Water Balance Study for the Northern Cities Area

April 2007

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For:

City of Pismo Beach

City of Grover Beach

City of Arroyo Grande

Oceano Community Services District

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Table of Contents

List of Figures

List of Tables

List of Appendices

Executive Summary

Introduction

This document presents a water balance for the Northern Cities Area groundwater basin under current management conditions. The objective of this updated and independent water balance is to improve the understanding of the groundwater system as a basis for improved monitoring and management, including potential increased use. The water balance analysis will support local decision-making with regard to the amounts of groundwater that may be extracted safely under varying natural and human-influenced conditions.

The water balance was performed on the Arroyo Grande groundwater basin also known as the Northern Cities Area as defined in the Santa Maria Basin adjudication, shown on **Figure 1**. This area is defined by boundaries based on significant geologic, hydrologic, geographic, and management factors. The study period for the water balance extends from water year 1986 through water year 2004. Average rainfall over this study period approximates the long-term average rainfall and encompasses both wet and dry years to allow assessment of climatic variations in the water balance. The study period makes good use of available data and represents the current state of the basin. Overall, outflows from the groundwater basin are matched by inflows, with no significant change in groundwater storage over the period.

Inflows

Inflows to the groundwater basin include deep percolation from rainfall, return flows from irrigation, storm water infiltration ponds, infiltration through stream beds, and subsurface inflow from adjacent areas. Inflows are variable over the study period and average about 8,500 AFY. Deep percolation, stream infiltration, and subsurface inflow are the major components of inflow and are summarized below.

Stream infiltration along Arroyo Grande represents one-quarter of the average volume of inflow to the basin. The flow in the creek is relatively constant, as flow is controlled by Lopez Dam upstream of the Northern Cities Area. For this analysis, the rate of infiltration was considered constant and thus, the calculated volume of infiltration remained relatively constant on both a monthly and annual scale. However, the stream infiltration rate may vary due to differing stream flow conditions and changing groundwater levels along the stream. More monitoring is recommended to define the infiltration capacity from Arroyo Grande Creek during different times of the year and with different flow conditions. Stream infiltration averages 2,017 AFY over the study period. Other creeks cross the groundwater basin, but the permeable channel lengths are limited and infiltration is considered negligible.

Precipitation that percolates to the underlying groundwater basin is considered deep percolation and occurs over the entire study area. Deep percolation is dependent solely on precipitation and the amount of runoff that occurs. Runoff is greater in areas with a high portion of impervious area such as urban areas where roads, buildings, and parking lots reduce direct infiltration of precipitation. This runoff can be captured by infiltration basins, which is discussed as a distinct water balance element. The area where most of the precipitation results in deep percolation is characterized by native vegetation. Deep percolation occurs only in months with heavy precipitation, usually December to February, and varies greatly based on amount of rainfall. In dry years, zero deep percolation occurs from precipitation. In wet years, roughly half of the inflow is from deep percolation. The estimate of deep percolation could be improved using more detailed information on the portion of impervious cover in urban areas. Reducing the area of impervious cover and expanding infiltration basins to capture runoff could increase the volume of deep percolation, especially in wet years.

Groundwater inflow primarily occurs along the eastern study area boundary, which includes subsurface flow from Nipomo Mesa and through the alluvium along Los Berros Creek. Subsurface inflow may also occur along the northern study area boundary within the alluvial sediments of Pismo Creek, Meadow Creek, and Arroyo Grande Creek. Because of limited data, the estimated volume of inflow is highly uncertain; a reasonable range is from 1,000 to 10,000 AFY. Based on current data, our best estimate of this inflow is approximately 3,470 AFY. Subsurface outflow, discussed in the next section, is similarly uncertain and improved data or assumptions resulting in a modified subsurface inflow estimate would likely result in a similarly modified subsurface outflow estimate. Increase monitoring of water levels and additional geologic studies could provide more information on subsurface inflow and outflow.

Return flows from irrigation and storm water infiltration ponds combined currently represent less than one quarter of the total inflow volume. The average annual contribution is 114 AFY, 990 AFY, and 329 AFY for urban return flows, agricultural return flows, and infiltration basins, respectively. While relatively small, these elements may be the most amenable to local management. Expansion of the storm water infiltration pond system could result in significantly more recharge during wet years. While changes in irrigation practices to improve landscape irrigation efficiency would result in slightly decreased outflows through urban and agricultural pumping, such changes also would result in decreased inflows from return flows.

Outflows

The three components of outflow—urban pumping, agricultural pumping, and subsurface outflow—each represent approximately one third of the total average estimated outflow of about 8,500 AFY. Urban pumping is the water balance element that is best monitored and most amenable to management in terms of volume and location. Urban pumping averages 2,269 AFY over the study period. Agricultural pumping was evaluated based on estimated harvested area of crops and average applied irrigation rates for the area. Few data are readily available on the crop rotations and seasonal variation of agricultural water use and therefore pumping. It is anticipated that the acreage of agricultural in the study area will not change significantly in the future. Agricultural pumping was estimated at 3,300 AFY.

Subsurface flow to the ocean is an important element of the water balance. Groundwater outflow prevents salt water intrusion and ensures the long term sustainability of groundwater supply. The fresh water and sea water are in dynamic equilibrium along the coast. A significant increase in pumping and/or a significant decrease in inflow would decrease subsurface outflow causing sea water intrusion. The extent of intrusion can be estimated analytically or numerically, but the best indicator of the freshwater/seawater interface is sentry wells. Subsurface outflow averages approximately 2,959 AFY.

Safe Yield

Safe yield—the amount of water that can be safely pumped from a basin—is not a fixed number but varies with changing hydrologic conditions and with management practices. While often equated with total recharge (inflow), it is better defined as the portion of total inflow that can be effectively captured by wells and pumped from a basin without causing negative effects. Negative impacts can include chronic groundwater level declines and—in a coastal basin like the Northern Cities Area—seawater intrusion.

In the Northern Cities Area, a single safe yield value of 9,500 AFY is cited in the *2002 Groundwater Management Agreement* among the Northern Cities with subdivisions for agricultural irrigation, subsurface outflow to the ocean, and urban use. This study demonstrates that the *Agreement's* subdivision for agricultural irrigation (5,300 AFY) is higher than the 3,300 AFY used for agricultural over the past 20 years. In addition, the *Agreement's* amount for subsurface outflow (200 AFY) is unreasonably low; the value estimated in this study is approximately 2,959 AFY under current operating conditions. While the minimum amount of subsurface outflow needed to prevent seawater intrusion is unknown, the outflow over the study period apparently has been sufficient because groundwater levels have been stable and above sea level near the coast.

The *2002 Agreement's* allotment for urban use was 4,000 AFY, subdivided as follows:

City of Arroyo Grande	1,202 AFY
City of Grover Beach	1,198 AFY
City of Pismo Beach	700 AFY
Oceano Community Services District	900 AFY

During the study period, total urban pumping averaged about 2,269 AFY and generally increased from about 1,790 AFY to nearly 3,400 AFY, but remained below the 4,000 AFY allotment. The gradual increase in urban pumping has not resulted in detected basin-wide groundwater level declines or seawater intrusion. Accordingly, no immediate change is suggested to the urban allotment of 4,000 AFY. However, realizing that the many of the elements in the water balance are estimates and recognizing the potential for seawater intrusion, it is strongly recommended that monitoring of basin-wide water levels and sea water intrusion through sentry wells be continued and expanded. Specific recommendations are listed in the next section.

Agricultural Conversion

The Settlement Agreement provides that the various urban parties' allocations can be increased through the agricultural conversion credit. A standard method of computing agricultural conversion credit has been developed for adoption by the Northern Cities (see **Appendix D**). Based on application of this method, the agricultural credits for the cities of Arroyo Grande and Grover Beach are 111.9 AFY and 209.0 AFY, respectively.

Recommendations

The water balance described above is intended to support the development of future monitoring programs and management decisions. With more monitoring and investigation in the basin, assumptions used in the water balance can be tested or replaced with data. This will lead to a greater understanding of spatial and seasonal variability in water balance elements. In our opinion, proactive management can increase the yield of the basin without irrevocably damaging the basin, as long as development is incremental and monitored. Key recommendations are described below.

Monitoring

- **Implement a monitoring and reporting program –** Such a program will support future management decisions with regular updating of the state of the groundwater basin.

- **Depth specific monitoring wells** - Sentry wells along the coast can detect changes in water quality and notify of the threat of seawater intrusion. It is recommended that the existing sentry wells be re-employed for monitoring of groundwater levels and quality. Addition of more sentry wells should be considered.

- **Dedicated wells for water level monitoring** - Additional groundwater level monitoring wells, preferably dedicated wells, should be considered as part of a regular monitoring program. Reliable water level data can assist in the estimation of subsurface inflow, outflow, change in storage, and the general state of the basin.

- **Additional stream gaging** - Stream infiltration may vary due to stream flow conditions and changing groundwater levels. More studies performed at different times of the year and with different stream flow volumes are recommended to accurately estimate the infiltration from Arroyo Grande Creek.

Management

- **Use data from the monitoring program to inform management decisions -** A well-crafted and consistent monitoring program can increase the understanding of the basin, provide up-to-date information about the state of the basin, and aid in management decisions.

- **Expand infiltration pond system -** Expansion of the storm water system could significantly increase the amount of water recharged to the aquifer.

- **Manage use of available groundwater and surface water supplies –** The Northern Cities—singly and in combination—have a portfolio of water supplies including Lopez Reservoir, State Water Project, and groundwater. Other potential future sources include desalination and water recycling. Additional monitoring and incremental development of groundwater would support increased understanding of how groundwater can be used in conjunction with other sources, for example through water leases or trades. It should be possible to modify use of these sources to optimize use of Lopez Reservoir and groundwater storage to enhance water supplies in drought.

- **Plan and prepare for prolonged droughts –** In periods of prolonged drought, inflow may be significantly less than outflow due to the lack of deep percolation. At that time, management measures must be implemented to prevent excessive groundwater level decline and seawater intrusion.

- **Assess impacts on groundwater quality from pumping both volume and location -**. Pumping occurs in localized pumping centers in the Tri-Cities Mesa. Future numerical modeling could help redistribute pumping to optimize pumping and minimize potential negative impacts like seawater intrusion or induced inflow of poor quality water from depth.

Introduction

This report provides a water balance analysis for the Northern Cities Area; **Appendix A** provides the working files. The study included three major tasks. The first task involved a thorough review of previous water balances studies. This task documented the methodologies and findings of previous studies, clarified the relevance of previous safe yield estimates, and supported development of the methodology for this Water Balance Study. This review of past investigations and the methodology for this water balance is provided in **Appendix B**. Another task involved a synoptic survey of Arroyo Grande Creek that was conducted to further refine the estimated recharge from the creek. A memorandum describing the synoptic survey and findings is included in **Appendix C**. A third task involved assessment of the current methods used to re-allocate water supply as agricultural lands within the city limits are converted to urban uses. These methods and recommendations on developing a standard method are documented in a technical memorandum in **Appendix D**.

A water balance for a groundwater basin consists of three major elements: inflow to the basin, outflow from the basin, and change in storage of the basin. The difference between the inflow and the outflow over a given study period should equal the change in storage during that period. Change in groundwater storage was estimated independently from water level data, so any residual represents the net error that results from data gaps, estimates, and assumptions. Accordingly, this relationship can serve to determine a reasonable range of values for each element of the water balance and the sensitivity of the water balance to specific elements.

Throughout this report, areas are shown to the nearest acre, and water balance items are shown to the nearest acre-foot (AF). As a result, large numbers may appear to be accurate to four or five digits, which is not the case. Values for data that are measured directly, such as water levels, streamflow, and groundwater pumping, are probably accurate to two or possibly three significant digits. Values for data that are estimated, such as recharge from natural streamflow, recharge from deep percolation, groundwater storage changes, and groundwater inflows and outflows, are probably accurate to only one or two significant digits. All digits are retained in the text and tables to preserve correct column totals in tables and to maintain as much accuracy as possible during subsequent calculations based on the information presented in this report.

Objective

The objective of this updated and independent water balance is to improve the understanding of the groundwater system as a basis for improved monitoring and management. The water balance analysis supports local decision-making with regard to the amounts of groundwater that may be extracted safely under varying natural and human-influenced conditions. The water balance analysis also supports improved monitoring and may provide some of the basis for development of a focused computer model for the Northern Cities. The water balance methodology and data are thoroughly documented in this report, so that the water balance is reproducible and understandable.

