LOWER CACHE CREEK GROUNDWATER STUDY

4.5 AGGREGATE MINING AND GROUNDWATER RESOURCES

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Introduction

This section presents an evaluation of potential impacts of mining on groundwater resources along Cache Creek. The impacts of historic mining on groundwater resources were considered in Section 4, Historical Perspective on Groundwater. To summarize in a few words, the historical perspective demonstrated that the major factors affecting local groundwater resources are related to agriculture and irrigation. Historical mining, occurring almost entirely in the channel, has resulted in thalweg lowering that has in turn caused minor, localized groundwater level declines.

The purpose of this evaluation is to develop guidelines for management of future mining in order to protect groundwater quantity and quality, and even enhance overall groundwater basin management. Management of groundwater in a mining area would be best accomplished in the context of overall regional groundwater management. However, the guidelines or recommendations developed in the following paragraphs are not predicated on the existence of regional management.

This evaluation focuses on off-channel mining, which is projected to be the preponderance of future mining activities. Nonetheless, potential future impacts of thalweg lowering are addressed.

This evaluation necessarily involves consideration of final reclamation options, given that comprehensive final reclamation plans are not yet available. Nonetheless, review of existing plans and discussion of long term reclamation objectives and options provides a general picture of long-term reclamation of off-channel areas primarily to agriculture and wet pits dedicated to groundwater recharge or management and habitat enhancement.

Impacts on Groundwater

Potential impacts are subdivided into two groups: impacts on groundwater quantity (recharge, levels and flow), and impacts on groundwater quality. This evaluation is based on consideration of mining options along Cache Creek, but does not consider specific plans; mining scenarios are generalized to represent a reasonable range of options.

Potential impacts of mining on groundwater are described below and as appropriate, one or more scenarios are presented to evaluate the significance or magnitude of the impact. Each potential impact is presented with appropriate recommendations to avoid or minimize the impact. This discussion provides a systematic examination of each groundwater issue.

Following the discussion of specific impacts on groundwater quantity and quality, the major mining and reclamation alternatives are summarized, thereby providing a synthesis of issues related to each alternative and measures that can be taken to minimize adverse impacts and to maximize opportunities.

Groundwater Zones

Impacts and guidelines are framed as appropriate in terms of four general groundwater zones along Cache Creek. These general zones are indicated below with reference to the streamway reaches developed by Northwest Hydraulic Consultants.

1) The westernmost zone is a groundwater recharge or forebay zone above Esparto Bridge, corresponding generally to the Capay and Hungry Hollow reaches.

2) Immediately downstream is a transition zone from Esparto Bridge to Highway 505, where the creek varies from gaining to losing, depending on groundwater levels. This corresponds to the Madison reach.

3) The next zone is characterized by the occurrence of shallow groundwater and perennial streamflow conditions and extends generally from Highway 505 to Stevens Bridge. This corresponds generally to the Guesisosi and Dunnigan Hills reach.

4) The easternmost reach is another groundwater recharge zone below Stevens Bridge, corresponding to the Hoppin reach.

Impacts on Groundwater Quantity

Potential impacts on groundwater quantity include evaporation losses from quarries reclaimed as wet pits or lakes; impacts on groundwater levels and flow due to fines disposal, backfilling, and pit sedimentation; potential impacts on groundwater recharge; and impacts of dewatering. Reclamation options or opportunities with potential impacts on groundwater quantity also are discussed. These include use of pits for water storage and artificial recharge.

Evaporation Losses

Existing and potential mining plans along Cache Creek indicate the probability of reclamation of "wet pit" quarries as perennial lakes. Based on experience elsewhere in California, these lakes may range in size from 10 to over 100 acres, with depths of 50 to 200 feet.

Any wet pit reclamation plans would involve exposure of the water table to create a lake, which will be subject to evaporation losses. Evaluation of the impact of such losses is achieved best through comparison with alternative land uses. Alternative land uses defined for this evaluation include locally extensive crops with a range of evapotranspiration water demands. These are small grains (barley), tomatoes, almonds, and improved pasture. In addition, the alternative of a well-watered turf grass also is presented; this would reflect the possibility of a well-groomed golf course, park or playing field, or cemetery.

Information on evaporation and evapotranspiration are available from studies conducted by the California Department of Water Resources (California DWR, 1975), including collection of data at the Davis agroclimatic station. Evaporation from this and other stations in the southern Sacramento Valley were used by the DWR to estimate a general pan evaporation value of 65 inches for most of Yolo County. To convert this pan evaporation to lake evaporation, a pan coefficient between 0.70 to 0.75 can be assumed.[1] For this analysis, a coefficient of 0.725 and a pan evaporation of 65 inches was used to compute an estimated lake evaporation rate of 47 inches/year or 3.92 feet/year. This value reflects year-round evaporation losses from a reclaimed wet pit or lake surface.

The lake evaporation and alternative evapotranspiration rates from the alternative land uses are presented in Table 4.5-1 below. Evapotranspiration losses are based on estimated growing season evapotranspiration for principal Sacramento Valley crops, and the estimated evapotranspiration of well-watered turf. The evapotranspiration rates are gross rates, reflecting the seasonal water demand of the crop, but neither the impact of evaporation from off-season bare soils or the effect of rainfall.

TABLE 4.5-1

EVAPOTRANSPIRATION LOSSES OF ALTERNATIVE LAND USES

Land Use	Evapotranspiration inches/year
Turf	49.2
Lake	47
Pasture	43.7
Almonds	28.5
Tomatoes	27.4
Barley	11.4

SOURCE: Todd and Associates, 1995.

The above rates are expressed as losses of a depth of water in inches/year. To express the potential losses in terms of volumes of water consumed per year, a total potential lake area of 500 acres was assumed. Based on the above rates, 500 acres dedicated to lake surface would lose some 1,960 acre-feet/year of water to evaporation. To extend this example, if this 500 acres were entirely dedicated to tomatoes, evapotranspiration losses would be about 1,140 acre-feet/year. The net evaporation loss of 500 acres of lakes relative to tomato fields would be 820 acre-feet/year.

As indicated, the evapotranspiration losses from a lake are within the range of local land uses. However, lake losses are high relative to the listed crops, and exceeded only by the losses from a well-tended turf. In addition, it should be noted that reclamation of a parcel as a lake is essentially irreversible, while crops can be changed.

Evaporation losses from wet pits or lakes can be lessened through minimization of lake area, particularly shallow lake areas. Shallow lakes are more subject to warming, with resultant increases in evaporation. Evaporation losses from a wet pit or lake also can be offset by reducing the evapotranspiration losses elsewhere on the site (through crop choice or landscaping design) or through enhancement of groundwater recharge.

Groundwater Flow

Existing and potential plans for sand and gravel mining along Cache Creek include elements with potential impacts on groundwater levels and flow. These include creation of wet pits, disposal of fine sediments, backfilling of quarries with relatively impermeable sediments, and siltation or clogging of wet pits. However, the planned excavation of a series of wet pits may also enhance water conveyance through the upper Cache Creek groundwater basin (above Plainfield Ridge).

To quantify the impacts of pit area and depth on water level changes, a small scale numerical model was constructed. This model was used to simulate several scenarios representing potential future mining alternatives. These are presented in the discussion below.

Wet Pits

Sand and gravel quarries, when filled with water, function as zones of infinite permeability, reflect the level of the surrounding water table, and serve as excellent conduits for groundwater flow. A pit containing open water, regardless of its size, serves as a conveyance mechanism for groundwater flow. Thus its size, including areal extent and depth, is not a hydrogeologic variable which could adversely affect groundwater levels.

