroups comprise this relatively shallow freshwater aquifer system: Alluvium deposits, Basin deposits and the Riverbank and Modesto Formations. The Alluvium deposits, and Riverbank and Modesto Formations are all productive, mostly supplying shallow domestic wells. These units are composed of gravel, sand, and silt. In addition, the Modesto Formation has clay deposits. The Basin deposits (ex. Butte Basin) consist of low permeable clays that usually produce little water to wells. This shallower, generally unconfined, alluvial system overlies the Tuscan aquifer system.

The Tuscan and Laguna Formations are the source of water for deeper wells such as irrigation and municipal wells. Confined water occurs in the Tuscan and Laguna Formations and in the younger alluvium where it is overlain by flood-basin deposits. The fine-grained strata of the Laguna Formation yields moderate amounts of water since permeable sand and gravel zones are infrequent and minor in extent and thickness. The highest producing wells in alluvial uplands occur when the deeper Tuscan volcanic rocks are tapped. The Tuscan Formation contains an important deep aquifer theorized to underlie most of the valley area.

The Tuscan Formation is geologically divided into four units, Tuscan Formation units A, B, C, and D. As an aquifer system it is divided into two primary units, the Upper and Lower Tuscan. The Tuscan Formation units C and D define the Upper Tuscan, and the Tuscan Formation units A and B define the Lower Tuscan. The Lower Tuscan aquifer system is the greater water bearing of the two. The buried extent of the Lower Tuscan aquifer system in the northern Sacramento Valley is expansive. It extends from the Redding Basin to the Sutter Buttes and from the eastern margin of the valley, westward 10 to 30 miles. In the subsurface, the Lower Tuscan Formation covers an area of about 850 square miles and has an estimated average thickness of about 500 feet. The Lower Tuscan Formation is also exposed at the ground surface along the east side of the valley. In the central portion of the

valley, it is found at a depths ranging from 500 to 1000 feet below ground surface. This aquifer system consists of gravels, sands, and silts that typically yield high volumes of groundwater to wells.

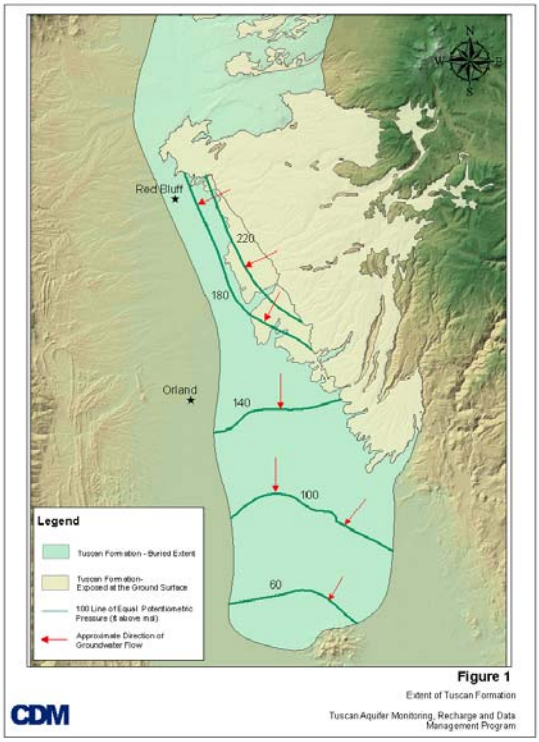


**Figure 2: Lower Tuscan Aquifer**

### ii. Groundwater Recharge

The major sources of groundwater recharge in Butte County are percolation of precipitation, deep percolation of applied irrigation water in agricultural areas, stream-aquifer interaction and subsurface inflow. Of the 3.77 million acre-feet of average annual rainfall, less than half is consumed by crop or vegetation evapotranspiration (ET) or urban/industrial uses within the county. Therefore, more than two million acre-feet are available for recharge or discharge via surface and subsurface outflow. Subsurface inflow from higher elevations and percolation of precipitation are the major sources of groundwater recharge in the mountain areas. Some recharge probably occurs along through-flowing streams in areas with permeable soils or alluvial deposits. Stream-aquifer interaction and deep percolation of precipitation are major sources of groundwater recharge in the valley. Most of this recharge occurs on alluvial fans where streams have sustained flow and the soil is highly permeable. In areas with clay soils or buried hardpan layers, high rates of surface runoff and ponding of water indicate locations where infiltration rates are low. Infiltration of surface runoff does occur at the basin margin where Tuscan and fanglomerate rocks are overlain by valley deposits. Deep subsurface inflow occurs in mountainous areas, flowing west to recharge the adjacent valley area.

It is hypothesized that under current hydrologic conditions the Lower Tuscan aquifer system recharges along the eastern margin of the northern Sacramento Valley, where the Lower

Tuscan Formation crops-out at the ground surface. However, it is not clearly understood how the area and source of recharge may change if the groundwater gradients in the Lower Tuscan aquifer system become altered due to increased groundwater extraction. The extent to which the Tuscan aquifer is confined throughout the valley is also uncertain. Regional studies to identify stream losses and general soil infiltration rates have been limited. Without proper understanding of stream-aquifer interaction and recharge mechanisms to both the shallow and deeper aquifers, increased groundwater extraction could result in environmental impacts through increased stream depletion or dewatering of important wetland habitat on the valley floor. Investigation of the recharge areas is required to more fully understand the implications of increased groundwater usage and to have the ability to improve groundwater basin conditions through enhanced recharge.

## D. Butte County Groundwater Management Plan and Related Policies

Groundwater resources have long played an important role in the development, growth, and sustainability of Butte County and its residents. Local groundwater management continues to increase in complexity and scope, driven by evolving demands for groundwater resources both within and adjacent to Butte County. Nearly one-third of Butte County's water demand is directly met from groundwater. The county's streams, creeks and ecosystem depend on a healthy groundwater basin. Butte County has recognized the importance of protecting groundwater and groundwater recharge to ensure a healthy water resource system. Through policies and programs, Butte County has incorporated groundwater recharge considerations into its water resource planning efforts. Butte County formalized the linkage between land use and water resource planning through its General Plan process. The proposed project will fulfill objectives of the Butte County Groundwater Management Plan, the Butte County Integrated Water Resource Management Plan, Butte County General Plan 2030, and the Northern Sacramento Integrated Regional Water Management Plan (NSVIRWM) Goals and Objectives. The proposed project will provide land use planners, water managers and stakeholders with practical information on groundwater recharge areas.