A compact disc holding all spreadsheets and data files used to calculate each element is included as **Appendix A**. The level of uncertainty and variability for each element of the water balance is addressed and key assumptions for each element are also listed, recognizing that assumptions were required when locally specific data are lacking. With more monitoring and investigation in the basin, assumptions can be replaced systematically with local data.

Previous Studies

A memorandum to the Northern Cities, *Review of Previous Water Balances and Preliminary Methodology* (Todd Engineers, 2006) provides a review of selected hydrogeologic reports on the Arroyo Grande Basin, focusing on interpretations of the local water balance. This memorandum, included in **Appendix B**, addresses two studies by the California Department of Water Resources (DWR), released in 1979 and 2002, respectively (revised final draft issued in 2000), and two reports by consultants. The review explains how and why published safe yield values differ and describes the methodological basis for this water balance.

Study Area

The water balance was prepared for the Arroyo Grande Groundwater basin also known as the Northern Cities Area as defined in the Santa Maria Basin adjudication and shown on **Figure 1**. This area is defined by boundaries based on significant geologic, hydrologic, geographic, and management factors. This area is similar to the Arroyo Grande Basin study area used as a basis for the 1979 study and subsequent 2002 *Management Agreement* among the Northern Cities, thereby providing a basic continuity. The major difference is extension of the southern boundary to the vicinity of Black Lake Canyon (a hydrologic feature) and simplification of the boundary across the Arroyo Grande Creek valley, which in 1979 extended slightly further up the valley. The main study area encompasses approximately 8,300 acres.

Consideration was given to the spatial impact of each water balance element to support definition of possible management subareas; as indicated on **Figure 1**, faulting is a factor allowing subdivision of the study area for management purposes. Nonetheless, the focus of this study is the larger study area, which will facilitate comprehensive monitoring and management activities that are both legally prescribed and related to water resources systems.

The water balance addresses the groundwater basin; in other words, accounting for inflows and outflows to the basin sediments below the water table and accounting for change in groundwater storage. **Figure 2** illustrates the surficial geology of the area, while **Figures 3** and **4** show geologic cross sections along the eastern and western boundaries of the study area, respectively. As shown, the relatively young, unconsolidated Quaternary formations, including the alluvium (Q), dune sands (Qs), and older dune sands (Qos), are water bearing units and overlie older aquifer units including the Paso Robles Formation (QTpr), Squire member of the Pismo Formation (QTpps) and Careaga Formation (Tpc).

The study area represents a *volume* and defining its boundaries is basic to understanding the inflows and outflows of the water balance. Each boundary is discussed below.

East

Figure 3 shows the cross section marked A-A' on the geology map (DWR 2002). The eastern boundary of the study area is about 23,900 ft. long and extends approximately from the intersection of Black Lake Canyon and Highway 1 to the southern edge of Arroyo Grande Valley at Highway 101. It coincides with the San Luis Obispo County Zone 3 management boundary and also with the northwestern boundary of the Nipomo Mesa Management Area (NMMA) (SAIC 2003). This eastern boundary is considered the only subsurface inflow boundary of the study area, bringing water into the Arroyo Grande basin from Nipomo Mesa and the Los Berros Creek drainage. The estimate of subsurface inflow across this boundary is discussed in detail in the Subsurface Inflow section.

South

The southern boundary of the study area, from the ocean to near the intersection of Black Lake Canyon and Highway 1, extends about 10,400 ft in an east-west line, roughly along Black Lake Canyon. Groundwater contour maps interpreted from water level data in wells across the area indicate that groundwater flow is roughly parallel to this southern boundary. This general trend in groundwater elevation data, along with the presence of surface water drainage parallel to this boundary, suggests that little to no groundwater is flowing across this boundary.

Northwest

The northwestern boundary of the study area coincides with Pismo Creek, running about 2,800 ft. from the outlet of Pismo Creek at the ocean to the intersection of Highway 101 and Pismo Creek. Given the lack of detailed water level data in this area, it is assumed that groundwater flow in the vicinity of Pismo Creek is parallel to Pismo Creek. This assumption is consistent with DWR water level contour maps for 1975, 1985, and 1995 (DWR 2002), which depict water level contours perpendicular to Pismo Creek. This northwestern portion of the study area boundary is therefore considered to be a no-flow boundary in our analysis.

North

The northern boundary of the study area lies along Highway 101 from its intersection with Pismo Creek to the southeastern edge of the Arroyo Grande Valley (approximately 20,200 ft.), and is generally coincident with the Wilmar Avenue Fault. Inflow to the basin may occur within the alluvial sediments of Arroyo Grande Valley and along the drainages of Meadow Creek and Pismo Creek, and from the more consolidated units (Paso Robles Formation, Pismo Formation, or Careaga Formation) into the basin across the Wilmar Avenue Fault. This boundary is discussed further in the Subsurface Inflow Section.

West

The western boundary runs along the coast from Pismo Creek in the north to Black Lake Canyon in the south. This boundary, the only area of subsurface outflow, is depicted in **Figure 4,** a cross section prepared for the subsurface outflow analysis summarized in this report. This boundary is susceptible to sea water intrusion if groundwater levels along the shore decrease. Sea water intrusion is also discussed in the Subsurface Outflow section.

Faults as Groundwater Barriers

Within the Arroyo Grande Basin, one or more faults may act as subsurface barriers to groundwater flow. DWR 2002 notes that "the Santa Maria River Fault may affect groundwater flow in parts of the basin" and that "from east of Highway 1 to about a mile east of Zenon Way, significant differences are found in groundwater elevations on opposite sides of the Santa Maria River Fault." Well data analyzed for this project generally corroborate this finding of significant groundwater elevation differences across the Santa Maria River Fault to the east of the study area. However, it is unclear if water levels taken across the fault are from wells in equivalent formations. Additionally, it is possible that the Santa Maria River Fault may act more as a barrier to groundwater flow within older formations, but less so or not at all in overlying alluvium, as appears to be the case with the Wilmar Avenue Fault to the north. The Oceano Fault also has the potential to act as a barrier to groundwater flow. However, without detailed groundwater elevation measurements from equivalent formations on either side of the Santa Maria River or Oceano faults, it is not possible to document the extent to which these faults act as barriers to groundwater flow.

Study Period

The study period for the water balance extends from water year 1986 through water year 2004. **Figure 5** shows the precipitation at the Pismo Beach Station from 1950 to 2005. Average rainfall over this study period (16.84 inches) approximates the long-term average rainfall (16.9 inches) and encompasses both wet and dry years to allow assessment of climatic variations in the water balance. The study period makes good use of available data and represents the current state of the basin, including the changing management of flow releases from Lopez Reservoir in recent years for the seismic retrofit and habitat conservation plan.

Inflows

Inflows to the groundwater basin include deep percolation from rainfall, return flows from irrigation, storm water infiltration ponds, infiltration through stream beds, and subsurface inflow from adjacent areas. The following paragraphs summarize each inflow, describe the method used to estimate the inflow and the results, and provide a discussion of the inflow, including assumptions and uncertainty with recommendations to improve the estimate. **Table 1** summarizes the entire water balance analysis on an annual basis, while **Table 2** provides a monthly summary.

Stream Infiltration

Stream infiltration is the volume of water that percolates through a streambed into the aquifer. Streams may either be gaining streams (where groundwater discharges to the surface) or losing streams (where surface water recharges the groundwater). Arroyo Grande Creek is a losing stream over most of the Arroyo Grande groundwater basin (from the USGS gage located just north of Highway 101 to the 22nd Street Bridge) and then becomes a gaining stream as it nears the ocean. Other streams in the area, Los Berros Creek, Meadow Creek, and Pismo Creek, are also losing streams along all or portions of their streambeds. However, the permeable channel lengths are limited across the study area and infiltration is considered negligible. The volume of water infiltrating to the groundwater is dependent on the permeability of the streambed material, the area of streambed, and the flow regimen of the streams. **Figure 1** shows the major local streams and stream gages in the study area.

Method

The rate of stream infiltration in Arroyo Grande Creek is not well known. Two studies have been performed to measure the infiltration rate.

Todd Engineers measured the creek and calculated infiltration on April 18, 2006. Flow was measured at three stations on Arroyo Grande Creek and at one station on Los Berros Creek, shown on **Figure 1**. Velocity measurements were taken using a current meter at several points along the creek channel and at two depths to account for variation in stream flow. The total calculated difference in flow from the USGS Gage to the Highway 1 Bridge, accounting for flow from Los Berros Creek into Arroyo Grande Creek, was 2.2 cubic feet per second. This difference is assumed to be the net amount of surface water that percolates to the aquifer. The study was performed after a particularly wet period, which may have resulted in a relatively low calculated infiltration. A short-term condition of high groundwater levels may have reduced infiltration, or shallow groundwater seepage into the creek may have masked the deep infiltration.

The only other stream infiltration study was conducted on Arroyo Grande Creek by Hoover and Associates and included as an appendix to a report by Lawrance, Fisk & McFarland. The study was based on two observations in June 1984: one day of very low flow and one day with flow close to 3 cubic feet per second (cfs) at the Arroyo Grande USGS gage. The location of the USGS gage and the 22nd Street Bridge are shown on **Figure 1**. The Hoover study reported 3.01 cfs infiltrated between the USGS gage and the 22nd Street Bridge, based on observations of flow at a series of points on the creek. The Hoover study estimated an average streambed infiltration of about 1.55 ft/day average along the Arroyo Grande creek stream bed from the USGS gage to the 22nd Street Bridge. The reach of the creek with the highest infiltration rate is located between the Fred Grieb Bridge and the Highway 1 Bridge. As the study is based on a single day and a flow rate of 3 cfs, it may not be applicable to greater flows along the creek (Lawrance, Fisk & McFarland, 1985). In the report, Hoover indicated that increased stream flow may result in increased infiltration as the width and head of the stream is increased. However, based on the field measurements taken by Todd Engineers, this may not be the only factor controlling infiltration.

Other estimates of stream infiltration have been used in previous studies. An estimate of 5 cfs infiltrating along the channel from the USGS gauge to the 22nd Street Bridge is generally used by the San Luis Obispo Flood Control District and is based on operating knowledge of Lopez Reservoir releases.

To determine the volume of stream infiltration, the actual monthly flow of the creek was examined and compared to an infiltration rate (3 cfs or 5 cfs). If the flow in the creek was greater than the estimated rate, then it was assumed that infiltration equaled that rate. If flow was less than the rate, it was assumed that the entire flow infiltrated to the groundwater. Both 3 cfs and 5 cfs were calculated separately to examine the possible variation in stream flow.

Results

The two rates were used to calculate stream infiltration on a monthly basis. The results on an annual basis are shown on **Figure 6**. The 3 cfs infiltration estimates show little variation from year to year, ranging from 2,046 AF to 2,450 AF. Because Lopez Dam controls flow to Arroyo Grande Creek, the flow in the creek over the study period has remained fairly constant, and accordingly the 3-cfs infiltration is relatively constant. The estimated infiltration volume is similar in dry years and wet years. The estimate of 5 cfs introduces greater variability, as shown in **Figure 6**. The 5-cfs based infiltration estimates range from 2,354 AF to 3,898 AF with an average of 3,100 AFY. Stream infiltration shows little variation seasonally.

Based on available data, the estimate based on 3 cfs appears the most reasonable in the context of the overall water balance, so these results are shown in the annual summary of the water balance in **Table 1.** Average annual infiltration amounts to 2,017 AFY. The average monthly infiltration is shown in **Table 2**. Lopez Reservoir releases water to maintain year-round flow in the creek, preserve habitat, and contribute to the local groundwater basin. As a result, infiltration per month averages 235 AF.

Discussion

Comparison of the water balance elements in Table 1 indicates that stream infiltration is one of the single largest sources of inflow to the groundwater basin. Accordingly, it warrants careful consideration. It is important to note that the estimate of stream infiltration is based on three major simplifying assumptions:

- The infiltration rate is 3 cfs along Arroyo Grande Creek.
- The infiltration rate remains constant over study period.
- No significant infiltration occurs from other creeks.

Stream infiltration varies due to stream flow conditions, groundwater levels, and pumping near the creek. In addition, on any given day, urban and agricultural runoff also may flow into the creek and complicate infiltration estimates. Yet, only two surveys have been conducted to evaluate the infiltration rate along Arroyo Grande creek. Additional studies—performed at different times of the year and under different flow conditions—are recommended to improve the accuracy of the stream infiltration estimates. In addition, no data are available on infiltration rates along the smaller creeks; extension of stream surveys to these smaller creeks may show some additional recharge to the aquifer.