A modeling scenario was simulated assuming a series of wet pits positioned along Cache Creek. The model was used to estimate the pattern of flow in the alluvial aquifer, as depicted in Figure 4.5-1. Estimated groundwater flow directions southeasterly through the alluvial valley are shown by arrows. Note that the existing pits do not pose a restrictive limitation to groundwater movement. Accordingly, no guideline restricting the proposed mining of open pits is necessary from the standpoint of groundwater levels and flow.

However, reclamation of a wet pit as a lake may raise concerns about sedimentation and biological clogging of the bottom and sides of the lake. In terms of groundwater hydraulics, potential impacts of sedimentation are similar to, but lesser in magnitude than those occurring due to backfilling (see below). In natural settings, sedimentation and biological clogging often occur in stagnant bodies of water. An open gravel pit penetrating the water table, however, is not a stagnant body of water. The water level in an open pit represents the water table and flow through the pit is governed by the ever-present hydraulic gradient in the aquifer. The resulting flow through the pit "freshens" the lake and minimizes biological clogging.

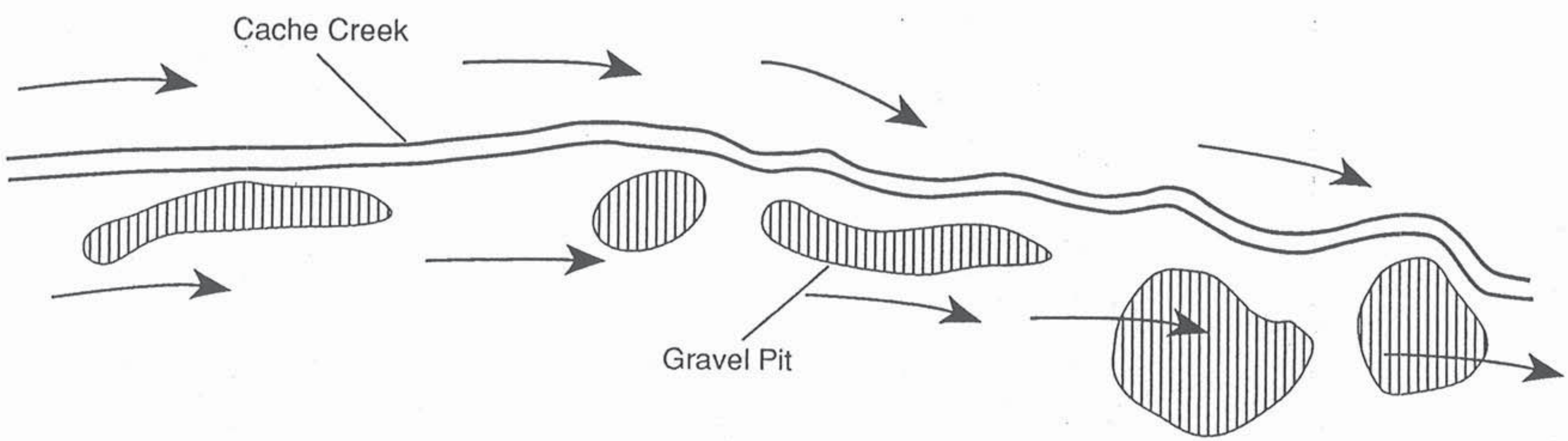

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Figure 4.5-1
Estimated Groundwater Flow Along Cache Creek

Measures can be implemented to maintain a clean lake. Appropriate measures include design of the pit with a perimeter berm to prevent intrusion of local runoff into the lake. Design of the lake to be deep with steep sides also minimizes sedimentation of the sides and biological clogging. However, such a design would minimize opportunities for habitat restoration and recreational access. If the lake is to be accessible to the public or used for recreational purposes, restrictions may be placed on site activities to prevent erosion and control potential sources of pollution. Such measures include limitations on water access and restrictions on motorized vehicles and watercraft. Public access would also require appropriate provision and siting of sanitary facilities, and regular maintenance of the site, including regular inspection and security measures. Protection of groundwater quality near a wet pit is discussed further in the section, Impacts on Groundwater Quality.

If a wet pit is to be reclaimed for recreational or water-dependent habitat, the range of lake level (i.e., groundwater) fluctuations should be addressed. Consideration of fluctuations is particularly important for relatively shallow wet pits (less than 50 feet deep) in areas (e.g., Hungry Hollow reach and near Woodland) where groundwater fluctuations of over 50 feet have occurred. Significant declines in groundwater/lake levels can result in an unattractive "bathtub ring," water facilities stranded high and dry, and loss of vegetation. Potential problems can be minimized best through siting of such facilities in areas of lesser groundwater level changes. Other measures such as design of a deeper lake with steeper sides (minimizing the appearance of mud flats), may be problematic for maintenance of vegetation and habitat and provision of recreation, both of which often require gentler slopes.

Sediment Disposal

Production of sand and gravel results in generation of fine-grained sediments that require handling and disposal. Fine-grained sediments are less permeable relative to native deposits, and inappropriate handling and disposal can result in loss of recharge capacity (see also Groundwater Recharge) or hindrance of groundwater flow.

A previously documented local example of inappropriate disposal involved replacement of native sand and gravel deposits with fine sediments along a portion of the bank of Cache Creek. This disposal effectively reduced the transmission of groundwater through the bank, particularly during high stream flows, and resulted in slower recovery of groundwater levels in nearby shallow wells during such events. This impact has been recognized as adverse and avoidable.[2]

Two broad options exist for fine sediment disposal: intentional widespread distribution of fines or localized disposal. Planned widespread distribution of fine sediments is involved in reclamation of mining areas to agriculture or to habitat (riparian or wetland). In both cases, fine sediments would be combined with surficial coarse-grained deposits to create a suitable, water-retaining substrate for plant growth. This substrate would be emplaced at or above the water table and would have no significant effect on groundwater flow. Creation of such a soil or soil substrate could affect local groundwater recharge by rainfall. If the area were characterized by permeable surficial sands and gravels, recharge would be reduced relative to the high recharge capacity that exists with exposed sands or gravels. However, no significant difference would exist relative to the predominant silt loam to silty clay loam soils in the study area. In fact, a finer-grained soil affords protection for groundwater quality. Accordingly, the disposal of fine sediments through planned widespread distribution would have no significant effect on groundwater recharge capacity.

Localized disposal of fine sediments typically involves a sediment holding pond, created through excavation or berming, and then filled gradually with accumulated fine sediments. In size, such holding ponds and resulting fine-grained deposits typically are on the order of ten or twenty acres with thicknesses of about ten or twenty feet. In geologic terms, the deposit would represent a fine-grained lense or layer of limited extent similar to those routinely encountered in alluvial sediments.

The holding pond and resulting fine-sediment deposit may be positioned above the water table. In this case, the deposit has no impact on groundwater levels and flow. Where the deposit extends into the groundwater, it will act as a relatively low-permeability lense or layer. As demonstrated in the following discussion of backfilling, groundwater flow through the deposit will continue with longer travel times, and groundwater levels immediately downgradient may be lowered somewhat, depending on the size and permeability of the deposit. However, groundwater flow will continue around and under the deposit. Accordingly, in most circumstances the impact on regional groundwater flow will be minor.

Any potential impacts on local groundwater levels and flows can be lessened by minimizing the extent and depth to which the fine-grained deposit penetrates the groundwater. As indicated by the local example described above of inappropriate disposal, consideration should be made of local and short-term groundwater flow conditions, such as local recharge from the creek during high-flow periods. Assessment of local impacts also should include the presence and depth of nearby wells.