The foundation of Butte County's water resource policies and programs are contained in the Butte County Groundwater Management Plan, the Butte County Integrated Water Resource Management Plan and the Butte County General Plan 2030. In 2004 Butte County adopted its Groundwater Management Plan. The Butte County Groundwater Management Plan established goals and actions intended to sustain local groundwater resources. The goals of the Groundwater Management Plan include:

- Minimize the long-term drawdown of groundwater levels;
- Protect groundwater quality;
- Prevent inelastic land surface subsidence from occurring as a result of groundwater pumping;
- Minimize changes to surface water flows and quality that directly affect groundwater levels or quality;
- Minimize the effect of groundwater pumping on surface water flows and quality;
- Evaluate groundwater replenishment and cooperative management projects.

The Butte County Groundwater Management Plan became a component of the Butte County Integrated Water Resource Plan (IWRP) that was adopted in 2005. The Butte County IWRP serves as the County's primary water resource strategic plan. Among the First Tier Policies identified in the Butte County IWRP include:

- Continuing ongoing water resources efforts;
- Protecting recharge areas through zoning;
- Informing and educating the public about water;

Butte County advanced its commitment to protecting and conserving water resources through the development and adoption of the Butte County General Plan 2030 on October 26, 2010. The Butte County General Plan 2030 created new and innovative approaches to bridge land use planning and water resource management. The General Plan confirms the County's commitment to protecting its water resources by incorporating water policies and programs into a Water Resources Element. The Water Resources Element included six goals:

- Maintain and enhance water quality
- Ensure an abundant and sustainable water supply to support all uses in Butte County
- Effectively manage groundwater resources to ensure a long-term water supply for Butte County
- Promote water conservation as an important part of a long-term and sustainable water supply.
- Protect water quality through effective storm water management
- Improve stream bank sustainability and protect riparian resources.

The General Plan 2030 included a number of policies and action items related to groundwater recharge. These policies and actions are necessary for Butte County to fulfill its obligations.

- Where appropriate, new development shall be Low Impact Development (LID) that minimizes impervious area, minimizes runoff and pollution and incorporates best management practices. (Water Resource Element Policy 1.4)
- Develop standards to determine where Low Impact Development techniques are appropriate. (Water Resource Element Action Item 1.3)
- The County shall protect groundwater recharge and groundwater quality when considering new development projects. (Water Resource Element Policy 3.1)
- Seek funding for and conduct comprehensive, countywide mapping of water resources and groundwater recharge areas. (Water Resource Element Policy 3.4)
- Evaluate gaps in existing federal, state and local standards, and develop additional standards as needed to preserve groundwater recharge and protect groundwater quality. (Water Resource Element Policy 3.2)
- Pervious pavements shall be allowed and encouraged where their use will not hinder mobility. (Water Resource Element Policy 5.3)

Butte County is one of the participating entities on the NSVIRWM Plan. The six counties of the Northern Sacramento Valley have been working together for over 10 years to lay the

foundation for an integrated regional plan to address water-related issues such as economic health and vitality; water supply reliability; flood, storm water and flood management; water quality improvements; and ecosystem protection and enhancement. The counties have committed to developing a valley-wide Integrated Regional Water Management Plan by September 2013. On June 4, 2012, the NSVIRWM Governing Board adopted Goals and Objectives. The project is consistent with the Water Supply Reliability Goal, Objectives:

1-1 Document baseline conditions and trends for surface water and groundwater resources
1-4 Coordinate and protect regional groundwater resources, consistent with locally developed groundwater management plans that monitor groundwater levels, groundwater quality and inelastic subsidence

As a member of the NSVIRWM Governing Board and Technical Advisory Committee, Butte County will keep the NSVIRWM informed regarding the project and its results.

## E. Baseline Data and Current Conditions

The likelihood of this project's success is high since an existing comprehensive set of data lays a strong foundation for this project. Investigations have been conducted to better characterize the hydrology and geology underlying Butte County, with many previous investigations focused on characterizing the Lower Tuscan aquifer. For decades, the network of groundwater elevation monitoring wells has compiled data on groundwater conditions. In addition, a developed numerical groundwater model of the valley aquifer systems within Butte County provides a framework in which to organize and compile new data and understanding. It also highlights areas of uncertainty where additional data collection would be valuable.

A suite of GIS layers will be necessary for developing the countywide groundwater recharge map. Butte County has or will be able to obtain such data as geology and soil layers, local streams, canals, irrigation district boundaries, and depth to water spatial data. This baseline data in conjunction with analysis in ArcMap will be used to create the recharge map and to identify potential areas for supplemental recharge.

The site investigation of the proposed project will build upon existing studies, data, and analyses on groundwater conditions in Butte County. This includes building upon data and insights from the Lower Tuscan Aquifer Monitoring, Recharge and Data Management Project ("Tuscan Aquifer Project") that is scheduled for completion in 2012. The Tuscan Aquifer Project investigated the recharge characteristics along five streams in the Lower Tuscan outcropping, included 10 infiltration tests, and conducted aquifer performance tests at three locations. Three new dedicated monitoring wells were installed as part of the project. Analyses of the field investigation will lead to improved understanding of groundwater conditions and the data will be evaluated and compared with data inputs to the Butte Basin Groundwater Model. The Tuscan Aquifer Project will provide data that expands the understanding of groundwater recharge, especially related to the Lower Tuscan and its groundwater-surface water interactions. The proposed groundwater recharge investigation will provide complementary data to further characterize recharge of the Lower Tuscan aquifer and/or the shallower, alluvial aquifer system.