It is also noteworthy that stream infiltration is a water balance element that is readily managed through changes in releases from Lopez Reservoir and changes in groundwater pumping locations and amounts. During the study period, changes occurred in the management of Lopez Reservoir releases, which represent a significant portion of the flow in Arroyo Grande Creek. Most notably, the habitat conservation plan (HCP) for the creek resulted in increased flow during fall and winter months. Average HCP releases are only 0.3 AF per month different than previous releases. This difference has not substantially affected recharge to the groundwater basin.

Deep Percolation

Deep percolation from precipitation is the amount of precipitation (rainfall) that falls on the ground and infiltrates through the soil to the underlying water table. In the Arroyo Grande Basin, deep percolation contributes a significant portion of the inflow. The volume of deep percolation is influenced by the amount and intensity of precipitation, soil type, topography, vegetation and evapotranspiration, hydrogeology of the vadose zone and aquifer, and area of impervious cover. Because the portion of rainfall reaching the water table is based on multiple characteristics, the volume can vary greatly over time and space and thus is calculated with significant uncertainty.

Method

Deep percolation was calculated over the study area through a runoff analysis and soil moisture balance. The runoff analysis used the SCS curve method to estimate the amount of precipitation resulting in runoff based on land use type, soil type, and precipitation amount. The soil moisture balance examines the portion of precipitation that does not result in runoff and determines the amount that will recharge the aquifer.

Data used in the SCS curve method to estimate runoff include precipitation amounts, land use and soil type. Rainfall data from the Pismo Beach station were collected from the National Oceanic Atmospheric Association's (NOAA) National Climatic Data Center (NCDC). Land use also plays a role in the calculation of deep percolation. The Department of Water Resources 1996 Land Use Map was used to calculate the area of general land use types (truck crops, pasture, urban, and native). Urban areas contain significant amounts of impervious areas including structures, parking lots, streets, sidewalks, and other paved areas. Precipitation that falls on these impervious areas is often captured by storm water systems. Some of the captured storm water may recharge the aquifer through infiltration ponds. This captured storm water is discussed separately in the Infiltration Pond section of this report.

Soil moisture holding capacity was derived from the San Luis Obispo County soil survey performed by the National Resource Conservation Service (NRCS). The soil types were divided into two categories based on soil moisture holding capacity: high soil moisture holding capacity and low capacity. **Figure 7** shows the locations of these two groups and **Table 3** summarizes the extent and soil moisture holding properties of each soil type.

Soils with high soil moisture holding capacity include the Marimel and Camarillo clay loam and sandy loams that occur primarily on the south side of Arroyo Grande Creek and along the boundary with Nipomo Mesa. Soils in the low capacity group are sandy, hold less moisture for ET, and thus are associated with more percolation. Note the broad extent across the study area. The soil moisture capacity of the low category is an average (weighted by area) of the remaining soils, mainly sandy soils. To accurately estimate the deep percolation, the study area was divided into eleven unique categories. Each area included a soil type, storm water drainage system, and land cover type (i.e., low capacity urban, low capacity agriculture/truck farming, high capacity urban, high capacity agriculture/truck farming).

The Curve Number runoff analysis was developed by the SCS (now the Natural Resources Conservation Service, NRCS). The method is described in the document, *Technical Release 55* from the U.S. Department of Agriculture (USDA 1986). Direct runoff (Q) is calculated as a relationship between rainfall (P), the potential maximum retention after runoff begins (S), and initial abstractions (I_a). Initial abstractions include water that is captured before it is able to runoff. This initial abstraction includes plant interception, initial infiltration, and surface storage associated with ground cover and can be expressed as a percentage of the maximum retention. For the purposes of this study, initial abstractions were assumed to be 20 percent of the maximum retention.

The potential maximum retention is estimated using a coefficient, or curve number (CN). The curve number is based on the land use and soil type. The curve number also accounts for the percent of impervious area typical to the associated land use. The soils in the area were divided into two groups: sandy soils with low soil moisture holding capacity (soil group A) and silty sandy loams with high capacity (soil group C). Different curve numbers were used for the ten categories, shown in **Table 4**.

The urban areas could be subdivided into categories such as industrial, roads and parking lots, parks, high density residential and low density residential. A weighted average of the curve numbers for each type was used. The percent of the urban area each category cover was based on aerial photos and extent of impervious area and shown in the table below. The area was treated as a mix of medium to high density single family homes, with 65 percent of the area estimated as impervious for high density and 35 percent impervious area estimated for medium density (Purdue 2006). Other estimates of impervious area in urban area range from 6 percent for lower density residential homes to 50 percent for commercial uses (Rantz, 1971).

Urban	%	A	C
High Density Single Family Homes	50	77	90
Medium Density Single Family Homes	20	61	83
Commercial/multi-family	20	89	94
Parks/open space	10	49	79
Urban Curve Number	**100**	**73.4**	**88.3**

The direct runoff was calculated monthly and subtracted from actual precipitation to get the effective precipitation, P_E (precipitation – runoff). It was assumed that all water not resulting in direct runoff is available to meet the evapotranspiration demands, contribute to soil water capacity, and recharge the aquifer. As the curve number differed by category, the effective precipitation also varied. The method is primarily designed for single events but is commonly used to predict runoff up to an annual scale. The following equations were used to calculate effective precipitation:

(1) $$Q = \frac{(P - Ia)^2}{(P - Ia) + S}$$

(2) $$Ia = 0.2S$$

(3) $$S = \frac{1000}{CN} - 10$$

(4) $$P_E = P - Q$$
$$P_E >= 0$$

Once the effective precipitation was calculated (precipitation less runoff), a soil moisture balance was performed. The soil moisture balance has two basic steps. The first calculates available water by subtracting interception and evapotranspiration (ET) demands from the effective precipitation. The second step examines the amount of available water that would be held in storage by the soil. The remaining water is assumed to recharge the aquifer as deep percolation. The basic formula of a soil moisture balance can be defined as:

Deep Percolation =
Effective precipitation - interception - evapotranspiration - soil moisture storage

For this analysis, this equation is applied on a monthly time step. The soil moisture storage value represents the amount water stored in the soil that is available to the plants. Traditionally, soil moisture balances use an interception value to account for precipitation that is intercepted by trees or other plants and prevented from directly contacting the soil. As most of the study area is dune land, urban areas, or low lying plants the amount of precipitation lost to interception was considered negligible. Interception in the recharge analysis should not be confused with the initial abstraction value in the runoff analysis. Initial abstractions include surface storage that occurs immediately, thus capturing precipitation before it can result in runoff.

The Arroyo Grande Basin is characterized by multiple land cover types, each with a unique ET demand. **Table 5** shows the types and the applied monthly ET coefficient. The area is divided into five types: urban landscaping (turf), agricultural land with truck crops, agricultural land with pasture, native riparian vegetation, and bare ground. The coefficient (K_{co}) and the reference ET (ET_o) are multiplied to determine the potential ET of the land cover. Potential ET refers the amount of water a plant or type of land cover could consume given sufficient water at all times. Actual ET is limited by the amount of water available from precipitation and soil moisture. During the winter months, rainfall often exceeds potential ET, so the plant's water needs are fully satisfied and actual ET is equal to potential ET. Reference evapotranspiration (ET) data from California Irrigation Management Information System (CIMIS) San Luis Obispo weather station was used. Actual potential ET data was used from April 1986 to September 2004 and monthly average ET data was applied to October 1985 to March 1986.

As noted previously, the soil moisture capacity was derived from the San Luis Obispo County soil survey. The capacity of each soil type was calculated using the entire rooting depth and specific soil moisture capacities for each depth zone presented in the soil survey. Soil types were divided into the same two categories as the runoff analysis, high soil moisture holding capacity and low capacity. The soil moisture capacity of the high category is an average (weighted by area) of Marimel and Still gravelly sandy clay loam soil types, 6.23 in. Camarillo was not included in the average as it only accounts for 0.01 percent of the study area. The soil moisture capacity of the low category is an average (weighted by area) of the remaining soils, 1.94 in.

The soil moisture balance was applied on a monthly time step to areas of unique soil type and land cover to determine the rate of percolation for each area. The rate of percolation was then applied to each area to calculate the total volume of recharge. **Table 6** summarizes the areas of each land use and soil type, while **Figure 8** shows the general areas of these land cover groups. Agriculture overlies the area of high moisture capacity soils.

Results

Figure 9 shows the annual deep percolation over the study period. Not unexpectedly, the amount of deep percolation varies based primarily on the amount of precipitation. In dry years, like 1990, no deep percolation occurred and all precipitation was consumed by ET or resulted in storm water runoff. In wet years, like 1998, deep percolation was about 5,700 AF. The average deep percolation for the study period is 1,300 AF. The average is greatly influenced by a small number of wet years.

Also, because deep percolation is based on precipitation, much more percolation occurs in the wet season versus the dry season, as demonstrated in **Table 2,** which shows the average deep percolation for each month. An average of 14 times more infiltration occurs during the wet season (October through March) than the dry season (April through

September). Often winter rains are sufficient not only to satisfy plant's potential ET demands, but also to fill soil moisture storage, and yield additional water. This additional water recharges the groundwater basin as deep percolation.

Figure 9 also shows the deep percolation by land use type. As indicated, most of the deep percolation occurs on native vegetation and bare ground (mostly dunes), with minor deep percolation of rainfall on agricultural land and urban landscaping. Comparison of **Figures 8** and **9** indicate that a substantial portion of the deep percolation occurs in the southernmost portion of the study area.

A major assumption that controls the calculation of deep percolation is the analysis of runoff. The curve number method provides an estimate of runoff based on soil type and land use. As discussed above, the urban portion of the study area was based on a mix of urban uses, assuming a preponderance of relatively high density land uses. To illustrate the range of deep percolation based on the urban uses, the analysis was performed using a curve number representing a less dense urban community with 35 percent impervious area and a more dense urban community with 65 percent impervious area. The annual estimated deep percolation based on these assumptions is shown on **Figure 10.** This exercise illustrates the uncertainty of the deep percolation analysis and a need for additional data on the area of impervious surfaces.

Another factor in deep percolation is the character of the underlying geology. The basin is characterized by alluvium and dune sands overlying terrestrial and shallow marine sedimentary deposits, and the occurrence of discontinuous clay layers within the study area. These clay layers are difficult to correlate and are likely not continuous throughout the basin (DWR 2002). This indicates that the clay layers most likely do not act as pervasive aquicludes and do not form significant barriers between aquifers. Percolating water (from deep percolation, infiltration ponds, and return flows) will work its way around these clay layers under the influence of gravity to join the main groundwater body. At the scale of the basin, the only significant effect of these clay layers on percolating water would be to slow its downward velocity, but not to significantly influence the rate or total quantity of deep percolation.

Discussion

Evaluation of groundwater inflow from deep percolation is based on a number of variables. The key areas of assumptions in the analysis are listed below:

- Selection of Runoff Curve Number
- Evaluation of Monthly ET of crop cover and native vegetation
- Assumption that all deep percolation reaches the water table.

As discussed above, the curve number method was used to calculate the amount of precipitation resulting in runoff. The curve numbers in most cases were selected based on average curve numbers reported by NRCS. The curve number for urban areas was based on an approximate mix of urban uses. Local data on the distribution of urban uses and the observed percentage of runoff from precipitation events would provide a more accurate estimate of the amount of runoff and available water for percolation. The soil moisture balance was used to determine the amount of water consumed by plants through ET. Coefficients for ET of various types of vegetation were estimated by land use; additional data could improve the accuracy of the estimated deep percolation. Portions of the urban storm water systems are designed to capture rainfall-derived runoff from urban landscaped areas and convey the water to infiltration ponds. Although these diversions are not specifically calculated, it is assumed that the volume of water available for deep percolation is the same with and without the runoff diversions, but that the deep percolation would occur in a different location (i.e., the infiltration basins).

In terms of timing, deep percolation from precipitation is the most highly variable aspect of the water balance. Wet years provide up to 5,800 AF of recharge, while some dry years provide no recharge. Most of the percolation occurs in the winter months. Because of the seasonal and annual variability, a large portion of the basin inflow during the study period occurs over the period of a few months. In periods of prolonged drought, inflow may be significantly less than outflow because of lack of deep percolation, suggesting that monitoring and management would be needed to prevent excessive groundwater level declines and even sea water intrusion.