Backfilling

Backfilling typically involves reclamation of a quarry to near-original ground surface through filling of the pit with fine sediments generated by mining. The land surface is regraded, stockpiled soils are restored, and the parcel is dedicated to agriculture or recreational use (parks, golf courses, etc.). It is recognized that some quarries throughout the state historically have been backfilled with debris and trash. Such backfilling may involve disposal of potential pollutants to groundwater. This would be contrary to County policies protecting groundwater quality and will be considered no further. Backfilling in this study presumes filling with clean, fine-grained sediments.

In the context of groundwater hydraulics, backfilling with fine sediments introduces a zone of reduced permeability in the aquifer. Accordingly, more flow is diverted around and under the pit as groundwater flow lines are directed away from the zone of lower permeability to that of higher permeability. Groundwater flow through the pit will continue to occur; however, the reduction in permeability increases the travel time of groundwater through the pit.

The introduction of a low permeability zone further influences the elevation of groundwater in the vicinity of the pit. Immediately upgradient of a reclaimed pit, the low permeability zone has a damming effect on groundwater. Accordingly, a slight rise in water levels occurs upgradient of a reclaimed pit. For the same reason, a slight lowering of water levels occurs immediately downgradient of a reclaimed pit. However, due to high permeability of the native gravels, groundwater levels quickly equilibrate, limiting the extent of groundwater decline downgradient of a reclaimed pit.

To quantify the impact of backfilled pits, varying pit areas and depths were simulated. Based on discussion of mining possibilities, a relatively large pit was assumed for analysis, covering an area of 135 acres with a depth of 80 feet below ground surface. Although no known plans call for backfilling on such a scale, it was conservatively assumed that such a pit would be backfilled with low permeability materials. The results of a numerical simulation conducted on this pit indicate that backfilling causes a maximum downgradient water level decline of seven feet, with a simulated decline of 1 foot at a distance of 570 feet downgradient of the pit. The upgradient rise is comparable, reflecting the fact that no change in total groundwater storage has occurred.

In the same manner, an average size pit (80 acres at 50 feet depth) was simulated. This pit, when backfilled, resulted in a maximum water level decline of four feet within 20 feet horizontal distance downgradient from the pit.

Several other scenarios were also simulated, varying pit locations, areas, depths, and shapes. Results of these runs indicate that siting and design for reclaimed pits should consider the following important local factors:

- Extent of the sand and gravel aquifer. Impacts of backfilled pit of a given size will be more pronounced on a relatively thin or limited aquifer section (e.g., near the margins of the basin) than a thick, centrally located section.

- Geometry, permeability and orientation of backfill in relation to the direction of groundwater flow. The impact of backfill is generally proportional to its size. A backfill with its largest face oriented against groundwater flow will have a larger impact than one oriented with groundwater flow. A less permeable backfill will have a greater impact than a more permeable one.

- Seasonal fluctuations in water levels. Impacts of backfilling are less distinguishable and significant in areas of widely fluctuating water levels.

- Location and depth of operating wells. Impacts of backfilling are generally inversely proportional to the distance from an affected well and the well depth.

Because of the large hydraulic conductivity of the valley aquifer, groundwater can readily flow through an open pit or around a backfilled pit. Only if the entire cross-section of the aquifer were backfilled would there be a significant impact on groundwater levels or flow. No such reclamation is known or expected to be proposed.

It should be noted that adverse impacts due to groundwater decline will vary by location, depending on the presence and depth of operating wells. Hence if no well is present immediately downgradient of a reclaimed pit (i.e., within 20 feet where a four to seven foot drop in water level occurs), then the water level decline attributed to the pit back-filling does not pose an adverse impact. Therefore, a single-value guideline limiting pit area and depth may not be applicable everywhere. Site-specific plans and conditions require analysis for implementation of such localized guidelines.

The following suggested steps would allow determination of probable impacts of backfilling and documentation of siting and design parameters to minimize impacts. The following should be addressed if a planned backfill penetrates either 50 feet or one half the saturated thickness of the shallow aquifer.

- Identify and locate all wells within 1,000 feet and, based on available data, characterize them in terms of depth, screen, pump setting, pumping and static water levels. If active wells are located, proceed with analysis.
- Based on existing water level records, document groundwater level fluctuations and trends to establish a baseline.
- Select or install three monitoring wells, one upgradient and two downgradient. These wells should be within 100 feet of the backfill perimeter, or sited according to hydrogeologic analysis.
- Establish a water level monitoring program on at least a quarterly basis.
- Perform an aquifer test to determine aquifer characteristics.
- Construct a small-scale model and simulate impacts on nearby wells. Potential adverse impacts attributable to backfilling may include drying up a well, exposing the pump or screens, or causing a significant water level decline relative to available drawdown or seasonal fluctuations.

Multiple Pits

The discussion of wet pits and backfilling presumed the existence of a single pit. However, regional mining often results in a series or cluster of pits.

As indicated in the discussion above, a wet pit serves as a conveyance mechanism for groundwater flow. Similarly, a series of wet pits convey groundwater, as illustrated in Figure 4.5-1, which shows flow lines through a series of pits.

Wet pits have been recognized as a conveyance system. An example is the Chain-of-Lakes now being developed near Pleasanton, California in the Livermore-Amador Valley. The Chain-of-Lakes will consist of a series of wet pits up to 200 feet deep and potentially encompassing 1,000 acres or more. These lakes are being created to aid in transmission of water from the valley's forebay area around an area of backfilled pits toward municipal well fields. The lakes will be connected not only by groundwater flow, but also by controlled interbasin surface water flow, allowing capture and storage of local streamflow.

A series of wet pits may be proposed along Cache Creek. This possibility already has raised questions concerning setback distances between individual pits in a series and maintenance of water levels in the pits. As previously indicated, an open pit containing water, regardless of its size, shape, and depth, serves as a transfer mechanism for groundwater flow. The exposed water surface of a wet pit does not serve as a control point on water levels, as opposed to the profile of a surface water body, such as Cache Creek. The exposed surface represents the groundwater table, whose slope governs flow of water through the mined area. Accordingly, no pit-to-pit setback distance beyond those imposed by existing property lines is necessary for a series of wet pits.

Conversely, backfilling of pits will have localized impacts on groundwater levels. Should a chain of backfilled pits be proposed, depending on the size and depth of these pits, pit-to-pit setback distances will be necessary to allow water levels to equilibrate. Depending on siting and design, a chain of backfilled pits could cause spatially extensive lowering of water levels. Determination of backfilled pit-to-pit setback distances should consider site-specific factors such as extent of the sand and gravel aquifer, size of pits, and geometry and orientation of pits in relation to the direction of groundwater flow. Pit-to-pit setback distances will be roughly proportional to the size of the pits. As previously stated, only if an entire cross-section of the aquifer were mined and backfilled would there be a significant impact on groundwater levels or flow. It should be noted that the mining industry has indicated no interest in such backfilling.

Groundwater Storage

Removal of the clay, silt, sand, and gravel from a wet pit results in the creation of additional groundwater storage capacity as water fills the space formerly occupied by geologic materials. The usable amount of this storage depends on the level of the lake, which is the water table. If water levels are high, little storage space is available to be filled. However, when water levels are low, storage capacity in the pit and adjacent aquifer can be filled on a short term basis by water managers. It should be noted that water diverted into a clean wet pit will flow quickly outward into the surrounding aquifer. Thus, storage in the pit is short-term. Also, any pit designated for storage should be carefully sited to prevent loss of stored water to the creek. Otherwise, siting of a pit for storage along Cache Creek would be determined primarily by location of existing water facilities.