Depth to groundwater data will be a crucial component of identifying promising areas for managed recharge. Groundwater level monitoring in Butte County is currently conducted primarily by a cooperative effort between Butte County and the Department of Water Resources (DWR). Historically, DWR has maintained the most comprehensive, long-term groundwater level monitoring grid, with approximately 212 different wells monitored over the last 50 years in the Sacramento Valley portion of Butte County. Within this period of time, the annual size of the monitoring grid has fluctuated from as few as 50 wells to as many as 180 wells, depending upon the activity of special studies in the area. Until 1989, the majority of these wells were measured semi-annually, during the spring and fall. Beginning in 1990, the frequency of groundwater level monitoring was increased to monthly, before returning to a semi-annual measurement in 1995. In 1997, the Butte County Department of Water and Resource Conservation, in cooperation with DWR, began to expand the number and frequency of groundwater level monitoring in the valley portion of Butte County. Improvement to the monitoring network has been primarily focused on adding dedicated monitoring wells outfitted with transducers. The Butte County Water Commission's Technical Advisory Committee (TAC) has played an integral part in providing guidance to prioritize areas for additional monitoring wells and to evaluate the data from monitored wells. Multi-completion, dedicated monitoring wells are located and screened to improve the coverage of the basin. The location of monitoring wells is based on the characteristics of the sub-basin, properties of the aquifer, and other data. For example, in 2007 two new multi-completion observation wells were installed in Butte County, one in the East Butte sub-basin and one in the West Butte sub-basin. In 2010, multi-completion wells were installed in the Vina sub-basin and the West Butte sub-basin. In addition to the groundwater level monitoring conducted by Butte County and DWR, California Water Service Company currently measures monthly groundwater levels in approximately 60 municipal groundwater supply wells in the Chico Urban area. California Water Service wells are typically deep wells that draw from the Tuscan Formation aquifer system.

Butte County, in cooperation with DWR, evaluates and reports groundwater elevation data. The seasonal and long-term changes in groundwater levels are determined using water level measurements from wells in the monitoring network. These data are typically depicted on hydrographs, which are graphical plots of the water level measurement history. Prior to 1997, data points for each of the hydrographs in Butte County generally consisted of two measurements per year. Since 1997, four level measurements are recorded each year. The addition of these summer measurements gives the hydrographs the appearance of greater fluctuation. Butte County primarily utilizes spring and fall measurements as a standard point of annual comparison and trend analysis.

Public access to groundwater monitoring data is an important part of Butte County's monitoring program. The DWR has maintained the Water Data Library that includes a database of groundwater level measurements for California. The Water Data Library contains over 100,000 individual groundwater level measurements, some dating back to the early 1930's. Beginning with the spring 2012 measures, DWR has transitioned away from the Water Data Library and has posted groundwater elevation data only on the California Statewide Groundwater Elevation Monitoring (CASGEM) program. Butte County also hosts an online groundwater management tool known as the BMOIC, or Basin Management

Objective Information Center. The data generated on either of these websites can be printed in varying formats. The DWR data can be accessed at: http://wdl.water.ca.gov or http://www.water.ca.gov/groundwater/casgem/data.cfm. The Butte County site may be viewed from the Department's main site, or by going directly to http://gis.buttecounty.net/bmoic3/GIS/Default.asp?loadfile=map.asp&county=.

For over a decade, Butte County has overseen the publication of an annual Groundwater Status Report. The Groundwater Status Report describes the hydrologic conditions, surface water deliveries, groundwater elevations of key monitoring wells and other factors affecting groundwater conditions in Butte County. Butte County was designated by DWR as the monitoring and reporting agency for the four sub-basins (Figure 1) in Butte County under the CASGEM program.

In 2006, Butte County's Basin Management Objective program was implemented. The BMO program established quarterly monitoring of key wells, establishment of basin management objectives, evaluation of data and outreach to stakeholders. Butte County has administered these groundwater elevation reporting programs based on sub-basins. The key wells were chosen as being representative of groundwater level conditions within each sub-basin.

The status of groundwater conditions is continually monitored and a number of reports are available. In 2001, Butte County produced a Water Resource Inventory and Analysis Report. The report identified that Butte County has adequate water resources available to meet demand within most areas of the county under normal hydrologic conditions. The Water Inventory and Analysis Report concluded that long-term trends in groundwater storage indicate the basin groundwater aquifer is not in a state of decline. During normal to wet years, the aquifer system recharges to its maximum storage capacity by the following spring. In 2005, the Department of Water Resources produced a report, Butte County Groundwater Inventory Analysis. In that report, the amount of groundwater in storage during the spring of 2000 was about 15,000 acre-feet greater than that of 1980. Review of the hydrographs for long-term comparison of spring-to-spring groundwater levels indicates a decline in groundwater levels associated with the 1976-77 and 1986-94 droughts, followed by a recovery in groundwater levels to pre-drought conditions of the early 1970s and 1980s. Valley-wide comparison indicates that there has been very little change in groundwater levels in most areas of the valley since the 1970s and 1980s. However, further long-term comparison of spring-to-spring groundwater levels from the 1950s and 1960s with current conditions indicates a trend of slightly declining groundwater levels in some areas of the West Butte and Vina sub-basins.

Seasonal fluctuation of groundwater levels in the unconfined portion of the aquifer system averages between three to five feet during years of normal precipitation, and seven to nine feet during periods of drought. The annual fluctuation of groundwater levels in the confined or semi-confined portion of the aquifer system averages about 10 feet during periods of normal precipitation and about 20 feet during times of drought. Wells constructed in unconfined parts of the aquifer system tend to show less seasonal fluctuation in groundwater level than those in the lower, confined aquifer system because of the greater interconnection between the shallow groundwater and the surface-water systems. The areas of greatest

groundwater level decline are those where groundwater is extracted for agricultural and/or municipal use during the summer months in the Vina and North Yuba groundwater sub-basins, the Durham area of the West Butte sub-basin, and the Cherokee Strip portion of the East Butte sub-basin. Hydrographs indicate that groundwater typically recharges during the winter months. Groundwater hydrographs for monitoring wells near Chico indicate a rather uniform seasonal fluctuation of 15 to 20 feet during normal years. During drought years, there tends to be a wider range of fluctuation depending upon the individual well. Wells in the southern portion of the county show less seasonal fluctuation than those in the north. The limited seasonal fluctuation is largely due to the recharge of the upper aquifer system from applied surface water and limited agricultural use of groundwater from the middle and lower aquifer system in the southern area of the county. This background understanding of aquifer conditions and dynamics will be valuable for interpreting the groundwater recharge map and identifying areas that could benefit from recharge activities.