In terms of spatial variation, deep percolation is relatively widespread across the study area. It is useful to emphasize here that the water balance elements for this study are expressed in terms of the entire study area. However, some elements of the water balance are areally extensive (such as deep percolation) and others are areally limited or localized (such as urban pumping). Clearly, deep percolation in the southern study area cannot be assumed to be available to wells in the northern portion. In addition, faults in the study area (specifically the Santa Maria River Fault and the Oceano Fault) may act as impediments to groundwater flow such that percolation on the southern side of the fault may not contribute recharge to northern side. Hydrogeologic data including geologic and geophysical logs, pumping test information, and water level data are particularly scanty in the area around the faults. More information is needed to fully characterize the significance of the faults as boundaries in the study area.

Infiltration Basins

Precipitation that falls on much of the impervious urban area is routed to infiltration ponds or other storm water collection systems. Both the Cities of Arroyo Grande and Grover Beach maintain infiltration ponds to capture runoff and infiltrate the water to the groundwater basin. The City of Arroyo Grande divides the city into three major zones, drainage zones A, B, and C. Zone A is the tributary area to existing infiltration basins and encompasses approximately 670 acres (37 percent of the City's surface area). The drainage zone overlies sandy soils with an infiltration rate estimated at 6 inches per day. If a rain storm occurs such that the infiltration basin overflow, the excess water is diverted to local creeks. Zone B overlies clay rich soils and infiltration basins are not as effective. Storm drains in Zone B direct runoff to local creeks. Zone C is located on the hills north of Highway 101. Most the drainage area does not overlie the aquifer, but runoff may flow to the Arroyo Grande basin area.

Figure 11 shows the infiltration basins in the area, while **Table 7** conveys relevant information about the basins. Currently, Arroyo Grande has eight infiltration basins overlying the study area, including some privately operated infiltration basins. Most are connected through pipelines and pumping stations. Six of these basins have been in use for the entire study period. Two ponds have recently been added to the system and are included in the estimates of percolation from infiltration basins only during the years they were in operation. The tributary watersheds of the various basins range from 10 acres to 457 acres. They are designed to accommodate runoff for most storms and in the event of overflow, the excess water is diverted to local streams. Grover Beach currently has one infiltration basin located on Mentone Avenue. The City of Grover Beach is currently redesigning their storm water system and may build new infiltration basins in the future.

Method

The percolation from storm water diverted to the infiltration basins in the Arroyo Grande Basin was estimated through precipitation data, calculated runoff, the ponds' tributary area, capacity of the ponds, and approximate infiltration rates. Information on the capacity or the tributary watershed of Grover Beach's Mentone pond was not available, so the information was extrapolated from Arroyo Grande. The 'footprint' area of the Mentone Avenue pond is about half that of the nearby Soto Complex/Ash Avenue ponds in Arroyo Grande. It was assumed that both the capacity and tributary area were also half that of the Soto Complex/Ash Avenue ponds.

Using a monthly time step, the amount of runoff was calculated using the SCS curve number method described in the deep percolation section. The rate of runoff (inches per month) was multiplied by the total watershed area of the infiltration ponds to obtain the total of volume available for percolation (AF per month). The storm water system of the City of Arroyo Grande is in excellent condition and it is assumed that only minimal losses occur from the time the rainfall hits the ground to the time it enters the infiltration pond. It was assumed that the storm water system directing water to the Grover Beach Mentone Avenue pond is equally effective. For this analysis, 10 percent of all runoff is assumed to be lost due to wetting pavement, ET, and other unavoidable losses. The volume of runoff assumed to reach the ponds was then compared with the ponds' total capacity. If the amount of runoff was greater than the capacity, then the remainder was assumed lost to local creeks. It was assumed that all runoff captured in the ponds would infiltrate over the monthly time step.

To test the appropriateness of the monthly time step, another approach was applied to calculate the infiltration from the six Arroyo Grande basins on a daily time step. The volume of available storm water runoff was calculated using daily precipitation records from Pismo Beach and the area of impervious surfaces in the tributary watersheds. Once the volume of available storm water was calculated, it was compared with the storage capacity of the ponds. The capacities of the operating ponds were summed, recognizing that each is sized correctly for its given watershed or the ponds are linked such that spill water from one pond can be diverted to other ponds not yet at capacity. To examine the infiltration in each pond, the daily volume of storm water and existing water in the system (from previous daily rainfall) was combined and compared to the ponds' collective capacity. If the total incoming storm water and the existing water volume in the ponds exceeded the ponds' capacity, the volume was assumed to be equal to the capacity. In the event of runoff exceeding the ponds' capacity, excess flow was assumed lost to local creeks. The daily analysis revealed that runoff would exceed the ponds' capacity only in major rainfall events such as occurred in March 1991 and February 1998. During these wet conditions, the monthly analysis showed a similar amount of overflow from the ponds. Because there appears to be ample capacity in the ponds on a daily basis, the monthly analysis reasonably simulates percolation from the infiltration basins.

Results

Recharge through the infiltration basins occurs during rain events and thus varies seasonally and annually. **Figure 12** shows the annual percolation from the infiltration basins. The average amount of infiltration from the ponds that existed during the study period was 175 AFY. In 1990, a dry year, only 47 AF of collected storm water infiltrated. However, during the extremely wet year of 1998 the maximum infiltration was 773 AF. Because storm water and thus the water in the infiltration ponds are from rainfall, there is a significant seasonal variation. **Table 2** shows the average deep percolation for each month. An average of 10 times more infiltration occurs during the wet season (October through March) than the dry season (April through September).

The current infiltration basin can be expanded to collect more of the storm water for the Cities of Arroyo Grande and Grover Beach. Infiltration ponds also would be beneficial in Oceano. **Figure 13** shows how much storm water is not captured by the infiltration ponds through overflow of existing ponds or lack of ponds in some areas of the basin. For the purposes of calculation, only storm water on the sandy soils was considered, because the clay loam soil on the eastern side of the basin is less likely to be conducive to infiltration. Approximately 20 percent of all runoff is currently captured by infiltration ponds. An average of 131 AFY is lost due to overflow from existing ponds and another 1,070 AFY of runoff occurs from areas not tributary to the existing ponds.

Discussion

The estimate for recharge from infiltration basins was based on the runoff calculation prepared for the deep percolation analysis. The runoff was considered to be all the storm water in the urban tributary areas. As discussed in the deep percolation section, the curve number analysis for urban areas assumes an approximate mix of urban uses. Other assumptions include the effectiveness of the storm water system for transporting water, the effectiveness of the pond infiltration rates, and the likelihood of basins overflowing due to large amounts of precipitation. In addition, no information was available for the City of Grover Beach's Mentone Avenue ponds and estimates were made regarding its watershed area and capacity. The key assumptions for the infiltration basin analysis are summarized below:

- Runoff calculated through the curve number method adequately represents actual runoff.
- 90 percent of all runoff in the tributary area is captured in the ponds.
- Water in the ponds is able to percolate within the monthly time step.

- The volume and watershed area for the Mentone Avenue basin can be extrapolated from that of nearby Soto Complex/Ash Avenue ponds.

Infiltration basins are a good example of effective management for the groundwater basin in addition to good storm water management. The basins allow storm water that would otherwise be lost to the ocean to recharge the groundwater basin. The current infiltration basins only collect approximately 15 percent of the total storm water in the study area. While recognizing that the most cost-effective infiltration system exists already, the opportunity exists to capture and recharge additional storm water runoff up to 1,000 AFY. The cities of Arroyo Grande and Grover Beach are currently enlarging and improving their infiltration pond systems and the volume of water recharged from these ponds is expected to increase in the future. These and other expansions to the infiltration basin system will result in more inflow to the groundwater basin.

Return Flows

When land is irrigated, either for agricultural or urban uses, most of the water is consumed through evapotranspiration, but some water may percolate to the underlying water table. Urban return flow may also include leakage from septic systems, municipal pipelines, or other urban uses. **Figure 8** shows the general land use of the Northern Cities area. Percolation from irrigation in the urban areas is described as urban return flow. The agricultural area represents where agricultural return flow occurs. It should be noted that deep percolation of precipitation on agricultural and urban land is accounted for separately to avoid redundancy with the return flow from applied water.

Urban Return Flow

Method

Urban outdoor water use generally includes watering lawns and gardens, filling swimming pools, and other water uses in an urban area. For the purposes of this study, the urban area is considered any area served by municipal water. Although a small amount of agriculture still exists with the city limits, it is supplied by private wells and is not included in this analysis of urban return flow. The analysis of urban return flow examines the total water used for outdoor uses in urban settings and the portion of that water that percolates to the water table.

Because different customer types use a different portion of water outdoors, the distribution of customer type in each city was examined. Customer types include single family homes, multiple family homes, commercial and/or industrial uses, and landscape irrigation. The portion of each city overlying the aquifer was also considered as the City of Pismo Beach and the City of Arroyo Grande are not located completely with the study area boundary. The total water served to each customer type in the study area was calculated. The portion used outdoors was estimated and then the portion that percolates was calculated.

Each city (Arroyo Grande, Grover Beach, and Pismo Beach) prepared Urban Water Management Plans (UMWPs) in 2000 and 2005 which present the distribution of total water served to each customer type. Reported customer types include single family homes, multiple family home, commercial and/or industrial uses, and landscape irrigation. The volume of unaccounted-for water is also included in the UWMP. Water is lost from the system through leaking pipes or other losses. In the 2000 UWMPs, the distribution for each city was given for the years 1990, 1995, and 2000. Each city's distribution did not change significantly over time. The average percent of the total water served to each customer type was calculated. **Table 8** summarizes the distribution by city and customer type.

Oceano Community Services District is not required to prepare an UWMP and no information is available on the distribution by customer type. In order to estimate the distribution by customer type, the number of units in Oceano was researched. According to the US Census, in 2002 there were 1,121 owned housing units and 1,318 rented housing units. It was assumed most rented housing units are multi-family homes and most owned units are single family homes. While Oceano is estimated to have more multi-family units, single family homes generally use more water than multi-family units. Accordingly, it was assumed that the volume of water served to all single family customers was similar to that provided to all multi-family customers, 40 percent of the total system for each. Other uses were assumed to be similar to the neighboring cities, 10 percent for commercial customers, 5 percent for irrigation, and 5 percent for unaccounted losses.

Each customer type uses water differently. To estimate the amount of water used outdoors, the percent of outdoor use by each customer type was examined. **Table 8** shows the percent of water used outdoors by customer type. According to the Department of Water Resources, the indoor/outdoor split in the Arroyo Grande area for multiple family homes is 90 percent indoors and 10 percent outdoors (DWR applied water). This split is expected to be similar to commercial properties as well. Estimates on the indoor/outdoor split for single family homes vary greatly. The DWR website cites 88 percent used indoors and 12 percent used outdoors for the Arroyo Grande area (DWR applied water). The U.S. Environmental Protection Agency estimates that 37 percent of residential water use is used outdoors. For the purposes of this analysis, 37 percent was used.

Only water applied to land overlying the aquifer will percolate to the groundwater. The analysis began with a calculation of the portion of each city overlying the aquifer. The City of Grover Beach and Oceano Community Service District both are completely within the study area boundaries, thus any water applied outdoors may percolate to the water table. Approximately 36 percent of the City of Arroyo Grande is in the study area. It was assumed the distribution of customer type in the portion of the city overlying the aquifer is similar to the distribution of the entire city.

Only four percent of Pismo Beach is in the study area. According to the City of Pismo Beach, water is served to six communities that overlie the groundwater basin. These are mainly RV and mobile home parks. In 2005, these communities were served 104.8 AFY, 5 percent of the total Pismo Beach water system. Because only Pismo Beach serves only multifamily customers in the study area, **Table 8** shows that five percent of the total Pismo Water supply is served to multi-family homes.

Once the distribution of customer type and the area of the city with the study area were calculated, the water served to each customer type in all four municipalities was totaled. The total supply to each city for each month was divided among the customer types. The total water supply included all sources of water: groundwater, deliveries from Lopez Reservoir, and deliveries from the State Water Project. Data on the Oceano CSD SWP water supply were not available and were not included in the analysis. The water supplied to each customer type in each city was totaled to obtain the total water served to that customer type in the study area. For example, for single family water use, 36 percent of the total water supply for Arroyo Grande was used as total water supply to the area. The portion of the City of Arroyo Grande within the study area serves approximately 71 percent of the supply to single family customers. Grover Beach and Oceano supply 59 percent and 40 percent of the total supply to single family customers respectively. The volume of water served to single family customers from all municipalities was summed.

Urban irrigation is usually applied to meet the ET demands of landscaping. The portion of applied water that exceeds the ET demand results in urban return flow to the aquifer. A perfect irrigation system will apply just enough water to exactly match the ET needs of landscape and have no return flow. It was assumed that the average irrigation system is 90 perfect efficient, meaning that 10 percent of applied water results in return flows to groundwater.