Such storage in the pit and primarily in the aquifer can be used to temporarily retain available water for diversion to canals for irrigation or to the creek for habitat maintenance. In these cases, the stored water would be high quality, so that its mixing with local groundwater would have no significant adverse impact. Protection of the stored water and local groundwater quality would be important. As presented in the discussion of wet pits above, measures would include lake berms to prevent local water drainage into the lake, site surface water and erosion control, and site land use management.

Diversion of Cache Creek streamflow directly into a wet pit for storage likely would result in an influx of fine, suspended sediment into the lake, unless the water was previously retained or treated for sediment. Fine sediment would tend to settle in the lake, potentially reducing its storage capacity and clogging its bottom and sides. Such sedimentation problems can be minimized by diverting only flows with low sediment, treating flows prior to storage, or occasional removal of sediment from the lake.

Release of water from storage in a wet pit could be accomplished through pumping. In this case, consideration should be given to potential impacts on local groundwater levels, stream baseflow, nearby wells, and riparian vegetation. Such impacts can be minimized through pit siting and design, and operational guidelines (e.g., limitations on pumping rate or drawdown). Potential impacts on groundwater of a wet pit used for storage and pumping can be evaluated through the following suggested steps.

- Identify and locate all wells within 1,000 feet and, based on available data, characterize them in terms of depth, screen, pump setting, pumping and static water levels. If active wells are located, proceed with analysis.
- Determine distance to the creek and characterize its flow characteristics.
- Based on existing water level records, document groundwater level fluctuations and trends to establish a baseline.
- Perform annual or more frequent sampling and analysis of groundwater quality from pits and selected wells, including, but not limited to general mineral constituents, nitrate, pH, electrical conductivity, turbidity, and total coliform.
- Select or install three monitoring wells, one upgradient and two downgradient. These wells should be within 100 feet of the pit high water mark or sited according to hydrogeologic analysis.
- Establish a water level monitoring program on at least on a quarterly basis.
- Perform annual or more frequent sampling and analysis of groundwater quality from pits and selected wells, including, but not limited to general mineral constituents, nitrate, pH, electrical conductivity, turbidity, and total coliform.
- Perform an aquifer test to determine aquifer characteristics.
- Perform a Theis analysis of drawdown or construct a small-scale model to determine impacts on nearby wells or the creek. Potential adverse impacts attributable to pumping may include drying up a well or stream reach, exposing a well pump or screens, or causing a significant water level decline relative to available drawdown or seasonal fluctuations.

Wet pits may be considered for retention of poor quality irrigation tailwater. Storage of such poor quality water would entail significant potential adverse impacts to groundwater quality and nearby wells. It is unlikely that a site could be identified in the permeable sands and gravels of the study area that would afford acceptable safeguards for groundwater quality, even with pit lining and pit setbacks. Such a use is contrary to County policies protecting groundwater quality.

Groundwater Recharge

Sand and gravel mining potentially entails both adverse impacts on groundwater recharge and opportunities for enhanced recharge. Potential adverse impacts generally involve reduction of recharge because of inappropriate handling and disposal of fine sediments. Such impacts are discussed below in terms of in-channel impacts, off-channel distribution of fines, and off-channel local disposal.

Activities resulting in the release of fine sediments to the creek channel could cause siltation of the channel bottom and loss of recharge capacity. Such activities would be contrary to the Yolo County objective of increasing the recharge capability along Cache Creek. However, the intentional placement of fine sediments at specific locales to provide a suitable substrate for vegetation provides benefits that may offset localized losses of recharge capacity.

As discussed in the section on sediment disposal above, the intentional distribution of fine sediments to create substrate and soils for agriculture or habitat has no significant effect relative to the predominant soils in the study area. As noted above, a finer-grained soil affords protection for groundwater quality, because the capability to retain pollutants is generally greater in fine-grained soil than in coarse soil.

Localized disposal of fine sediments results in a fine-grained deposit or layer of limited areal extent. Percolation of rainfall through such a deposit would be lessened relative to the native sands and gravels. However, localized disposal typically involves only ten or twenty acres and therefore, impacts on groundwater recharge would be negligible. Minimization of the so-called footprint of such a deposit would be in accordance with Yolo County policy encouraging the use of nonimpervious surfaces.

Artificial Recharge

Aggregate mining can present opportunities for enhanced groundwater management through provision of ready-made or adaptable pits, basins, or channels for artificial recharge. Examples of successful partnerships between aggregate mining and groundwater basin management can be found throughout California; the example of the Chain-of-Lakes already has been mentioned. Another striking example is the extensive system of artificial recharge basins and channels along the Santa Ana River, operated by the Orange County Water District. This system consists of the Santa Ana River channel, which has been improved for flood control and recharge, and a series of large sand and gravel quarries reclaimed for surface water storage and recharge. Other examples exist in Santa Clara, San Bernardino, and Los Angeles counties.

An extensive literature exists on artificial recharge, including selection of method (in-channel spreading, shallow basins, deep basins, wet pits, recharge wells), design of facilities, and operation and maintenance. No single best method or mode of operation exists, as facilities and operations are tailored to project objectives, site characteristics, and recharge water quantity and quality.

However, in terms of surface water recharge, there is a general recognition that spreading grounds, channels, or basins situated above the water table provide considerable advantage over deep pits that intersect the water table. First, the presence of an unsaturated zone below the recharge facility provides filtration and attenuation of potential pollutants in recharging water. Recharge through a wet pit entails direct mixing of recharge water with groundwater. In order to protect the quality of groundwater, it is suggested that artificial recharge be accomplished through dry spreading grounds or basins. Ten to twenty feet of unsaturated zone is suggested to allow for groundwater mounding, to adequately filter and attenuate potential contaminants in the applied recharge water,[3] and to allow for alternative basin designs. Determination of the required unsaturated zone will depend, however, on specific recharge project plans.

In addition, recharge facilities above the water table can be dried out. Drying of a basin in itself can reduce biological clogging and allows frequent scraping of the basin to cost-effectively remove clogging sediment. Maintenance of effective recharge in deep wet pits typically relies first on diversion into the pit of clean, silt-free water only. Pits also can be cleaned through dredging.

Accordingly, provision of opportunities for artificial recharge along Cache Creek would involve preservation of selected in-channel areas that are permeable, situated above the high water table, relatively flat to promote water spreading, and accessible by equipment for building of low berms and scraping. Optimal off-channel sites could be provided through removal of any surficial fine-grained sediments and excavation for sand and gravel mining. Like the in-channel sites, off-channel recharge sites also would be permeable, with ground surface above the high water table, relatively flat, and accessible by earth-moving equipment. Selection of the specific future recharge method and design of recharge facilities is beyond these general requirements above, which are intended to preserve a wide range of recharge alternatives. In fact, potential future recharge sites could be returned to agriculture in the interim with replacement of suitable soils, followed by eventual additional excavation and design of facilities.

Potential areas for artificial recharge sites include the forebay or recharge groundwater zones identified at the beginning of this section. These include the Hungry Hollow (Esparto), Madison, and Hoppin reaches (below Stevens Bridge). These sites are in agreement with artificial recharge areas previously identified in Yolo County. In 1975, an investigation of Yolo County groundwater resources (Scott and Scalmanini, 1975) assessed the general potential for artificial recharge and identified sites for surface water spreading and well injection. General areas for surface spreading focused on the aforementioned reaches. More recently, Borcalli & Associates identified areas for artificial recharge above Esparto Bridge (Hungry Hollow reach), and areas for recharge and recovery along the Madison and Hoppin reaches.