Groundwater models can be a valuable resource management tool and a framework in which to organize data and test understanding of aquifer components and dynamics. The Butte Basin Groundwater Model was updated in 2008 to represent the basin with eight layers as a finite element numerical groundwater flow model using IWFM. As part of the Tuscan Aquifer Project, model parameters will be reassessed in light of recent stream gauging data, soil infiltration tests, and aquifer performance testing. The full geographic extent of the Lower Tuscan aquifer system is currently represented using two different analytical groundwater flow models. The area to the east of the Sacramento River, including the recharge zone, is modeled with the Butte County IWFM. The area to the west of the Sacramento River is covered in the Stony Creek Fan IGSM. Together, these models can be used to understand groundwater movement with respect to the Lower Tuscan aquifer system. The shallower alluvial aquifer system units are represented by the upper three model layers in the Butte County IWFM. Major rivers and creeks within the model domain are also modeled. Model development and results reflect current understanding (as of its latest update) and compilation of data. This provides a useful baseline and also a tool to evaluate uncertainties in the system. A few studies exist that help characterize properties, but they do not address all of the complexities of the hydrology or the specific characteristics at a particular site. The existing model provides useful background information regarding recharge estimates, stream-aquifer interaction, and deep percolation of applied water. The proposed project will provide additional data and understanding that can be incorporated in the model in the future.

Another previous modeling effort is the WEHY2010-Butte model developed by the Hydrologic Research Laboratory at the University of California, Davis. The WEHY2010-Butte model was funded by DWR through CALFED Watershed Program grant funds. The WEHY model covers Big Chico Creek, Little Chico Creek, Deer Creek, and Butte Creek watersheds. As potential contributors to recharge through stream-aquifer interactions, better understanding and quantification of rainfall-runoff processes in these watersheds is valuable. This model simulates hydrologic processes using distributed atmospheric data. It was used to estimate updated inflow data for the Butte County IWFM model and may also be of use for assessing recharge volumes in the future.

Planning, analysis, and field investigations are required to continue to meet the increasing county water resource needs and impacts from increasing local demands and changing climate. Existing data and monitoring efforts provide a strong background for the proposed project to successfully contribute valuable management tools and improved understanding of groundwater recharge and aquifer dynamics. Managing the surface water and groundwater resources within the county is essential to the long-term economic and environmental health of the county.

## F. Project Description

### Task 1: Groundwater Recharge Map

The protection and conservation of groundwater resources has been a cornerstone of Butte County policy for many decades. The identification, characterization, and protection of groundwater recharge are recognized as critical components to adequately protect the resource. The Butte County Groundwater Management Plan (GWMP) includes policies to minimize the long-term drawdown of groundwater levels. The Butte County Integrated Water Resource Management Plan includes a policy to "protect recharge areas through zoning." That policy created the linkage with land use planning and the General Plan update process. The Butte County General Plan 2030 was adopted in 2010 and included an optional Water Resource Element. A countywide map of groundwater recharge areas will be instrumental for the County to fulfill its General Plan 2030 policy of "protecting groundwater recharge and groundwater quality when considering new developments." The production of an updated countywide groundwater recharge map was identified as an action item necessary to implement this policy. Butte County has continually sought to improve the scientific understanding and employ innovative tools to manage and protect groundwater resources. The updating of the groundwater recharge map would achieve Butte County policies and management goals. Furthermore, landowners, planners and the general public have expressed a strong interest in having information on groundwater recharge locations. The proposed project will be an important public education and technical resource. The countywide groundwater recharge map will be developed and finalized through a public process to ensure the best product is produced and accepted by the public.

The 2004 Butte County GWMP includes a map (Figure 3) that identifies recharge areas that contribute to the replenishment of the Tuscan aquifer formation. The map complies with Water Code Section 10753.7(4) which requires that by January 1, 2013 groundwater management plan must include a map identifying the recharge areas for the groundwater basin. However, the map in the GWMP is not comprehensive nor does it incorporate the latest scientific data.


**Figure 3: Butte County Groundwater Management Plan Recharge Map**

In 2007, as part of the General Plan 2030 update process, a refined methodology was proposed that would identify areas that potentially contribute to groundwater recharge (Figure 4). The method was provided by the Department of Water Resources, Northern District. The method was part of the groundwater recharge section of the General Plan Update, *Settings and Trends Report*, Chapter 12 Water Resources. The effort involved the determination of potential recharge areas utilizing existing soils data (NRCS, 2006), geologic data (USGS, 1985) and digital elevation data. The datasets were compiled in a GIS format to help identify potential recharge areas for Butte County. In this effort, areas of potential recharge were identified based on soils and geology, overlaid with the slope of the local land surface. In general, loosely compacted soils with little or no clay have the highest permeability and potential for recharge. Similarly, surface geology that is comprised of coarse alluvial deposits, or slightly consolidated and cemented material, will have a higher permeability than finer-grained alluvial deposits, or more highly consolidated and cemented material. Finally, a flat or gradually sloping land surface which underlies the soils and geologic units will tend to have a higher potential for recharge than steep slopes which are conducive to rapid runoff. Utilizing existing data and GIS methods, two series of maps identifying potential recharge areas have been developed; one for soils and one for geology. The Potential Aquifer Recharge layer is illustrated using a continuous color ramp ranging from green to red, with the areas of higher recharge potential shown in green and the areas of lower recharge potential shown in red. Values in this Potential Aquifer Recharge Zone layer can potentially range from 1 (i.e., a permeability value of one, multiplied by a slope value of one) to 100 (i.e, a permeability value of ten, multiplied by a slope value of ten).

Areas with higher values in the Potential Aquifer Recharge Zone layer are considered more conducive to groundwater recharge based on the relative bedrock permeability and slope. A new layer, Potential Aquifer Recharge Zone #2 was mapped. The data was produced by multiplying the values of the reclassified Geologic Unit Permeability Values with reclassified Slope values. Values in this new layer could conceivably range from 1 (i.e. 1 x 1) to 100 (i.e., 10 x 10). Areas with higher values in the Potential Aquifer Recharge Zone layer are considered more conducive to groundwater recharge based on the relative bedrock permeability and slope. The layer was symbolized on a color ramp from green to red with the green shades showing the high values and the red shades showing the low values. This methodology will be used as a framework to develop the updated countywide groundwater recharge map using new or updated data sources.