In addition to applied irrigation on urban land, leaking pipes can provide recharge. The UWMPs provide data on unaccounted-for losses and these data were used to estimate the inflow to the basin from pipeline leakage. It was assumed some of this water is lost to evapotranspiration and an estimated 10 percent of the un-accounted water reaches the aquifer. Unaccounted water often includes meter problems, fire protection, hydrant flushing, as well as pipeline leaks. For this analysis it was assumed 50 percent of unaccounted water resulting in additional flow to the soil.

Results

Figure 14 shows the volume of urban return flow per year over the study period. The percolation from urban irrigation is fairly consistent over the study period. The average volume was 114 AFY and the annual values ranged between 101 AFY in 1986 and 140 AFY in 2002. Because it was assumed the distribution of customer types in the area remained the same over the study period, the amount of urban return flow varied only due to the change in total water supply to the area. Approximately 2.8 percent of total water supply results in urban return flow to the water table in the study area. Urban return flow varies seasonally with 1.5 times more return flow percolating in the dry summer months than the wetter winter months. This variation is expected as more irrigation occurs in the dry summer months.

As discussed above, the percentage of water use outdoors controls the volume of urban return flow. Estimates for the portion of total residential water demand used outdoors varies from 30 percent to 60 percent depending on the geographic location and type of community (Gleick 2004). For the purposes of the water balance, 37 percent of all single family water use was applied as irrigation. **Figure 15** shows the amount of urban flow assuming various percentages of single family outdoor use (12, 37, and 50 percent). The average return flow varies from 66 AFY to 155 AFY.

Discussion

Urban return flows result from irrigation water that is not consumed through ET. The amount of irrigation applied for urban landscapes varies by each user and their return flows also vary. Assumptions were made for the calculation of urban return flow to approximate average use and simplify the analysis. Key assumptions include:

- Arroyo Grande usage is similar throughout the City.
- Customer type distributions remain the same over the study period.
- No significant change in usage occurs seasonally.
- The portion of water supply used outdoors is 37 percent for single family homes and 10 percent for multi-family, commercial, and industrial uses.
- Urban irrigation efficiency is 90 percent.
- Fifty percent of unaccounted water represents pipeline leaks.
- State Water Project deliveries to Oceano would not significantly change the return flow estimates.

Urban irrigation may increase in the summer to compensate for the lack of precipitation. For this analysis, an average portion of total water supply was applied and no adjustment was made seasonally. However, since water supply is greater in summer months the fixed percent of total water supply resulted in greater irrigation use during this time. Accuracy of this analysis would be improved through documentation of the portion of water used outdoors by each customer type, urban irrigation efficiency, seasonal patterns of irrigation, and water use for the portions of Arroyo Grande overlying the groundwater basin.

Agricultural Return Flows

Method

Agricultural return flows are based on total amount of applied water and irrigation efficiencies. A grower applies enough water to satisfy the ET demand for a given crop. A perfectly efficient grower would apply only enough water to satisfy that need. Once the ET demand is satisfied, the remaining applied water is assumed to percolates to groundwater as agricultural return flow.

The DWR agricultural water use expert for the Southern District, Robert Fastenau, estimates that irrigation efficiencies in the area range from 70 to 85 percent, meaning that 15 to 30 percent more water is applied than needed to meet the ET demand (Fastenau, personal communication, 2006). In the study area, most farmers use sprinkler irrigation in the beginning of the growing season and drip irrigation for the remainder of the season. The different irrigation methods vary in efficiency; sprinklers have an efficiency rate of

70 percent and drip irrigation is more efficient at 85 percent. Due to improved irrigation methods, a relatively insignificant portion of the applied water results in runoff.

Consumed fraction is a similar concept representing the portion of applied irrigation that is consumed by the plant through ET. According to the DWR website, the average consumed fraction for truck crops in the Arroyo Grande area from 1998 to 2002 was approximately 70 percent. The remaining 30 percent represents agricultural return flow. Agricultural return flows in the basin were calculated based on the applied water and the consumed fraction. The methodology to estimate applied water is discussed in the Agricultural Pumping section. Based on the consumed fraction data, 30 percent of the calculated applied water percolates to groundwater.

Results

Agricultural applied water was estimated as 3,300 AFY, as discussed in detail in the Agricultural Pumping section. Based on the consumed fraction reported by DWR, 990 AFY would return to the aquifer through agricultural return flow. As agricultural pumping was calculated on an average annual basis, agricultural return flow could not be estimated beyond an average annual basis. Return flows are not considered to vary greatly on a monthly basis.

Discussion

Key assumptions in the analysis of agricultural return flow include:

- Evaluation of applied water (see Agricultural Pumping)
- Irrigation Efficiency/Consumed Fraction is 70 percent
- No return flows occur as runoff.

Agricultural return flows are estimated based mainly on applied irrigation and irrigation efficiency. Local data for irrigation efficiencies in the study are not readily available but future studies may provide more information. This element is a relatively small portion of the overall water balance and additional data will not significantly change the estimated volume of return flow.

Subsurface Inflow

The amount and location of subsurface inflow depend on the definition of the boundaries of the study area. Groundwater inflow primarily occurs along the eastern study area boundary, which includes subsurface flow from Nipomo Mesa as well as the alluvium along Los Berros Creek. Subsurface inflow may also occur along the northern study area boundary within the alluvial sediments of Pismo Creek, Meadow Creek, and Arroyo Grande Creek.

Method

Evaluation of subsurface inflow along the eastern study area boundary was performed by applying Darcy's Law of saturated flow in a porous medium. This method is straightforward, and requires simply a groundwater gradient and a representative transmissivity for each portion of the study area boundary where subsurface inflow occurs. The equation for evaluating the total subsurface inflow (Q) along a boundary segment by this method is:

$$(5) \qquad Q = TiW$$

where T is the representative transmissivity of the boundary segment, i is the groundwater gradient across (and perpendicular to) the boundary segment, and W is the width of the boundary segment. The groundwater gradient is defined as the slope of the water table, or the change in head over distance. One representative transmissivity and groundwater gradient was used for the entire eastern study area boundary, because insufficient well data are available to obtain consistent and corroborative gradients across more finely divided segments of the eastern boundary. Flow from the alluvial sediments along Los Berros Creek was not estimated separately from the rest of the eastern boundary because of a lack of well data along Los Berros Creek in the vicinity of the study area. However, the alluvial sediments of Los Berros Creek were included in the evaluation of the overall transmissivity for the eastern study area boundary.

In order to obtain a representative transmissivity, the geology of the study area was evaluated with particular attention to the study area boundaries. Selected cross sections were developed to represent the conditions along pertinent segments of the study area boundary. After review of previous geologic work in this area (DWR 2000, DWR 2002, CH2M Hill, SAIC, Cleath & Assoc. 2003), it was determined that the geology summarized in DWR 2002 was sufficiently comprehensive and accurate to be used in this study. It is noted that DWR 2002 also has been relied upon by other studies of groundwater flow (Papadopoulos, SAIC, etc.) **Figure 2**, derived from Plate 2 in DWR 2002, shows the surface geology of the study area and indicates the locations of two cross sections, A-A' and B-B' shown on **Figure 3** and **Figure 4** respectively. **Figure 2** also shows that there are three major faults within the study area: the Wilmar Avenue fault along the northern study area boundary, and the Santa Maria River fault and Oceano fault in the central portion of the study area.

Along each boundary segment determined to be an inflow or outflow boundary, hydraulic conductivities were estimated for each of the geologic formations present. Hydraulic conductivities were derived from DWR 2002, which supplied hydraulic conductivity estimates from aquifer pumping test data, well yield data, and known conductivity ranges for represented rock types. For this analysis, conductivities were assigned to each geologic unit, which approximated the geometric mean of the values given in DWR 2002 while producing reasonable results. Assigned conductivities are shown in **Table 9**. The hydraulic conductivity of each geologic unit was then multiplied by the unit thickness to produce a transmissivity, and the transmissivity values of units within a given segment of the study area boundary were then summed to produce the representative transmissivity for that boundary segment.

Groundwater gradient data were determined from water level data. Data were obtained for a variety of monitoring and production wells from San Luis Obispo County, United Stated Geological Survey and the Department of Water Resources. Data spanned the study period and were compiled in a single database. Groundwater contour maps were constructed by interpreting these water level data, and served to define which boundary segments were to be considered inflow, outflow, and no-flow boundaries. Due to inconsistent data, water level maps were not used to determine groundwater gradients. Instead, gradients between well pairs were used to derive groundwater gradients across flow boundaries, with multiple well-pairs averaged over the course of the study period to smooth individual inconsistencies. Well pairs used for this analysis are listed in **Table 10**. Gradients were calculated from those months when all well pairs had data and were averaged. Once the transmissivity and groundwater gradients were determined, total flow across the boundary segment was then calculated using Darcy's Law, equation 5.

Subsurface inflow may also occur along the northern study area boundary. Potential inflow across the northern boundary can be divided into two categories:

1. Flow within the alluvial sediments of Arroyo Grande Valley and along the drainages of Meadow Creek and Pismo Creek, and
2. Flow from the more consolidated units (Paso Robles Formation, Pismo Formation, or Careaga Formation) across the Wilmar Avenue Fault.

Generally, groundwater elevation data from the bedrock units north of the study area are lacking, but groundwater elevation contours from DWR 2002 and a review of water levels indicate that groundwater flow is generally parallel to the boundary, indicating little groundwater flow into the basin across the northern boundary. This may be an indication that the Wilmar Avenue Fault acts as a groundwater barrier in non-alluvial geologic units along the northern boundary, but without more detailed groundwater level monitoring, this conclusion is tenuous. It is assumed that the recent alluvial sediments along Arroyo Grande Creek, Meadow Creek, and Pismo Creek overlie the Wilmar Avenue Fault and thus the fault does not act as a significant barrier to groundwater movement in the alluvium (DWR 2002).

Subsurface flow as well as surface flow from Arroyo Grande Valley is assumed to be included in the USGS gage measurements. Gaging station 11141500 is located on Arroyo Grande Creek in an area of high bedrock; at that gaging station, water can be observed flowing directly over a non-alluvial, consolidated rock unit. It is assumed that this bedrock forces groundwater in the upstream alluvium to discharge into the creek at this point. Accordingly, the surface discharge measured at this gaging station accounts for any subsurface flow along the Arroyo Grande Creek Valley. The Hoover Study showed that, between the USGS gage and measurements of the creek at Traffic Way there was a net loss of approximately 200 AFY from Arroyo Grande Creek to groundwater, which constitutes subsurface flow into the basin, but is accounted for as stream infiltration (Lawrance, Fisk & McFarland, 1985).

Groundwater may flow across the northern study area boundary within the alluvium of Meadow Creek. Cleath & Associates (2003) examined groundwater in the Oak Park area along Meadow Creek and roughly estimated flow into the Arroyo Grande basin from Meadow Creek alluvium to be 65 AFY. This estimate was based on the assumption that the groundwater elevation gradient in this area is equal to the ground surface elevation gradient. Without detailed groundwater elevation data to verify this estimate, its accuracy is uncertain. However, given that 65 AFY represents only about 2% of the subsurface inflow estimated for the eastern boundary, for all practical purposes, the northern boundary appears to be a no-flow boundary.

Results

Using the calculated average gradients and representative transmissivity, the mean inflow along the eastern study area boundary is 3,470 AFY. A more precise determination of subsurface flow on a yearly or seasonal basis was considered, but available well data were too variable and inconsistent to yield reliable, representative, regional groundwater gradients at these short timescales. Effects on groundwater levels in wells that are short-term (such as storm events) or small-scale compared to the study area (such as localized pumping activity) are not likely to significantly affect the regional pattern of groundwater flow, particularly in deeper, less permeable units. Therefore, subsurface flows were calculated using groundwater gradients that were averaged to more accurately represent the long-term, regional gradient.

Because hydraulic conductivities and gradients are estimated, the volume of inflow is highly uncertain and may reasonably range from 1,000 AFY to 10,000 AFY. Based on the method described above, the subsurface inflow can be reasonably estimated at 3,470 AFY. Additional monitoring may eliminate some or all of the uncertainty.