The recent application to appropriate water from Cache Creek by Yolo County Flood Control and Water Conservation District (YCFCWCD) identified potential use of 1,000 acres for recharge basins. This acreage area probably will include sites reclaimed from existing sand and gravel mining. However, the application recognizes that recharge basins may also be developed by YCFCWCD. Accordingly, the entire 1,000 acres will not necessarily be provided through sand and gravel mining. The specific siting and overall extent of facilities, including both in- and off-channel, has not been determined.

Dewatering and Groundwater Discharge

There are no known proposals to dewater wet pits for mining in the Cache Creek area. However, it has been a practice with considerable impact on groundwater resources in other areas. These impacts include significantly lowered groundwater levels, sometimes on a regional scale, and discharge of water from the groundwater basin without full recovery or use. Impacts on affected wells could be lessened through well deepening or replacement. This would be a considerable challenge in the Cache Creek area to identify all wells adversely affected by dewatering in a context of already varying groundwater levels, and to minimize impacts on those wells. Furthermore, dewatering without full recovery of water likely is contrary to the Yolo County policy stating that groundwater should be protected against overdraft. Nonetheless, dewatering losses could be minimized through planned routing and recovery of discharge water, or through offsite artificial recharge. Minimization of the loss of discharge water probably would be effective and reliable only in the context of a carefully managed groundwater basin.

Streambed Lowering

Section 4.4, the Historical Perspective on Groundwater, identified thalweg lowering as one result of in-channel mining with ramifications for groundwater resources. The impact on groundwater resources of historic thalweg lowering was documented to be minor, localized groundwater level declines and associated loss of groundwater storage capacity. However, such documentation is bounded by available data from existing wells. Accordingly, a numerical model was constructed to estimate the spatial extent of groundwater decline in the vicinity of the creek due to the thalweg lowering. The model simulates the regional aquifer with a uniform and steady hydraulic connection between the aquifer and Cache Creek. A model scenario was simulated in which the thalweg was lowered by ten feet. The spatial distribution of groundwater levels was observed, indicating that there is minimal influence (less than five feet decline) on groundwater levels beyond 1,000 feet away from the creek.

This simulation and analysis of historical water level data suggests that lowering of the thalweg in Cache Creek, due to in-stream mining activities, has resulted in localized decline of groundwater levels near the creek. The historical perspective endorsed limitations on in-channel mining as a prudent measure to prevent future channel declines and groundwater storage loss. This recommendation stands, and should be achieved within the context of the overall streamway restoration.

Impacts on Groundwater Quality

Potential impacts on groundwater quality include exposure of the water table to surface contamination, loss of aquifer filtration capacity, and concentration of salts due to water table exposure to evaporation. All of these pertain only to wet pits.

Surface Contamination

Introduction of contaminants to an open wet pit can adversely impact groundwater extracted by nearby domestic or agricultural wells. The potential for such an impact can be evaluated through determination of the wellhead protection areas of wells under expected pumping conditions near proposed open pits. The setback distance of pits to wells may differ for each proposed pit, depending on location, use, and pumping rates of wells.

Figure 4.5-2 depicts the results of a hypothetical scenario simulating the relationship between a large pumping well or well field and a wet pit. Note that flowlines on the figure represent the path of all groundwater contributing to the well. For the sake of clarity, the regional flowlines have been omitted. These would indicate groundwater flow through the entire area, generally parallel to the creek, and through the pit. Under the simulated scenario (well pumping rate of 2,500 gpm), a setback distance of 250 feet would be sufficient to protect the quality of extracted groundwater from potential contaminants released at the pit. As indicated above, site specific analysis of wellhead protection would be required to quantify a setback distance for a particular pit.

Another scenario was analyzed, simulating the presence of a pumping well located downgradient of a wet pit. In this scenario, a domestic well discharging at 200 gallons per day was assumed to be operating for a period of 30 days. Figure 4.5-3 depicts the wellhead protection area of such a well, delineating a setback distance of approximately 60 feet. As shown in the figure, a wet pit present upgradient of this well outside of the wellhead protection area will not contribute water (and hence contamination) to the well within the 30 day operating period. Assumption of a large pumping well or well field downgradient of the pit results in a setback of about 450 feet.

Given sufficient time, if contaminants were introduced at the pit, some will reach the downgradient well. However, the concentrations of these contaminants will be significantly reduced through travel along the setback distance to the well. Some of these processes are illustrated below.

Initially, contaminant concentrations introduced to the pit will be significantly reduced through the process of dilution. An 80-acre pit with a wetted depth of 50 feet contains approximately 1,303 million gallons of water. In the unlikely event that a 55-gallon drum containing a chemical is released to such a pit, the chemical dilution factor due to pit water would approximate 4.2×10^{-8}. This would serve to reduce chemical concentrations of most contaminants to below their maximum contaminant level drinking water standards (MCLs). Larger pits provide larger dilution factors. In addition to the natural dilution in pit water, contaminant attenuation will occur during migration along the setback distance from the well through the subsurface processes of dispersion, retardation, chemical reactions, and decay.