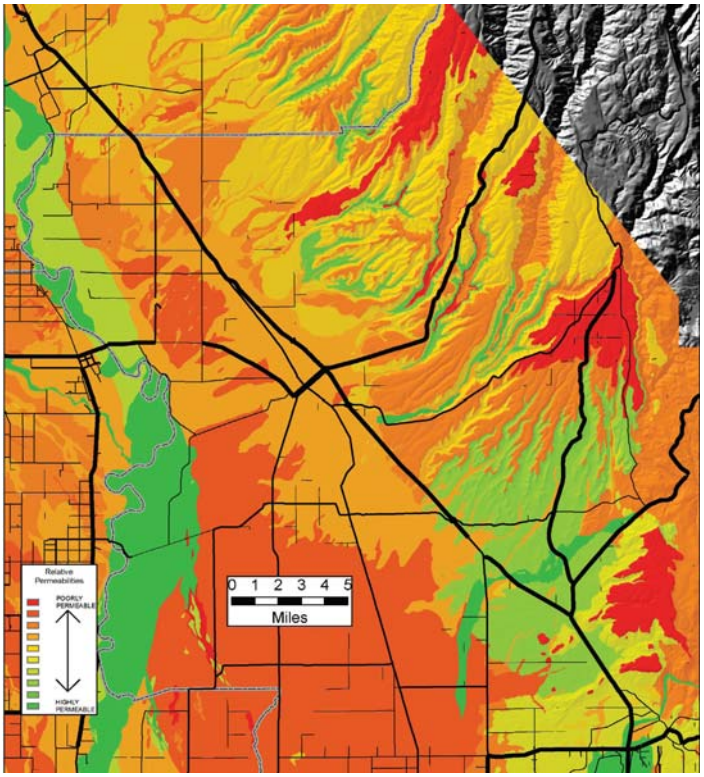


**Figure 4: Draft General Plan 2030 Groundwater Recharge Map**

The development of the countywide groundwater recharge map will initially be based on the methodology previously described. The initial methodology will utilize the most currently available data and be subject to public presentation and comment. One of the newer datasets will be the 2010 NRCS soil survey. Another new data source will come from the Lower Tuscan Aquifer Monitoring, Recharge and Data Management Project (i.e. "Tuscan Aquifer Project") that was initiated in 2009. A major aspect of the Tuscan Aquifer Project was the study of groundwater recharge along the Lower Tuscan outcrop. Specific work included conducting field data collection and analysis to characterize groundwater recharge along the Lower Tuscan aquifer in Butte and Tehama Counties. The Tuscan Aquifer Project

will be completed in 2012 and the data and information from that study will be used to inform the development of the countywide recharge map.

The development of a countywide groundwater recharge map is critical to fully evaluate groundwater conditions (e.g., BMOs) and to improve water resource management decisions. The public has expressed a strong interest in the countywide groundwater recharge map. Ultimately, the revised recharge map will be amended into the Butte County Groundwater Management Plan and will become part of Butte County's GIS land use database. To ensure that the groundwater recharge map is successful in meeting technical and public demands, a public participation process will be part of the project. The public will have the opportunity to review and comment on the project at regularly scheduled presentations before the Butte County Water Commission. The Butte County Water Commission is a nine member body appointed by the Board of Supervisors. Five members are appointed by each of the Board of Supervisors, another two must be served by groundwater and two by surface water. The Water Commission is the principle advisory body to the Board of Supervisors on water resource issues and also serves as a public venue for reviewing projects and program activities. The development of the countywide groundwater recharge map will be brought to the Water Commission at key junctures for comment and input. The Butte County Water Commission has a Technical Advisory Committee (TAC) that will be utilized to review the map's development. In addition to the TAC, other technical collaborators such as NRCS, Butte County Department of Development Services, etc. will be asked to provide technical comments on the project. Throughout the project, Butte County will include other opportunities to inform the public. Periodic updates of the project development will be put in the Department's monthly newsletter, Water*Solutions*. At the completion stage, a recommendation from the Water Commission to the Board of Supervisors will be sought to approve finalizing the countywide groundwater recharge map and to incorporate it into the Groundwater Management Plan.

**Task 2: Managed Groundwater Recharge Area Locations**

Based on the countywide groundwater recharge map, an analysis will be conducted to identify areas that may benefit from managed groundwater recharge activities. Groundwater contours, monitoring well levels, and other indicators will be evaluated to identify areas in the County that have drawdown problems and would benefit from groundwater recharge activities. The first step in the process will be the development of criteria to determine potential groundwater recharge locations. Three general categories should be considered, 1) physical potential for recharge (identified in Task 1), 2) logistical considerations (potential water source, means of recharge appropriate for the nature of the target aquifer system, etc.), and 3) areas of groundwater demand (storage space in the aquifer available to receive recharged water). When identifying areas of groundwater demand, it will be important to identify which aquifer system (shallow, unconfined Alluvial aquifer or deeper, confined Tuscan aquifer) the drawdown occurs in. This will influence the methods considered for managed recharge. Criteria for the methods of recharge activities (flooded fields, spreading basins, canals, enhanced stream recharge, gravel pits, injection wells) will also be developed.

The second step of this task will produce a technical memo and map of areas where groundwater recharge may be viable and beneficial. The results could be used in the future to develop a feasibility study and conduct a pilot test. Improving and enhancing

groundwater recharge has been identified as a county policy. The Butte County IWRP Plan identified the need for and potential opportunities for coordinated management programs. Coordinated management programs have generated controversy and concern, particularly when programs are developed to support water demands outside the region. However, coordinated management programs can be enormously beneficial to enhance local water resource sustainability. The Butte GWMP includes a goal of minimizing the long term draw-down of groundwater levels. The exploration of enhanced groundwater recharge opportunities would be consistent in meeting the GWMP goal.

The formal public review process will be made through the Butte County Water Commission. The Water Commission serves as a public venue for reviewing projects and program activities. The Butte County Water Commission Technical Advisory Committee (TAC) will be utilized to review the development of the countywide managed recharge project locations. Throughout the project Butte County will include other opportunities to inform the public. Periodic updates of the project development will be put in the Department's monthly newsletter, Water*Solutions*. The development of the groundwater recharge project locations will be brought to the Water Commission at key junctures for comment and input.

**Task 3: Groundwater Recharge Investigation (GRI)**

Effective groundwater management requires understanding recharge processes in order to make informed decisions. Better characterization of natural recharge mechanisms, source and flow paths of recharged water, and interconnectedness of the valley's aquifer systems will aid groundwater management efforts, guide land use decisions, and provide valuable information for managed recharge projects that may occur in the future. The GRI will select and instrument a representative study area (smaller than a sub-basin but larger than a parcel) to explore and observe natural recharge mechanisms during the recharge period, October-April. Supplemental monitoring may occur during the irrigation season to assess the recharge characteristics of applied water, if appropriate for the site. This task has four main objectives and outcomes:

1. To evaluate how conducive to recharge a particular representative area/site is and help overcome uncertainties in characterizing groundwater recharge potential.
2. To identify, and possibly quantify, the source and destination of naturally recharged water at the site. What aquifer system responds to the recharge? Is there storage space in the aquifer for managed supplemental recharge?
    a. Dependent on site location, the GRI will seek to better understand and potentially provide parameters describing the interconnectedness of the shallower alluvial aquifer and the Lower Tuscan. To what extent is the Lower Tuscan confined in the chosen area?
3. To identify possible sources of water for supplemental recharge in the study area.
4. To explore and employ a suite of tools and data types that may be of use for future investigation of a managed recharge site for recharging flood flows or another surface water source. Especially valuable techniques and data will be identified. This project will provide lessons learned and background information useful for such a future effort.