Discussion

Evaluation of subsurface inflow is based mainly on groundwater gradients in the area of the study area boundary, the cross-sectional areas of each geologic unit, and the associated hydraulic conductivities of the units. Key assumptions for the analysis of inflow are:

- Estimated hydraulic conductivities
- Selected unit thicknesses
- Average gradients from well pairs are representative
- All subsurface flow from Arroyo Grande Creek Valley becomes surface flow near the USGS gage station

This element of the water balance is not only large, but highly uncertain. Accordingly, improved monitoring and additional study are recommended to reduce the uncertainty. First, dedicated water level monitoring wells on both side of the Nipomo Mesa boundary would help determine gradients, while additional water level data would define seasonal variations in subsurface inflow. Additional studies of available well logs along the boundary would improve the calculation of formation thicknesses. Future pumping tests and review of all available pumping tests would provide additional information regarding local hydraulic conductivities.

Outflows

Outflows from the groundwater basin include groundwater pumping, evapotranspiration from groundwater-fed lakes, and subsurface flow to the ocean. Other means of evapotranspiration are subsumed in the analysis of specific inflows, namely deep percolation and return flow. The following paragraphs define each outflow, describe the method used to estimate the outflow, summarize the results, and provide a discussion of uncertainty with recommendations to improve the estimate. Outflows are included in **Table 1** on an annual basis, while **Table 2** provides a monthly summary.

Pumping

Groundwater extraction or pumping is a major component of outflow from the groundwater basin. In the Arroyo Grande Basin, groundwater provides supply to both municipal and agricultural users. Documentation of groundwater pumping is available from the municipal users of the basin, generally from 1954 to the present. However, the amount of groundwater produced for agriculture purposes is uncertain, as local agricultural wells are not metered and pumping rates are not reported.

Groundwater pumping is guided by the 2002 *Groundwater Management Agreement* among the groundwater users of the basin. Pumping amounts were subdivided by the *Agreement* based on findings of the 1979 DWR report, *Water Resources of the Arroyo Grande Area.* The report indicated that approximately 5,300 AFY was used for agricultural irrigation and provided 200 AFY for subsurface outflow to the ocean. Adjustments were made to the original water balance in the report to account for additional water entitlements from the Lopez project. This adjustment increased the water available for urban use to 4,000 acre-feet per year. The available water was divided among the four municipalities based on their historical maximum groundwater pumping. The division is shown below:

Applied irrigation to agricultural land	5,300 AF
Subsurface flow to the ocean	200 AF
Urban Use	
City of Arroyo Grande	1,202 AF
City of Grover Beach	1,198 AF
City of Pismo Beach	700 AF
Oceano Community Services District	900 AF

Urban Pumping

Method

Table 11 summarizes basic information on the municipal supply wells, while **Figure 16** shows the well locations. Each municipal purveyor currently meters the amount of groundwater pumped. However, some gaps exist in the historical record. First, pumping records are not available from the City of Grover Beach before January 1992. Accordingly, the monthly volume pumped by Grover Beach before 1992 was estimated using the City's portion of the total pumping from all municipalities from 1992 through

1997. The distribution of pumping changed in 1997 because of the importation of State Water Project Water, and therefore was not included in this analysis. For example, from 1992 through 1997, the volume that Grover Beach pumped in October was an average of 41.2 percent of the total pumping. In October 1985, Arroyo Grande, Pismo Beach and Oceano pumped a total of 52.3 AF. Assuming that Grover Beach averaged 41 percent of the total, then pumping can be estimated as 36.7 AF (41.2 percent of 89 AF, 36.7+52.3). In addition, no data were available for Oceano for August and September 2004. It was assumed the pumping was similar to August and September in 2003.

Results

The pumping amounts from each municipal purveyor are shown on **Figure 17**. Urban pumping ranged from 1,790 AF in the beginning of the study period (Water Year 1986) to 3,400 AF at the end of the study period (Water Year 2004). The cities of Arroyo Grande and Grover Beach have increased pumping over the time period to meet the growing water demands. The City of Pismo Beach and Oceano CSD both contracted for water from the State Water Project and decreased pumping when deliveries began in late 1997. **Figure 18** shows the water supply to urban parties in the Northern Cities Area by source. Note that the SWP supply to OCSD is not included in the State Water Project totals. **Table 2** shows the average urban pumping by month. There is a seasonal component to pumping, where pumping in the summer months is greater than in winter months. An average of twice as much pumping occurs during the dry season (April through September) than the wet season (October through March). **Figure 19** shows the total monthly pumping.

Discussion

Urban pumping is well monitored and there is little uncertainty in the estimates. Two key assumptions were made in the analysis to fill in missing data. The assumptions pertain to:

- Grover Beach pumping before January 1992
- Oceano pumping in August and September 2004

For the water balance, only the volume of pumping is considered. However, the location of pumping plays a critical role in defining the source of the pumped water. For example, the source of pumping can derive from deep percolation, stream infiltration, subsurface inflow from the east, or if wells are poorly located, from subsurface inflow from the west, which brings the risk of sea water intrusion. Currently, municipal pumping occurs in localized pumping centers located in the Tri-Cities Mesa. Future numerical modeling could help redistribute and even increase pumping while minimizing the risk of seawater intrusion.

Agricultural Pumping

Method

DWR prepares land use maps showing areas of irrigated agricultural land and crop patterns. Land use maps exist for the southern San Luis Obispo area for 1985 (**Figure 20**) and 1996 (**Figure 8)**. Between 1985 and 1996, irrigated agricultural land decreased in acreage; however, the 1996 land use map did not include agricultural land within the urban areas of the study area. The 1985 DWR land use shows about 320 acres of agricultural land in these urban areas. As part of the Agricultural Conversion Credit, **Appendix B**, Arroyo Grande and Grover Beach indicated that approximately 230 acres of agricultural land has been converted to urban uses. The remaining 90 acres is assumed to remain agricultural use as reported by the DWR 1985 land use map. The major crops in the area have not changed over time and include strawberries, lettuce, broccoli and other cole crops (e.g. broccoli, cauliflower, and cabbage). **Table 12** shows the major crops and respective portion of agricultural land according to the DWR 1996 land use map.

DWR's Division of Planning and Local Assistance also reports irrigated crop area, harvested area, applied water rates, and other agricultural data for counties and Detailed Analysis Units (DAU). **Figure 21** shows the Arroyo Grande DAU. Note that the Arroyo Grande DAU is much larger than the Northern Cities Area. Nonetheless, the distribution of crop types is similar in the larger DAU and the smaller study area. In both areas, approximately 90 percent of the agricultural land is in truck crops, mainly broccoli and lettuce.

The annual acreage of irrigated land by crop type for San Luis Obispo County was also examined (DWR, Updates to the California Water Plan, various dates) to consider possible trends during the study period. Agricultural land uses in San Luis Obispo County for available years are shown on **Figure 22.** Total irrigated acreage increased in the county over the study period. Most of the growth was in grapes or vineyards; however, truck crops increased slightly. The county-wide review substantiated local data indicating that agriculture and cropping patterns are fairly constant.

DWR reports both the irrigated land area in the DAU and the harvested area for years 1998-2001. If a certain field supports two crops in a year, the harvested area is twice the actual land area. DWR estimates that more than one crop per year are grown on only about 25 percent of irrigated land in the DAU. However, crops grown in the Northern Cities area (lettuce and broccoli) often yield two harvests per year because of their short growing seasons; lettuce typically grows in 70 to 80 days and broccoli grows in 50 to 150 days depending on the season. According to Richard Fastenau, the agricultural water use expert for DWR's southern district, most farmers will grow lettuce during the warmer months and broccoli during the cooler winter months. This crop rotation sustains soil fertility and provides for overall better quality of produce (Fastenau 2006). Other truck crops do not have the same cropping pattern; for example, strawberries on one land acre may yield one harvested acre a year. Although about 6 percent of the Northern Cities agricultural land area was reported as strawberries in 1996, the crop is often rotated with other truck crops. Because the type crop grown on a particular acre may change year to year, it was assumed all irrigated land in the area could yield two crops per year.

Applied water is the amount of water applied to a crop for irrigation; units are generally given as AF per harvested acre per year. In the Northern Cities area, all applied water is from groundwater pumped by privately owned wells. The amount of applied water varies by crop and geographic location. DWR presents estimates of applied water by DAU for certain years. Most truck crops are grouped together and the applied water use is a weighted average. For example, the acreage of broccoli is multiplied by the applied water for an average broccoli crop and the acreage of lettuce is multiplied by the applied water for an average lettuce crop and divided by the total acreage. The resulting rate would estimate total water when applied over the whole area. These applied water values are shown for selected crops on **Table 13**. The applied water for truck crops (lettuce, cole crops, strawberries, etc.) ranged from 0.86 to 1.0 AF per harvested acre per year. Applied water for pasture or grain crops averaged about 0.46 and 2.81 AF per harvested acre per year, respectively.

Table 13 shows the irrigated land area calculated from the DWR land use maps for both 1985 and 1996. Acreage was adjusted slightly to include the agricultural land still remaining within the urban areas. The table also shows the estimated harvested acreage, assuming that all truck crops produce two harvests a year. The DWR-estimated applied water rate is applied to the harvested acreage and the water use for each major crop type is calculated. The results are shown based on the areas on the two available land use maps. Because the agricultural land area in the Northern Cities area decreased only slightly over the study period, the average water use is assumed to represent the approximate water use annually.

Results

Based on the above methodology, agricultural pumping is estimated to equal the volume of applied water, 3,300 AFY. Total applied water varies based on the ET demands of a particular crop, length of the growing season, type of irrigation, amount of precipitation, irrigated land area, harvested area, and personal preference of the grower. Because of the many variables, significant uncertainty exists. Further research in this area may be warranted, including detailed field surveys, interviews with local growers about irrigation methods and crop rotations.

Seasonal water use is difficult to estimate as it depends on the crop rotation schedules of farmers in the area. Although there are certain suggested crop patterns, it is ultimately up to the individual grower when to plant and harvest (Fastenau, personal communication). Generally more water would be used in the summer than the winter. The winter months have more precipitation and the crops generally grow at a slower rate in the colder temperatures, thus requiring less irrigation.

In addition, the amount of precipitation in a given year would also affect the volume of applied water, with a dry year requiring more applied irrigation to compensate for the lack of precipitation. This effect is not specifically addressed as no data exist on specific irrigation practices in the area and practices would vary by grower. However, by using an annual average, the short term variations in applied water should not affect the overall volume.

Discussion

Agricultural pumping represents approximately one third of the total water balance outflow. It is anticipated that the acreage of agricultural land in the study area will not change significantly in the future, having remained relatively constant.

Agricultural pumping was estimated based on the following key assumptions:

- Agricultural practices do not vary over the time period.
- All truck crops land produces two harvests.
- Applied water rate estimates are based on crop type.

Additional data would improve the analysis and estimate of the seasonal and annual variability of applied water. However, the needed data (including detailed crop rotation information, irrigated acreage over time, and irrigation practices) vary by farmer and acquisition of such data would require considerable investigation.

Subsurface Outflow

Subsurface flow to ocean is an important element of the water balance. Groundwater outflow prevents salt water intrusion and ensures the long term sustainability of groundwater supply.

Method

Figure 4 (cross section B-B') shows the geology inferred along the western boundary of the study area, derived from the DWR 2002 report. The western boundary of the study area is about 27,900 ft. long and extends along the shore from approximately Black Lake Canyon to Pismo Creek.

The geology along this cross section is well defined by well data, with the exception of the area just south of the Santa Maria and Oceano Faults. Formation thicknesses in this area are extrapolated from DWR 2002, but the depths of geologic contacts are estimated. This western boundary is considered the only subsurface outflow boundary of the study area. The representative transmissivity of 8800 ft^2/day for this western boundary is a product of the formation thicknesses from **Figure 4** and the hydraulic conductivities from **Table 9**, corresponding to an average hydraulic conductivity of 105 gpd/ft^2 and an average section thickness of approximately 630 feet.

Five well pairs (listed in **Table 10**) were used to calculate the average groundwater gradient across the western study area boundary. Inconsistencies in individual water level measurements (potentially caused by pumping activities, measurement error, storm events, etc.) were smoothed by averaging gradients over the entire study period, yielding an average gradient of 0.0017 across the western boundary. This gradient is generally consistent with groundwater elevation contour maps created from well data for this project. The subsurface outflow was calculated using Darcy's Law as described in the Subsurface Inflow section.

Results

The mean outflow to the ocean along the western study area boundary is 3,400 AFY. Only limited seasonal or annual variation occurs in water levels along the boundary (**Figure 24**). The stable water levels indicate that the subsurface outflow has not varied significantly over the study period.