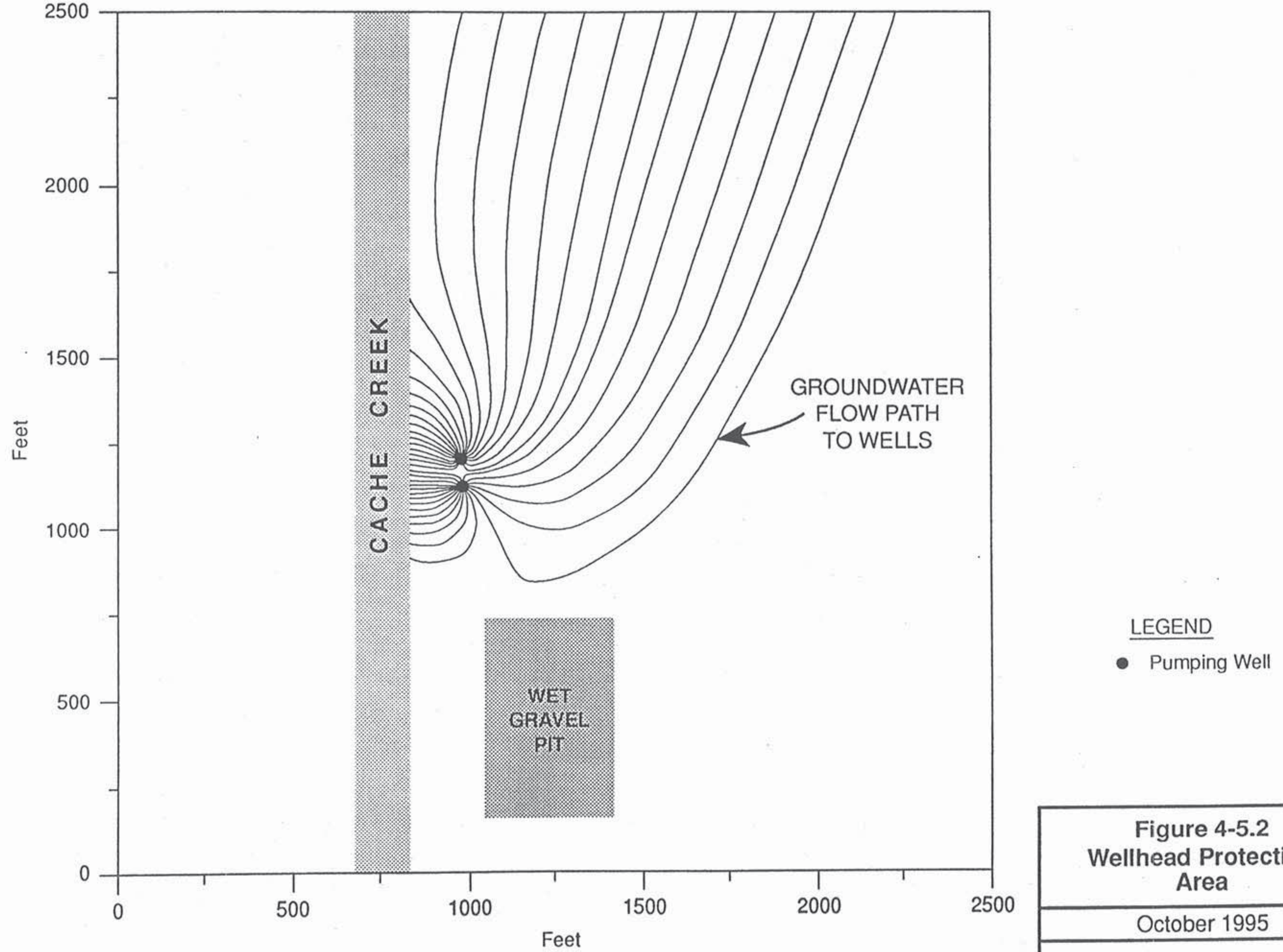

Figure 4-5.2
Wellhead Protection Area

October 1995

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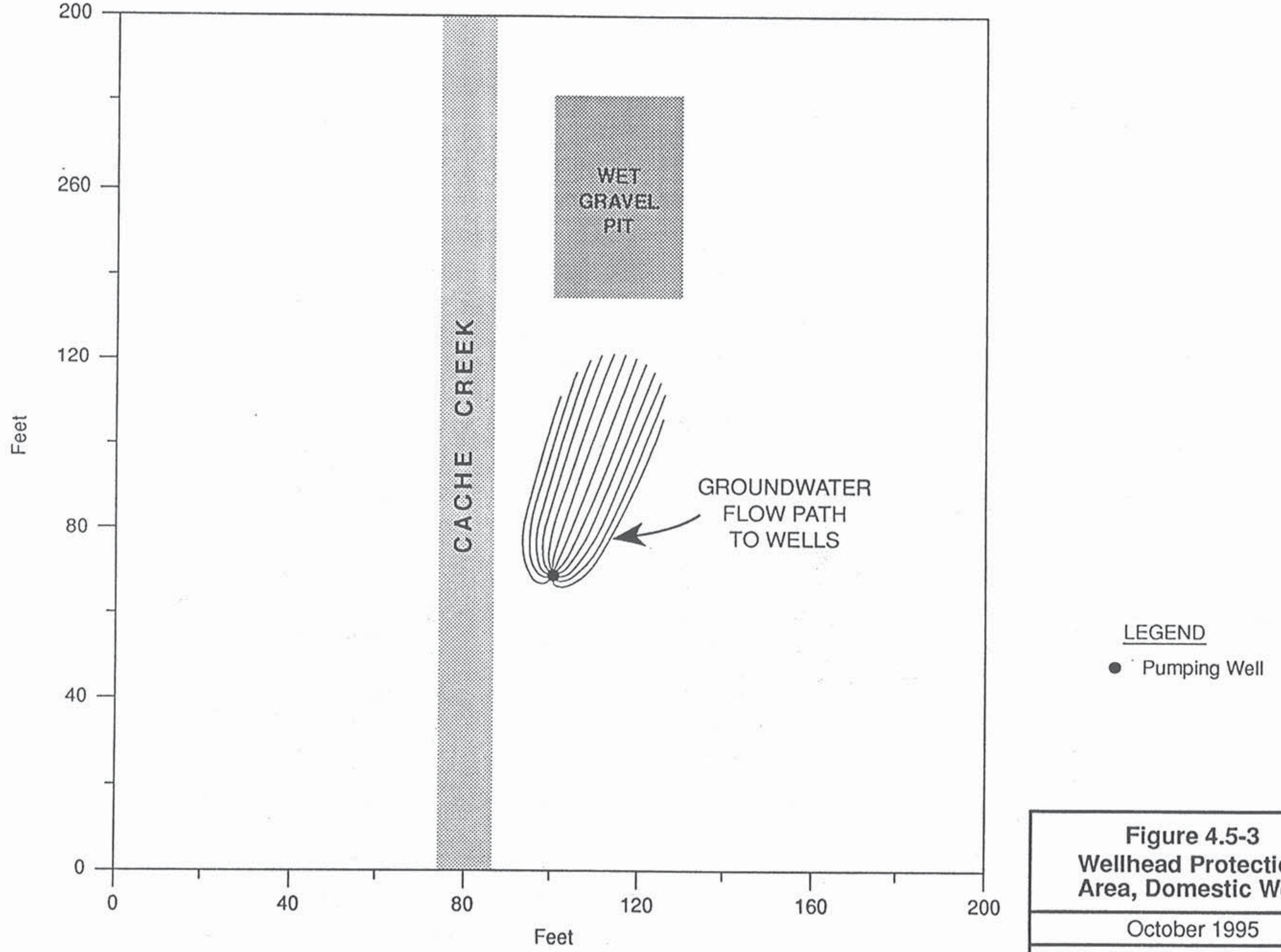

Figure 4.5-3
Wellhead Protection Area, Domestic Well

October 1995

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Despite the protection afforded by dilution and subsurface attenuation, it is paramount that the quality of water in the lake be protected. Appropriate site design and maintenance measures have been described previously for wet pits. These include design of the pit with a perimeter berm, site runoff and erosion control, and restrictions on site activities. To safeguard water quality in local wells, potential impacts of a wet pit can be evaluated through the following suggested steps.

- Identify and locate all wells within 1,000 feet. Based on available data, characterize them in terms of pumpage, depth, and screens. If active wells are located, proceed with analysis.
- Select or install three monitoring wells, one upgradient and two downgradient. These wells should be within 100 feet of the pit high water mark or sited according to hydrogeologic analysis.
- Perform an aquifer test to determine aquifer characteristics.
- Establish a setback of 1,000 feet to a municipal well or perform a capture zone analysis conservatively assuming 30 days of continuous pumping to determine a setback distance avoiding coincidence of the pit and capture zone.
- Establish a setback of 500 feet to a domestic drinking water well or perform a capture zone analysis conservatively assuming 30 days of continuous pumping to determine a setback distance avoiding coincidence of the pit and the capture zone.

Loss of Filtration

Pumpage of wells near the creek induce flow of water from the creek into the aquifer. Since the surface water in Cache Creek is exposed to suspended materials, contaminants, and pathogens (disease-causing organisms), these are introduced into the aquifer due to well pumpage. However, aquifer materials serve as a natural filtration system removing and attenuating pollutants and pathogens. Accordingly, the concern has been raised that creation of wet pits along Cache Creek will reduce the filtration capacity of the aquifer between the creek and local wells.

Potential adverse impacts of filtration loss on extracted groundwater will vary with location, well pumping rates, and the source of water to the wells. This, once again, requires that the wellhead protection area of pumping wells near wet pits be delineated. Wet pits should be sited beyond the wellhead protection areas of drinking water wells, so that groundwater reaching the well undergoes filtration through aquifer materials.

In the case of backfilled pits, the filtration capacity of the aquifer is increased due to the presence of finer materials introduced into the aquifer.