*Site Selection*
The draft countywide groundwater recharge map produced in Task 1 and locations identified in Task 2, will be used to identify potential investigation areas based on their promise for potential groundwater managed recharge in the future. In addition, the investigation area will need to have sufficient preexisting data available to provide a baseline understanding of the hydrology and geology. Available data could include well logs, groundwater elevation monitoring data, dedicated monitoring wells, and aquifer performance tests. Another factor will be whether the locations were studied as part of the Tuscan Aquifer Study. Resulting data from that study (quantified stream-aquifer interaction, infiltration tests, or pump test results) could provide helpful background information or an already set stage to continue or expand some of that data collected as part of this GRI. The geology and hydrology in Butte County presents complexities and uncertainties on a localized basis. Geophysical investigation and data collection will better characterize the subsurface to evaluate potential for managed recharge activities in the future.

The study site should not have buried features (pipes, conduits, certain geologic formations) that would preclude or interfere with geophysical data collection. Authorization from the landowner(s) to an appropriate size of land will be necessary to instrument and collect data at particular sites within the study area. Receiving authorization may be a limiting factor in determining the study location.

A number of prospective areas may be suitable for the study area and a geophysical investigation. Locations in the Esquon, M&T Ranch, and Pentz subinventory units (SIU), and the Vina Basin may meet optimal criteria for the groundwater recharge investigation.

**Esquon Sub Inventory Unit (SIU)** presents one area having sites appropriate for a geophysical investigation. It is situated on the western portion of the hypothetical recharge area to the Lower Tuscan aquifer. Towards its western boundary, it may contribute recharge to the Durham/Dayton area. The Esquon Sub-Inventory Unit (SIU) covers an area of about 11,600 acres in the northern portion of the East Butte Inventory Unit. It is bordered by the Pentz SUI to the north, Western Canal SIU to the south, Cherokee SIU to the east, and Butte Creek to the west. Geologic formations in the Esquon SIU, from youngest (shallowest) to oldest (deepest), include Basin Deposits, Modesto Formation, Tuscan Unit C (Upper Tuscan) and Tuscan Unit B (Lower Tuscan). In the Sacramento Valley Region of Butte County, fresh groundwater-bearing units include, from youngest (shallowest) to oldest (deepest), the Modesto, Riverbank, Laguna, Tehama and Tuscan Formations. Those included in the Esquon SIU are the Modesto Formation, Tuscan Unit C (Upper Tuscan) and the Tuscan Unit B (Lower Tuscan). The Esquon SIU generally corresponds to the water service areas associated with the Durham Mutual Water Company and Rancho Esquon. Agricultural land use within the SIU includes production of orchards, rice, and grain crops supported by both surface water and groundwater. The water supply portfolio is about 53% surface water, 36% groundwater, and 11% reused surface water. The water from the Rancho Esquon diversion from Butte Creek supplies water to the orchards, rice and state, federal and private wetlands within the sub-inventory unit. The water diverted from Butte Creek is believed to help recharge groundwater in the Durham/Nelson area according to the Department of Water Resources, Northern Region. Data on groundwater conditions have been collected from Rancho Esquon for many decades. Other

investigations have been conducted in Rancho Esquon including an aquifer performance test as part of the Tuscan Aquifer Project. The transection of Butte Creek through Rancho Esquon will provide an opportunity to further investigate the relationship between Butte Creek and the underlying aquifer. Investigating Rancho Esquon is important due to the apparent decline in groundwater elevations in wells primarily tapping the Tuscan aquifer system there.

The **M&T SIU** covers an area of about 8,200 acres in the northwestern portion of the West Butte Inventory Unit. It is bordered by Big Chico Creek to the north, the Llano Seco and Durham Dayton SIUs to the south and east, and the Sacramento River and Angel Slough SIU to the west. The M&T SIU corresponds roughly to the water serviced area of the M&T Chico Ranch. Agricultural land use includes orchards, rice, and row crops supported by groundwater and surface water. In a normal year, about 27% of the M&T SIU is in summer agricultural production supported by groundwater. The M&T Ranch, located within the SIU, gets its surface water from two different sources. The Ranch diverts water out of Butte Creek east of Chico and allows it to flow down Edgar Slough/Comanche Creek where it runs through south Chico and then west to the Ranch. Once it reaches the Ranch, it then flows south to the Llano Seco Ranch. The Butte Creek diversion supplies water to the M&T Ranch, the Llano Seco Ranch, and Dayton Mutual. The diverted Butte Creek water, according to the California Department of Water Resources, helps recharge the groundwater in south Chico, the Hegan Road area, and the Stanley Avenue/Rodgers Road area. The M&T Ranch and the Llano Seco Ranch also jointly own a pumping plant on the Sacramento River, west of Chico. This surface water source helps supply the irrigation water needs for orchards, row crops, rice and federal, state and private wetlands. This river water also helps recharge the groundwater in the Ord Ferry Road, Seven Mile Lane and Dayton West Road area. The northeast part of the ranch, just south of Big Chico Creek, is primarily orchards and is supplied solely by groundwater. Geologic formations in the M&T SIU, from youngest (shallowest) to oldest (deepest) include Quaternary Alluvium, Basin Deposits, Modesto Formation and the Tuscan Unit C (Upper Tuscan). Fresh groundwater-bearing units include, from youngest (shallowest) to oldest (deepest), in the M&T SIU are the Modesto Formation and Tuscan Unit C (Upper Tuscan). A study site in this area would allow for the investigation of the interconnectedness of the Lower Tuscan and the shallower Quaternary Alluvium and Basin Deposits. As part of the Tuscan Aquifer Project, M&T Ranch was one of three locations where aquifer performance tests were conducted.