Discussion

The outflow of fresh water along the coast maintains a dynamic equilibrium between the onshore fresh water and offshore sea water. **Figure 23** is a schematic east-west cross section that illustrates the wedge-shaped interface between the overlying fresh water and the denser sea water. The interface is a transition zone composed of brackish water with a specific geometry and location that is dependent on the amount of subsurface fresh water outflow. **Figure 23** shows three theoretical transition zones, all located at the shoreline and each associated with an amount of subsurface freshwater outflow. In general, greater fresh water outflow is associated with a steeper interface and greater distance of the interface from inland wells. A reduced fresh water outflow results in flatter interface, with the dense sea water moving inland as a sea water intrusion wedge.

The geometry of the seawater wedge beneath the western boundary of the study area was evaluated to check the subsurface outflow estimate and also to examine the potential effects of different outflows on seawater intrusion. The following equation was used to evaluate the elevation of the freshwater/seawater interface (z):

$$z^2 = \frac{2\rho q x}{\Delta\rho K} + \left(\frac{\rho q}{\Delta\rho K}\right)^2 \qquad (6)$$

where x is the horizontal distance perpendicular to the coast, q is the discharge per foot of aquifer (parallel to the coast), K is the hydraulic conductivity of the aquifer, ρ is the density of fresh water, and $\Delta\rho$ is the difference in density between sea water and fresh water.

The geometry of the freshwater/seawater interface was determined analytically for three outflow values: for 200 AFY as cited in the 2002 *Groundwater Management Agreement*; for 3,000 AFY, which approximates this study's estimate; and for 10,000 AFY, which is a possible, but high-end value. All three are depicted on **Figure 23**. As shown, a discernable, but compact seawater wedge occurs at the estimated outflow of 3,000 AFY. An outflow of 200 AFY indicates a much more extensive seawater wedge, while an outflow of 10,000 AFY indicates a near-vertical freshwater/seawater interface. Local wells are not known to have been affected by sea water, so it is likely that subsurface outflow from the study area lies within the broad predicted range of 1,000 to 10,000 AFY. Note that an outflow of 200 AFY, as cited in the *Agreement*, would result in an unreasonably shallow freshwater/seawater interface, occurring at a depth of only 200 feet at a location 800 feet inland from the shore.

The extent of intrusion can be estimated analytically or numerically but the best indication of the freshwater/seawater interface is sentry wells. Sentry wells along the coast can detect the diagnostic changes in water quality that accompany incipient seawater intrusion. These wells should be sited and designed to address geologic variability and monitored on at least a semi-annual schedule. Sentry wells should be focused on areas of the greatest subsurface outflow, namely near Arroyo Grande and Pismo Creeks.

Key assumptions for subsurface outflow include:

- Hydraulic conductivities
- Unit thicknesses
- Average gradients from well pairs

Other Outflows

Other water balances have identified the lakes in the southern portion of the study area as potential outflows. These lakes are most likely fed by groundwater but it is unclear if the groundwater is a separate perched aquifer or part of the larger Arroyo Grande groundwater aquifer. Little or no data address the source of the lakes, the volume they contain, or water level fluctuations. For the purposes of this study, it is assumed that the evaporation from the lakes represents an insignificant outflow.

Groundwater Storage

Change in groundwater storage can be computed as the difference between inflows and outflows in the water balance. It also can be calculated independently by examining groundwater level data. This independent calculation is an important check on the overall accuracy of the water balance.

Groundwater storage was computed as the product of the saturated groundwater basin volume and the average specific yield of the basin sediments. The groundwater basin volume is based on knowledge of the geologic framework of the basin and monitoring of groundwater levels, while the specific yield is derived from pumping test data or estimates based on sediment characteristics. Evaluation of change in groundwater storage is based on monitoring changes in groundwater levels. The groundwater basin can be defined as the entire volume from the water table down to bedrock. In the case of coastal basins like the Arroyo Grande Basin—with the risk of sea water intrusion—the usable basin volume is defined as the volume above mean sea level, which can be utilized with minimal risk of sea water intrusion.

Method

Change in groundwater storage was computed by evaluating the difference in groundwater elevation across the study area, multiplying it by the horizontal area of the study area, and then multiplying again by the representative specific yield of the study area. Hydrographs from selected wells are shown on **Figure 24.** The change in storage was evaluated in this manner for two time periods: 1986-1997 and 1998-2002. These time periods were chosen in order to characterize the effect of the wet period around 1998.

Groundwater elevations were determined across the study area from analysis of well data compiled from the San Luis Obispo Water Level Database, Department of Water Resources, and the USGS National Water Information System. Water level measurements were used to construct groundwater elevation contour maps for the study area. The contours on these maps were created from a combination of inverse-distance weighting of data from wells, hydrogeologic judgment, and overall trends in groundwater flow patterns. To examine the study period, three pairs of years were used: 1985-1986, 1997-1998, and 2002-2003. Data and contours for autumn measurements for each two-year group were averaged together in order to smooth irregularities in water level data. All applied data were October water level measurements, thereby minimizing seasonal and early spring rainfall effects. After averaging, a digital representation of the water table for the entire study area was created with ArcGIS software for each of the three time periods. These digital groundwater elevation surfaces were composed of ten by ten meter squares or cells. Each cell was assigned a groundwater elevation value by a geostatistical process termed kriging, which analyzed the well data and the groundwater elevation contours together to derive the most probable groundwater elevation for each cell.

Elevation differences were calculated between the groundwater elevation surfaces, and the difference multiplied by the surface area. This volume was then multiplied by a specific yield of 0.11 to produce the total change in storage. The specific yield value of 0.11, taken directly from DWR 2002, is based on well logs of the area.

Result

From the 1985-1986 time period to the 1997-1998 study period midpoint, the calculated net change in groundwater storage within the study area was about +2,650 AF. From 1997-1998 to the 2002-2003 endpoint, the calculated net change in groundwater storage within the study area was about -2,250 AF. The calculated net change in groundwater storage for the entire study period is about +450 AF, approximately 0.3 percent of total inflow over the study period or 0.05 AF per acre.

Discussion

The change in storage as calculated by the change in water levels can be compared with the change in storage derived from total inflow less total outflow.

Inflow – Outflow = Change in Storage

The difference between inflow and outflow was summarized for the same time periods that the water level change in storage was calculated; the results are shown on the bottom of **Table 1**. The results of the two methods are similar; the small difference is likely the result of rounding, uncertainty, or imprecise assumptions. In the beginning of the study period, between 1986 and 1997, the groundwater in storage increased by 2,500 AFY and from 1998 to 2004, groundwater in storage decreased a similar amount. The intervening temporary increase in storage was the result of the extremely wet years of 1997 and 1998. Although the volume of groundwater in storage varied from year to year, no significant cumulative change in storage occurred.

Findings

Table 1 presents each water balance element with its annual estimate for each water year from 1986 through 2004; the annual average also is shown. **Table 2** summarizes the water balance elements on a monthly basis. As discussed in the individual sections, some elements are more variable than others on both an annual and month scale.

Figure 25 illustrates the annual inflows. As shown, deep percolation of rainfall is both significant and highly variable, contributing approximately half of the inflow in wet years, such as 1998, and no inflow in dry years, such as 1991. Both stream infiltration and subsurface inflow are significant inflows that are relatively steady over time.

Figure 26 shows average inflows for each month. Deep percolation varies greatly on a monthly basis, contributing about half the inflow in winter months and no inflow during the summer months. The other major inflows, stream infiltration and subsurface inflow, are considered to be relatively constant on monthly scale, acknowledging that little information is available on their seasonal variation.

Figure 27 and **Figure 28** illustrates outflow on an annual and average monthly basis. Relative to annual inflows, annual outflows are quite steady through the study period. On a monthly basis, outflows increase during the summer months, mostly because of increased urban pumping. Little or no variation is shown in agricultural pumping or subsurface outflow, in part reflecting a lack of information.

Figure 29 shows the annual comparison of inflows to outflows. Inflows vary more than outflows annually and thus some years show more inflow than outflow and others less. On a cumulative and average basis, inflows and outflows balance each other. On a monthly time scale, inflows also vary more than outflows and are greater in the winter rainy season. Outflow is slightly greater in the summer months because of increased urban pumping.

Safe Yield

The safe yield, also referred to as perennial or sustainable yield, is usually defined as the amount of water that may be pumped from a basin without causing negative effects in the basin. Negative impacts could include chronic groundwater level declines and—in a coastal basin like the Northern Cities Area—seawater intrusion. The safe yield is not a fixed number, but is dependent on both the natural system and on management, and varies with changing hydrologic conditions.

In the past, the term safe yield, implying a fixed quantity of extractable water basically limited to the average annual basin recharge, was widely used. However, it is falling into disuse because it implies a never-changing value that does not reflect changing conditions and does not ensure sustainability of the water supply (Todd 1980). In the U.S. Geological Survey Circular 1186, the authors supported a more fluid view of groundwater management, rather than a static value: "As human activities change the system, the components of the water balances (inflows, outflows, and changes in storage) also will change and must be accounted for in any management decision." (Alley, et al. 1999).

In the Northern Cities Area, a single safe yield value of 9,500 AFY is cited in the *2002 Groundwater Management Agreement* among the Northern Cities with subdivisions for agricultural irrigation, subsurface outflow to the ocean, and urban use. This *Water Balance Study* demonstrates that the *Agreement's* subdivision for agricultural irrigation (5,300 AFY) is higher than the 3,300 AFY used for agricultural over the past 20 years. In addition, the *Agreement's* amount for subsurface outflow (200 AFY) is unreasonably low; the value derived in this study is 2,959 AFY. While the minimum amount subsurface outflow needed to prevent seawater intrusion is unknown, the outflow over the study period apparently has been sufficient.

The *2002 Agreement's* safe yield allotment for urban use was 4,000 AFY, subdivided as follows:

City of Arroyo Grande	1,202 AFY
City of Grover Beach	1,198 AFY
City of Pismo Beach	700 AFY
Oceano Community Services District	900 AFY

During the study period, total urban pumping averaged about 2,269 AFY and generally increased from about 1,790 AFY to nearly 3,400 AFY, but remained below the 4,000 AFY allotment. The gradual increase in urban pumping has not resulted in basin-wide groundwater level declines (as indicated by the near-zero groundwater storage change) or detections of seawater intrusion. Accordingly, no change is suggested to the urban allotment of 4,000 AFY. However, realizing that the Water Balance Study includes some uncertainty and recognizing the potential for seawater intrusion, it is strongly recommended that monitoring of basin-wide water levels and sea water intrusion through sentry wells be continued and expanded.

It is recognized that the total amount and the various urban parties' allocations can be increased by about 100 to 200 AFY through the agricultural conversion credit provided in the *2002 Groundwater Management Agreement.* A standard method of computing agricultural conversion credit has been developed for adoption by the Northern Cities (see **Appendix D**).

Recommendations

The water balance described above can aid in the development of future monitoring programs and management decisions. With more monitoring and investigation, assumptions used in the water balance can be tested or replaced with data leading to a greater understanding. Proactive management can increase the yield of the basin without irrevocably damaging the basin. Key recommendations are described below.

Monitoring

- **Implement a monitoring and reporting program –** A monitoring program will support future management decisions with regular updating of the state of the groundwater basin.

- **Depth specific monitoring wells -** Sentry wells along the coast can detect changes in water quality and notify of the threat of seawater intrusion. These wells should be depth specific and monitored on at least a biannual schedule. It is recommended that the existing sentry wells be re-employed for monitoring of groundwater levels and quality. Addition of more sentry wells should be considered. Sentry wells should be located near the areas of the greatest subsurface outflow, near Arroyo Grande and Pismo Creeks.

- **Dedicated wells for water level monitoring –** Additional groundwater level monitoring wells, preferably dedicated wells, should be considered as part of a regular monitoring program. Reliable water level data can assist in the estimation of subsurface inflow, outflow, change in storage, and the general state of the basin. Additional water level data can also indicate changes in water levels near coast which may indicate potential for sea water intrusion. Water levels taken at the same well on a regular basis, at least semi-annually, can provide needed data on the seasonal variability of elements of the water balance.

- **Additional stream gaging -** Stream infiltration may vary due to flow, bank storage, and groundwater levels. Urban and agricultural runoff also flows into the creek and may complicate infiltration estimate as they contribute to flow unevenly over the stream reach. More studies performed at different times of the year and different flow volumes are needed to accurately estimate the infiltration from Arroyo Grande Creek.

Management

- **Use data from the monitoring program to inform management decisions -** A well crafted and consistent monitoring program can increase the understanding of the basin, provide up to date information about the state of the basin, and aid in many management decisions. Data from monitoring activities should be well organized to allow for easy updating and analysis.