Salt Concentration

The estimated evaporation loss from a wet pit or lake was documented above in the section describing potential impacts on groundwater quantity. Such evaporation losses also entail potential impacts on groundwater quality, because the evaporation of water results in some concentration in the lake of salts in the native groundwater. To estimate this concentration, an pit area of 80 acres was assumed for a brief analysis of the salt loading. Using a rainfall of 17 inches and evaporation of 47 inches, a salt loading of about five percent was computed. In other words, a volume of native groundwater entering the pit with a total dissolved solids content of 500 parts per million (ppm) would leave the pit with a total dissolved solids content of 525 ppm. Impacts of alternative land uses with similarly high evapotranspiration demands (e.g., pasture or turf) would have a similar effect. This assumes no leaching of salts in the soil, which could increase the salt loading.

Summary: Major Mining and Reclamation Alternatives

The major mining and reclamation alternatives identified in this study are in-channel mining, off-channel reclamation to agriculture, off-channel wet pits, off-channel backfilling, and artificial recharge. Each is summarized below in terms of relevant groundwater issues, thereby providing a synthesis of issues related to each major mining and reclamation alternatives and measures that can be taken to minimize adverse impacts and to maximize opportunities. These measures are the basis of Chapter 6 Recommendations.

In-Channel Mining

Historical thalweg lowering of the Cache Creek channel has been identified as a result of in-channel mining. In terms of groundwater, thalweg lowering results in small and localized groundwater level declines and loss of storage capacity. However, these losses are permanent. They also are preventable, by limiting in-channel mining to that needed for streamway restoration and flood control.

Release of fine sediments to the Cache Creek channel could result in loss of recharge capacity. Such releases can be prevented by site surface water and erosion control, and by proper disposal of fine sediments produced by mining. It is recognized that benefits may be derived from the intentional placement of fine sediments to establish vegetation.

Off-Channel Reclamation to Agriculture

Reclamation to agriculture is a major alternative for shallow mining that has no significant effect on groundwater. The intentional distribution of fine sediments from mining to create substrate and soils for agriculture has no significant effect on groundwater recharge. In fact, a finer-grained soil affords protection for groundwater quality.

Off-Channel Wet Pits

Another major alternative for off-channel sites is mining below the water table to create a wet pit. Subsequently, the wet pit would be reclaimed as a perennial lake for recreation, habitat, water management, or combinations of the three.

With regard to wet pit mining, dewatering of a wet pit would involve significant impacts on groundwater levels and supply. Reduction of adverse impacts would be difficult in the Cache Creek area, given the number of private wells, context of fluctuating groundwater levels, and water management requirements for effective routing and recovery of discharge water. Such impacts could be avoided entirely by disallowing plans for dewatering.

With regard to reclamation of wet pits as lakes, maintenance in perpetuity of the water quality in the lake is essential. If that requirement is satisfied, then impacts on groundwater will be minimal. If a wet pit is maintained appropriately, sedimentation and clogging will be minimal, and groundwater flow through the lake will continue. The exposed water surface in a pit is the water table. If a series of wet pits is envisioned, the water surfaces in the pits will be governed by the groundwater gradient. Accordingly, no pit-to-pit setback distance is needed beyond those imposed by property lines.

The sole irreversible impact is the loss of water due to evaporation and resulting salt loading. Nevertheless, as documented in Chapter 5, such impacts due to a wet pit are comparable to those resulting from evapotranspiration by local crops and landscaping turf. Evaporation also can be minimized somewhat through design of the lake to be deep, with steep sides, and minimal shallow areas. A deep lake also helps ensure that water will be present in the lake for recreational and habitat purposes, even through droughts. As noted in Chapter 5, one side or a portion of the lake perimeter can be designed with gentle slopes to allow recreational access and establishment of habitat.

If the water quality in a wet pit or lake is preserved, by definition there will be no adverse impact on groundwater quality. However, it is recognized that contaminants potentially could be introduced into a wet pit despite the site design, maintenance, and security measures indicated in Chapter 5. Accordingly, a set of secondary safeguards is prudent. First, evaluation of wellhead protection areas for nearby wells will aid in development of specific guidelines for siting and design of wet pits. Simplified, small-scale computer models may be applied for such analysis. In addition, potential impacts on nearby wells can be detected through down-gradient monitoring. Impacts also can be reduced through provision of a setback to wells, best determined on a site-specific basis through capture zone analysis, as described in earlier sections.

Wet pits also are considered for use in water management for: (1) storage of poor quality water, (2) storage of high quality water, and (3) artificial recharge. Any considered use of wet pits for retention of poor quality water entails significant adverse impacts on groundwater quality. Such impacts are best avoided by disallowing such storage. Wet pits also can be used for temporary clean water storage, and can be designed and maintained to preserve water quality. Adverse impacts on wells, streamflow, and riparian vegetation can be minimized through pit siting and design, and operational guidelines. Artificial recharge can be accomplished through wet pits. However, as discussed below, dry basins and spreading grounds are superior for artificial recharge because they provide access for sediment removal and filtration benefits.

Off-Channel Backfilling

Inappropriate handling and disposal of fine sediments generated by mining can result in loss of recharge capacity and hindrance of groundwater flow. Adverse impacts can be lessened through use of fine sediments in reclamation for agriculture or habitat. In the case of localized disposal of fine sediments, the fine sediments typically are placed above the water table, and there is no impact on groundwater, except in some cases during high groundwater periods. In these situations, impacts on groundwater flow can be lessened by minimizing the depth and extent to which the fine sediment deposit penetrates the water table. Similarly, impacts of localized disposal on recharge capacity can be lessened by minimizing the footprint of a disposal area.

Backfilling of a pit introduces a zone of lower permeability in the aquifer, causing a localized downgradient decline in groundwater levels and a corresponding localized upgradient rise. Potential adverse impacts can be minimized through pit siting and design. Siting and design for backfilled pits should consider the local factors, including extent of the aquifer, size and orientation of pits relative to groundwater flow, fluctuations in water levels, and location and depth of wells. Accordingly, a single-value guideline for siting and design of pits will not be applicable everywhere, and site-specific plans and conditions require monitoring and analysis for determination of guidelines. Suggested steps are described in the earlier section on backfilling.

Artificial Recharge

Aggregate mining can create opportunities for artificial recharge through provision of shallow basins situated above the water table. It is generally recognized that spreading grounds, channels, or basins situated above the water table provide considerable advantage over wet pits. First, the presence of an unsaturated zone below the recharge facility provides filtration and attenuation of potential pollutants in recharging water. Ten to twenty feet of unsaturated zone is suggested to allow for groundwater mounding, to adequately filter and attenuate potential contaminants in the applied recharge water. In addition, recharge facilities above the water table can be dried out to reduce biological clogging and to allow scraping to remove sediment. Potential areas for artificial recharge include the forebay or recharge reaches near Esparto and below Stevens Bridge near Woodland.

Aggregate Mining and Groundwater Management

Although aggregate mining may present a variety of potential problems for groundwater resources, it also presents opportunities for enhanced groundwater management. These opportunities (already discussed above) are the provision of pits, basins, or channels for artificial recharge, and use of pits for water storage and conveyance. To summarize, preferred artificial recharge basins are dry basins or channel areas located in the forebay or recharge areas of the basin near Esparto and Woodland. Wet pits, presuming that they are maintained and kept clean, pose no obstacle to groundwater flow, and in fact, can enhance storage and transmission of water.