The **Pentz SIU** covers an area of about 1,900 acres in the northern portion of the East Butte Inventory Unit. It is bordered by Butte Creek to the north, the North Fork of Dry Creek to the south, foothills to the east, and Highway 99 to the west. The land uses within this SUI are non-irrigated native vegetation, pasture, and low density residential. Current groundwater use in the Pentz SUI is minimal. Geologic formations in the Pentz SIU, from youngest (shallowest) to oldest (deepest), include the Modesto Formation, Tuscan Unit C (Upper Tuscan) and Tuscan Unit B (Lower Tuscan). Fresh groundwater bearing units in the Pentz SIU are the Modesto Formation, Tuscan Unit C (Upper Tuscan) and Tuscan Unit B (Lower Tuscan). The DWR completed installation of a multi-completion monitoring well, SWN 21N02E26E003-6, in September 2007. This well was constructed as a quadruple completion well, which means that the bore hole contains four casings isolated in separate

geologic strata, allowing for monitoring of the groundwater levels contained in the respective aquifer systems. There are currently only four years of measurements available for this new well, and therefore BMOs cannot be established for these wells at this time. Monitoring wells installed by Butte County Public Works at the Neal Road Recycling and Waste Facility could be selected for inclusion in this project. Monitoring groundwater is a regulatory requirement for operation of the waste facility, therefore both level and quality measurements are taken quarterly at each of the waste facility's monitoring wells. Choice of this area would result in exploring recharge mechanisms to the Tuscan aquifer system.

The **Vina Basin** covers about 75,000 acres in the northern Sacramento Valley Region of Butte County. It is bordered by Tehama County to the north, Big Chico Creek to the south, the Sacramento River to the west, and the foothills to the east. In a normal water year, about 50% of the Vina IU is in summer agricultural production supported by groundwater. Another 10% of the inventory unit is within the Chico Urban Area, which uses groundwater for its municipal supply. During the past 5 years, approximately 2500 acres of land have been developed into orchards in the Vina SIU. All of the new orchards rely on groundwater, mostly from new wells. Geologic formations in the Vina SIU from youngest (shallowest) to oldest (deepest) include Quaternary Alluvium, Basin Deposits, Modesto Formation, Riverbank Formation, Tuscan Unit C (Upper Tuscan) and the Tuscan Unit B (Lower Tuscan). Fresh groundwater-bearing units include, from youngest (shallowest) to oldest (deepest), the Modesto Formation, Riverbank Formation, Tuscan Unit C (Upper Tuscan) and the Tuscan Unit B (Lower Tuscan). Depending on the chosen study area within the SIU, recharge to the Alluvium and Basin Deposits or the Tuscan aquifer system or a combination of the two and their interaction would be explored. As part of the Tuscan Aquifer Project, the Vina Basin was one of three locations where aquifer performance tests were conducted.

*Field Investigation*

The GRI will include collection and analysis of a variety of types of data to provide a clearer understanding of recharge sources, groundwater flow paths, deep percolation, stream-aquifer interactions, vertical interconnection of aquifer systems, and overall evaluation of the study area's conduciveness to groundwater recharge. Depending upon the chosen study area, some of these aspects will be more fully explored than others, as appropriate and feasible based on the particular characteristics of the study area. First, a review of existing data and previous studies pertaining to the study site will be conducted and evaluated. Then, to optimally add to the existing data, a variety of techniques and methods may be of value for this effort. A combination of the following will be used to quantify and explore mechanisms of natural recharge processes in the chosen study area.

The field investigation will likely involve conducting a geophysical survey on a portion of the study area, if practical and feasible. The geophysical survey will provide an initial detailed assessment of the underlying stratigraphy for use in selecting locations for boreholes or piezometers. Geophysical measurements provide a means of mapping lateral and vertical variations of one or more physical properties or monitoring temporal changes in conditions, or both. ASTM International has established a number of standards relevant to the geophysical investigation of groundwater. The ASTM Standard Guide for Selecting Surface Geophysical Methods (D6429) provides a source for describing the usefulness of

geophysical methods and provides a set of standard methodologies. Given the specialized nature of conducting a geophysical investigation, a successful approach requires the development of well-developed objectives. Once the study area is selected and access granted, specific objectives for the site will be defined which will guide the choice of geophysical techniques to be used.

Employing geophysical methods to complement existing data to map natural hydrologic conditions can be a cost effective means to improving the understanding of hydrologic conditions and recharge. Geophysical methods measure the physical, electrical, or chemical properties of soil, rock, and pore fluids. A contrast in physical conditions must be present for geophysical measurements to be successful. For example, the contrast between different soil types such as loams compared to clays can be detected by the differences in acoustic velocity of the materials. In some cases, the differences in measured physical properties may be too small for anomaly detection by geophysical methods. Because physical properties of soil and rock vary widely, some by many orders of magnitude, one or more of these properties usually will correspond to a geologic discontinuity. The boundaries determined by the geophysical methods will usually coincide with geological boundaries, and a cross-section produced from the geophysical data may resemble a geological cross-section, although the two are not necessarily identical.

Some geophysical methods applicable for this project include ground penetrating radar (GPR), frequency domain electromagnetic profiling, direct current (DC) resistivity profiling, seismic refraction/reflection, and frequency domain electromagnetics. The methodologies are relatively non-intrusive and cost effective. A number of different geophysical applications can be used to identify geologic and hydrologic conditions including:

- Soil/Unconsolidated Layers—This includes determining the depth to, thickness of, and areal extent of unconsolidated layers. These layers may be discontinuous or include lenses of various materials and can be detected because of differences in their physical properties as compared to adjacent materials.
- Depth to Water Table—This includes determining the depth at which a subsurface unit is fully saturated. The water table (top of the saturated zone) can be detected because of the changes in physical properties that are caused by saturated conditions. The ability to detect the water table may depend on the geologic unit in which it occurs. Seismic methods can be used to detect the water table in most unconsolidated materials. Electrical, electromagnetic, or GPR methods may be used to detect the water table in either consolidated or unconsolidated materials.
- Voids and Sinkholes—This includes karst features, such as weathered depressions in rock, open, water-filled, or sediment-filled sinkholes, and cavities or larger cave systems. In many cases, the target of concern may be beyond the effective resolution or depth range of some or all of the surface geophysical methods; however, deep cavities often show signs of their presence in the near surface and may be interpreted using shallow geophysical data. The ability to detect a given size cavity decreases with increasing depth for all surface geophysical methods.

The appropriate geophysical methods will be chosen depending on the study area's geology and hydrologic conditions. Surface and borehole geophysical measurements generally can be made relatively quickly, are minimally intrusive, and enable interpolation between known

points of control. Continuous data acquisition can be obtained with certain geophysical methods at speeds up to several km/h. In some cases, total site coverage is economically possible. Because of the greater sample density, the use of geophysical methods can be used to define background (ambient) conditions and detect anomalous conditions resulting in a more accurate site characterization than using borings alone. Geophysical methods can be used to confirm and improve the characterization of hydrologic and geologic findings and provide fill-in data between other measurements. The theory of applied geophysics is quantitative; however, geophysical methods often yield interpretations that are qualitative in nature. Geophysical data will be correlated with other data from the site location (e.g., borings).

Another investigative method may include the installation of new piezometers. It is anticipated that this approach will involve two phases. The first phase will include drilling soil borings to install piezometers based on the results of the geophysical survey discussed above. During drilling, continuous cores will be collected for preparation of detailed lithologic logs. Alongside these borings, soil infiltration tests could be conducted to quantify surficial infiltration rates. This could build upon data collected during the Tuscan Investigation that included 10 soil infiltration tests overlying Tuscan formation outcrops. As a result of that investigation, the Department has a double ring infiltrometer that could be used to quantify infiltration rates in the study area.

After completing phase one piezometers, additional piezometers will be installed at appropriate depths to assess the potential for recharge and to monitor infiltration rates during the recharge period. During the drilling of these phase two borings, down-hole permeability tests will be collected at major lithologic boundaries identified during the coring of the soil borings in the first phase. This method will allow estimates of infiltration rates for subsurface units. Using this information in conjunction with the detailed lithologic logs, selected borings will be used to install moisture/electrical conductivity sensors. Placed at various depths, these sensors will be used to observe the progression of the wetting front as moisture infiltrates through the subsurface during the study period.

Existing monitoring wells and new piezometers will be instrumented with transducers to continuously monitor water level throughout the study period. Since this investigation will measure and observe natural recharge processes, precipitation data will be needed to be able to analyze changes in water levels/soil moisture with respect to rainfall events and cumulative seasonal rainfall. A CIMIS station located in the Durham area may be sufficient in providing accurate and representative weather data, depending on the chosen study area. Alternatively, a weather station measuring rainfall, solar radiation, temperature, relative humidity, and wind speed and direction could be purchased and set up within the study area. Relevant surface water features (river, irrigation canal, etc) within or related to the study area may also be instrumented with flow gauges to assess gains or losses to/from the aquifer.

Collection and analysis of water samples for isotopes and other chemical constituents from both surface and groundwater sources within and potentially influencing the study area will likely be part of the suite of collected data. Laboratory analysis for general chemistry would likely include Na, Ca, Mg, K, Fe, Cl, $HCO_3$, $CO_3$, $SO_4$, F, B, $NO_3$, As, hardness, alkalinity, conductivity and total dissolved solids. Field parameters of conductivity, pH, and

temperature will be monitored for all new and existing wells in the study area. Select stable isotope measurements may include carbon, hydrogen, oxygen, sulfur, and/or boron. Water chemistry and isotope data can be helpful for addressing uncertainties in the conceptual model of groundwater recharge and flow paths. This type of data can often identify recharge sources to better understand groundwater pathways and aquifer dynamics. The primary objective of this testing will be to assess recharge source and interactions between surface water and groundwater. With the choice of study area, the procedures and methods to collect and analyze surface water and groundwater samples will be further developed to include specifications on the frequency, choice of analytes, and QA/QC procedures.

Since the investigative methodologies are not overly intrusive, permit requirements are not expected to be required. However, a specific study design may include the installation of temporary piezometer wells, other monitoring structures, or soil borings. Certain approaches may require permits from the Butte County Department of Environmental Health.

Given the variety of approaches and data sources, it is the interpretation and integration of all site data that results in useful information for site characterization. The conversion of raw data to useful information is a value-added process that experienced professionals achieve by careful analysis. Such analysis must be conducted by a competent professional to ensure that the interpretation is consistent with geologic and hydrologic conditions. A Technical Memorandum will be produced describing the study area, reviewed baseline data and data from previous studies, estimated groundwater recharge properties, and a description of the geophysical survey method and results. A discussion of the subsequent investigation detailing its components and methods will be presented. After completing the field investigation and data analysis, a draft and final report will be prepared that summarizes the study's findings. The report, at a minimum, will include a summary of site selection, data collected, recharge processes, flow mechanisms, and problems encountered during the study and how they were resolved. A methodology for future recharge assessments could be outlined based on lessons learned from this investigation.

Results from the GRI will serve to inform decisions at the particular location studied while also potentially improving the identification of groundwater recharge areas countywide. This task will serve to validate the understanding of locations that significantly contribute to groundwater recharge, improve the characterization of the hydrology and geology, and scope cost effective methodologies that could be deployed in other situations.

As with the other tasks, throughout the project Butte County will take opportunities to inform the public at Water Commission meetings and will pursue feedback and guidance from the TAC. Periodic updates of the project development will be put in the Department's monthly newsletter, *WaterSolutions*, and posted on the website.

### Task 4: Administration and Project Management

The purpose of this task is to provide program supervision and coordination of the project team for the duration of the work to ensure timely and successful project completion. The work in this task includes developing and maintaining schedules, project status meetings, and compliance with quality assurance/quality control procedures. The project will require

contracting with an environmental/engineering consulting firm. The task will include the administration of the request for proposals (RFP) process for professional services. Prospective consultants will be asked to propose a specific groundwater recharge investigative methodology based on the objectives and potential methodologies set forth by this proposal. The task will include the execution and administration of the subcontract for the project.

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## G. Sources

This document draws from a number of sources, all of which are available on the Department of Water and Resource Conservation's website at: http://www.buttecounty.net/waterandresource.

- Butte County Water Inventory and Analysis, March 2001
- Butte County Integrated Water Resources Program Report, May 2005
- Butte County Groundwater Inventory Analysis, DWR (2005)
- Groundwater Management Plan, September 2004
- Newsletter series by the University of California Cooperative Extension
- Butte County General Plan 2030
- Lower Tuscan Aquifer Project
    - Lower Tuscan Project Needs Assessment (2007)
    - Tuscan Aquifer Project Quarterly Reports
    - Tuscan Aquifer Project Newsletters