Management of groundwater in a mining area would be best accomplished in the context of overall regional groundwater management. However, guidelines developed in the report are not predicated on the current existence of regional management. In the case of artificial recharge, provision of areas for artificial recharge is based upon preservation of a suitable unsaturated zone. If short-term water management does not include use of artificial recharge areas, then these areas may be restored to agriculture in the interim. Subsequently, water managers would have a reasonable range of artificial recharge opportunities to consider for a site, including a variety of designs for shallow basins or even wet recharge pits. With regard to water storage and conveyance, water projects planned in the near future may influence mining plans. However, such water projects also can be developed based on pre-existing wet pits.

Monitoring

This section concerns monitoring on mining sites that would be required to adequately assess potential impacts on groundwater of mining activities and reclamation. In addition, eventual incorporation of site monitoring activities into a regional water monitoring program is discussed.

Site Monitoring

On a site-specific basis, monitoring will involve installation or selection of monitoring wells, measurement of water levels in wells and pits, and water quality sampling for wells and pits. Such monitoring already exists at several mining sites along Cache Creek. Specific attributes of site monitoring are dependent on the character of the site, depth of mining relative to the water table, and reclamation plan. For example, shallow mining above the water table with reclamation to agriculture involves no significant impacts on groundwater and requires no special monitoring.

Backfilling or wet pit mining near drinking water wells, on the other hand, will require more intensive monitoring and data analysis. For example, wet pits entail evaporation losses and some concentration of salts. Although the concentration of salts is small, it should be considered carefully because of the regional context of increases in total dissolved salts. Accordingly, site groundwater and pit water quality should be monitored to establish baseline conditions and to determine the impact of the wet pit alone. Monitoring to evaluate potential impacts on groundwater for a site with backfilling or wet pit mining may include the following:

- installation or selection of one upgradient well to document background or baseline conditions;
- installation or selection of two or more downgradient wells to establish groundwater gradients and to assess potential impacts of mining and reclamation;
- quarterly or more frequent monitoring of groundwater levels; and
- annual or more frequent sampling and analysis of groundwater quality from pits and selected wells, including, but not limited to general mineral constituents, nitrate, pH, electrical conductivity, turbidity, and total coliform.

It should be noted that specific monitoring requirements will be determined on a site basis, and may change through time. For example, if monitoring detects significant changes in quality, then the sampling frequency may be increased or the analysis may be modified. Conversely, a sustained sampling record indicating no problems may justify a reduction of the monitoring effort.

In addition, as previously stated, site-specific analysis of potential groundwater level declines due to backfilling and evaluation of wellhead protection areas will be required to develop specific guidelines for the design of pits. Simplified, small-scale computer models may be quickly and efficiently applied for such analysis. The USEPA and the U.S. Geological Survey have several public domain models capable of simulating subsurface processes requiring analysis for evaluation of gravel mining operations.

Site-specific hydrogeologic data (such as aquifer transmissivity, stratigraphy and aquifer geometry, storage capacity of the aquifer, hydraulic gradient, recharge rate, and nearby well pumpage) together with data characterizing the proposed gravel pits are required for input into these models. To collect such data, groundwater both upgradient and downgradient of the proposed pit locations requires monitoring (see above). Aquifer testing also is required for estimation of aquifer transmissivity.

Regional Monitoring

As with overall management, it would be preferable for such quarry-site monitoring to be embedded firmly in an overall regional water monitoring program, as presented below. Responsibility for sites reclaimed as artificial recharge and water storage/conveyance facilities would ultimately rest with a water management agency.[4] This agency would rely on data generated by both the regional and site monitoring programs for its management decisions. Accordingly, responsibility for water-related monitoring at mining sites should be assumed by the water agency even as quarry operations continue. This would enhance the credibility and usefulness of the site-specific monitoring programs. Given the scope of potential future mining, the responsible water agency would develop a system of identifying pits and tracking progress in quarrying and reclamation. The agency also would institute a program of regular measurement of water levels in wells and wet pits; sampling of water quality in pits, wells, and the creek; and synoptic studies along the creek to document groundwater/surface water relationships. Data would be compiled, analyzed, and reported on a regular basis and applied to the water agency's management practices.

Development of such a monitoring program will be incremental, building on the site-specific monitoring plans developed now and in the near-future by the mining industry. Eventually, monitoring of active quarry sites would be incorporated into the regional water resource monitoring by the water agency. Eventually, the water agency would assume full responsibility for the fully reclaimed water facility, and the mining area monitoring would be subsumed entirely with regional monitoring. Monitoring along the Santa Ana River and associated pits is an example of this ultimate phase.

As to the scope and nature of regional monitoring, the Available Data section of this report provides the background for an overview of water resource monitoring in the Cache Creek region. To summarize briefly, review of the Available Data section reveals the lack of a comprehensive water resources monitoring and data analysis program for the Cache Creek region conducted by a single, responsible water agency.

Review of available data also suggests the following specific monitoring tasks that may be incorporated into such a comprehensive program:

- maintenance of rainfall data, and continued recording of rainfall at Davis;
- re-establishment of the Capay gage with the cooperation of the USGS;
- establishment of regular synoptic studies to determine surface water/groundwater relationships along Cache Creek;
- compilation and maintenance of a complete database of irrigation diversions;
- maintenance and updating of a library of water well drillers reports, geologic and geophysical logs, and other geologic information;
- conduct of pumping and aquifer tests, and maintenance of data files on aquifer characteristics;
- maintenance of a database of municipal pumping and evaluation of agricultural and other groundwater pumpage;
- continued monitoring of groundwater levels and compilation of level data in a single database, followed by semiannual (spring and autumn) production of water table contour maps and long-term hydrographs; and
- critical review of the groundwater quality database and revision of the monitoring program, including selection of key wells for sustained and regular monitoring, definition of suitable constituents and parameters for analysis, regular data compilation, and periodic analysis and reporting in the form of maps and graphs.

Collection and analysis of the above information provides the basis and context for additional suggested investigations, including evaluation of the regional water balance (perennial yield), evaluation of the salt balance, study of the causes of subsidence, and regional evaluation of potential groundwater contamination by pesticides and fertilizers, and other pollution problems. Additional investigations, including isotope studies, can be considered after establishment of a regular program of basic data compilation and analysis.

Use of a Regional Model

As demonstrated in this section, small scale modeling can aid in assessment of the potential local impacts on groundwater of mining activities and reclamation before field initiation. Regional computer models also can simulate the cumulative or regional impacts of mining, reclamation and water management activities, including analysis of site-specific relationships between groundwater and surface water supplies, artificial recharge operations, and aggregate mining.

It is widely recognized that regional computer modeling serves as an important tool for groundwater basin management. However, construction of such a model requires more data, time, and expertise than simplified, site-specific models. In addition, regional models typically are updated as additional data become available through time, and are actively applied on an on-going basis as a management tool. Accordingly, best use of regional modeling is predicated on regional management and monitoring, and relies on long-term monitoring and data analysis. Application of such a model to the Cache Creek Basin will require continued and expanded monitoring of groundwater. Additional quantification of well pumpage is also suggested. Aquifer parameters will require quantification through initiation of aquifer tests at several locations and depths within the basin. Accordingly, a regional model would be developed best in the context of regional groundwater management and monitoring.

ENDNOTES

1. Dunne, Thomas and Luna Leopola. *Water in Environmental Planning.* 1978.

2. Luhdorff & Scalmanini. *Ground-Water Resources in the Vicinity of Cache Creek, Yolo County, California.* 1992.

3. Bouwer, Herman. "Design and Operation of Land Treatment Systems for Minimum Contamination of Groundwater." *Ground Water 12:140-147.* 1974.

4. This water management agency is not defined here. Many options exist for future regional water management, including further development of water management activities by the Yolo County Flood Control and Water Conservation District, expansion of the County's role, creation of a new water management agency, or a joint agency agreement.