- **Expand infiltration basin system -** Infiltrations basins are a good example of effective management for basin. The basins allow storm water that would otherwise be lost to the ocean to recharge the groundwater basin. The current infiltrations basins collect only a small portion of the total storm water in the study area. Expansion of the storm water system could significantly increase the amount of water recharged to the aquifer. The cities of Arroyo Grande and Grover Beach are currently enlarging and improving their infiltration pond systems and the volume of water recharged from these ponds is expected to increase in the future. These and other expansions to the infiltration basin will result in more inflow to the groundwater aquifer.

- **Manage use of available groundwater and surface water supplies –** The Northern Cities—singly and in combination—have a portfolio of water supplies including Lopez Reservoir, State Water Project, and groundwater. Other potential future sources include desalination and water recycling. Additional monitoring and incremental development of groundwater would support increased understanding of how groundwater can be used in conjunction with other sources, for example through water leases or trades. It should also be possible to modify use of these sources to optimize use of Lopez Reservoir and groundwater storage to enhance water supplies in drought.

- **Plan and prepare for prolonged droughts –** Some elements of the water balance, like deep percolation vary greatly based on precipitation. Because of the seasonal and annual variability, a large portion of the inflow to the basin for the study period occurs over the period of a few months. In periods of prolonged drought inflow may be significantly less than outflow due to the lack of deep percolation. At that time management measures must be implemented to prevent excessive groundwater level decline and seawater intrusion.

- **Assess impacts on groundwater quality from pumping both volume and location -** For the water balance, only the *volume* of pumping is considered, but the *location* of pumping plays a critical role of seawater intrusion. Pumping occurs in localized pumping centers in the Tri-Cities Mesa. Intense pumping in a localized area may increase the chance of upward migration of poor quality water (upconing) or lateral seawater intrusion. Future numerical modeling could help redistribute pumping to optimize pumping amounts and to minimize negative impacts like seawater intrusion and induced inflow of poor quality water from depth.

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TABLES

Table 1. Annual Water Balance by Element

	Water Year																			
Water Balance Element	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**AVG**
Inflow (AFY)																				
Stream Infiltration	1,957	1,981	1,863	2,116	1,937	1,912	1,994	2,116	1,898	1,768	2,172	2,172	2,172	2,172	1,987	2,172	2,017	2,012	1,905	2,017
Deep Percolation	757	668	949	564	0	1,417	2,061	4,632	317	3,066	1,810	4,190	5,856	341	1,603	1,307	220	348	579	1,615
Infiltration Ponds	359	398	330	192	47	234	391	630	235	411	296	493	773	287	323	350	118	185	193	329
Urban Return Flow	101	105	114	115	111	103	114	111	103	129	107	113	104	115	119	119	140	120	126	114
Agricultural return flow	990	990	990	990	990	990	990	990	990	990	990	990	990	990	990	990	990	990	990	990
Subsurface inflow	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470	3,470
INFLOW TOTAL	7,634	7,612	7,716	7,447	6,554	8,126	9,019	11,949	7,013	9,834	8,845	11,428	13,365	7,375	8,493	8,408	6,955	7,126	7,263	8,535
Outflow (AFY)																				
Urban Pumping	1,787	2,251	2,221	1,989	1,992	1,994	2,093	2,188	2,131	1,820	2,424	2,627	1,942	2,244	2,313	2,293	2,739	2,665	3,398	2,269
Agricultural Pumping	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300
Subsurface Outflow	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959	2,959
OUTFLOW TOTAL	8,047	8,510	8,480	8,249	8,252	8,253	8,352	8,448	8,391	8,080	8,683	8,887	8,201	8,503	8,572	8,553	8,999	8,925	9,657	8,528
DIFFERENCE	-413	-899	-764	-802	-1,697	-127	667	3,501	-1,378	1,754	162	2,541	5,164	-1,128	-79	-145	-2,044	-1,799	-2,395	6

	1986-1997	**1998-2004**	**1986-2004**
Inflow (AF)	103,178	58,985	147,265
Outflow (AF)	100,631	61,410	144,337
DIFFERENCE (AF)	2,546	-2,425	121
Change in Storage (AF)	2,650	-2,250	450

Table 2. Annual Monthly Contribution by Water Balance Element

	Inflow (AFM)						Outflow (AFM)				
Month	**Stream Infiltration**	**Deep Percolation**	**Infiltration Ponds**	**Urban Return Flow**	**Agricultural Return Flow**	**Subsurface Inflow**	**Urban Pumping**	**Ag Pumping**	**Subsurface Outflow**	**OUT (AFM)**	**IN (AFM)**
Jan	181.3	374.5	55.3	7.0	82.5	289.2	95.2	275.0	246.6	616.8	808.4
Feb	159.8	608.5	90.2	6.4	82.5	289.2	95.2	275.0	246.6	616.8	1,076.7
Mar	172.9	281.9	55.0	7.7	82.5	289.2	131.6	275.0	246.6	653.2	716.3
Apr	162.7	34.6	12.0	10.4	82.5	289.2	189.0	275.0	246.6	710.7	428.6
May	165.6	23.0	8.3	10.6	82.5	289.2	238.0	275.0	246.6	759.7	413.6
Jun	162.2	0.0	1.4	11.0	82.5	289.2	269.2	275.0	246.6	790.8	384.1
Jul	167.8	0.0	0.1	13.1	82.5	289.2	294.7	275.0	246.6	816.3	384.9
Aug	157.5	0.0	0.9	11.8	82.5	289.2	288.5	275.0	246.6	810.2	384.4
Sep	159.4	0.0	1.5	10.3	82.5	289.2	241.2	275.0	246.6	762.8	383.5
Oct	175.0	10.6	15.9	10.2	82.5	289.2	199.3	275.0	246.6	720.9	408.4
Nov	172.8	39.3	33.1	8.3	82.5	289.2	138.6	275.0	246.6	660.3	452.3
Dec	180.0	242.6	53.5	7.5	82.5	289.2	112.1	275.0	246.6	633.7	675.2
Average	168.1	134.6	27.3	9.5	82.5	289.2	191.1	275.0	246.6	712.7	543.0
Wet Season	1,041.8	1,557.4	302.9	47.0	495.0	1,734.9	771.9	1,650.0	1,479.7	3,901.7	4,137.3
Dry Season	975.1	57.6	24.2	67.2	495.0	1,734.9	1,520.7	1,650.0	1,479.7	4,650.4	2,379.0

Wet Season = October to March
Dry = April to September

Table 3. Physical Properties of Soils

Soil Type	Area (FT^2)	% Area	Capacity (in)	Group
Camarillo sandy loam	42,599	0.01%	9.45	H
Marimel sandy clay loam, occasionally flooded	29,639,568	8.2%	6.21	H
Marimel silty clay loam, drained	29,406,497	8.2%	6.25	H
Beaches	677,953	0.2%	1.97	L
Briones loamy sand, 15 to 50 percent slopes	1,506	<0.001%	1.45	L
Briones-Pismo loamy sands, 9 to 30 percent slopes	1,132,846	0.3%	1.40	L
Briones-Tierra complex, 15 to 50 percent slopes	81,002	0.02%	1.54	L
Chamise shaly loam, 9 to 15 percent slopes	164,620	0.05%	2.92	L
Chamise shaly loam, 15 to 30 percent slopes	23,525	0.01%	2.92	L
Corralitos sand, 0 to 2 percent slopes	520,701	0.1%	2.03	L
Corralitos sand, 2 to 15 percent slopes	1,138,596	0.3%	2.03	L
Corralitos variant loamy sand	364,337	0.1%	2.77	L
Dune land	97,110,499	26.9%	1.97	L
Elder sandy loam, 5 to 9 percent slopes	834,794	0.2%	3.80	L
Mocho fine sandy loam	4,317,232	1.2%	2.79	L
Mocho silty clay loam	2,596,933	0.7%	0.83	L
Mocho variant fine sandy loam	28,632,325	7.9%	1.83	L
Oceano sand, 0 to 9 percent slopes	127,730,677	35.4%	1.95	L
Oceano sand, 9 to 30 percent slopes	9,468,287	2.6%	1.95	L
Pismo loamy sand, 9 to 30 percent slopes	1,892,328	0.5%	1.10	L
Pismo-Tierra complex, 9 to 15 percent slopes	3,515,131	1.0%	1.53	L
Psamments and Fluvents, occasionally flooded	292,467	0.1%	1.70	L
Psamments and Fluvents, wet	8,052,191	2.2%	1.82	L
Riverwash	1,176,495	0.3%	2.45	L
Salinas silty clay loam, 2 to 9 percent slopes	361,412	0.1%		L
Still gravelly sandy clay loam, 2 to 9 percent slopes	372	0.0%	4.18	H
Tierra sandy loam, 2 to 9 percent slopes	2,217,333	0.6%	1.59	L
Xererts-Xerolls-Urban land complex, 0 to 15 percent slop	1,930,866	0.5%		
Xerorthents, escarpment	7,487,516	2.1%		
TOTAL ($feet^2$)	360,810,607	100.0%		
TOTAL (acres)	8,283			

H = High Capacity
L = Low Capacity

Table 4. Description and Curve Numbers by Land Use Types

	Cover Description		Curve Number for Hydrologic Soil Group			
Land Use Description on Input Screen	**Cover Type and Hydrologic Condition**	**% Impervious Area**	**A**	**B**	**C**	**D**
Agricultural	Truck Crops	0	64	75	82	85
Commercial	Urban Districts: Commerical and Business	85	89	92	94	95
Forest	Woods	0	30	55	70	77
Grass/Pasture	Pasture, Grassland, or Range	0	39	61	74	80
High Density Residential	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Industrial	Urban district: Industrial	72	81	88	91	93
Low Density Residential	Residential districts by average lot size: 1/2 acre lot	25	54	70	80	85
Open Spaces	Open Space (native vegetation, bare ground, lawns, parks, golf courses, cemeteries, etc.)	0	49	69	79	84
Parking and Paved Spaces	Impervious areas: Paved parking lots, roofs, drivesways, etc. (excluding right-of-way)	100	98	98	98	98
Residential 1/8 acre	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Residential 1/4 acre	Residential districts by average lot size: 1/4 acre	38	61	75	83	87
Residential 1/3 acre	Residential districts by average lot size: 1/3 acre	30	57	72	81	86
Residential 1/2 acre	Residential districts by average lot size: 1/2 acre	25	54	70	80	85
Residential 1 acre	Residential districts by average lot size: 1 acre	20	51	68	79	84
Residential 2 acres	Residential districts by average lot size: 2 acre	12	46	65	77	82
Water/ Wetlands		0	0	0	0	0

Source: Purdue Research Foundation 2006

Table 5. Area by Land Use and Soil Type

Land Use	Ground Cover	Curve Number	Total Area (acres)
High Capacity (Soil Group C)			
Agricultural	Truck Crops	82	1,047
Agricultural	Pasture	74	4
Native	Bare	79	27
Native	Vegetation	79	
Urban	Turf	88	263
TOTAL			1,341
Low Capacity (Soil Group A)			
Agricultural	Truck Crops	64	469
Agricultural	Pasture	39	63
Native	Bare	49	1,385
Native	Vegetation	49	1,655
Urban	Turf	73	3,407
TOTAL			6,979
GRAND TOTAL			8,320

Table 6. Monthly ET Coefficients by Land Use Types

		ET Coefficent, Kco											
Area type	**Ground Cover**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Urban Landscaping	Turf	0.67	0.67	0.67	0.96	0.96	0.96	0.85	0.85	0.85	0.68	0.68	0.68
Agricultural	Truck Crops	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Agricultural	Pasture	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
Dune Land	Bare ground	1.10	0.85	0.48	0.28	0.20	0.19	0.18	0.18	0.21	0.28	0.45	0.80
Native Riparian	Riparian	1.10	0.85	0.48	0.28	0.20	0.19	0.18	0.18	0.21	0.28	0.45	0.80

Source: CIMIS, 2006

Table 7. Information on Infiltration Ponds

City	Name	Pond Size (AF)	Watershed Area (AC)	Year Built
AG	South Elm Street	5.1	65.7	pre-1985
AG	Golden West Farroll Ave	0.6	10	pre-1985
AG	Ash Street Basin	96.9	457	pre-1985
AG	Poplar Street	15	76	pre-1985
AG	Grand Ave/ Courtland Street	5.7	21.1	pre-1985
AG	Berry Gardens	12.25	50.8	2001
AG	Village Glen Basin	6.81	31.6	
AG	Vista Del Mar Basin	2.57	40	2003
GB	Mentone	48.45	228.5	
SUM		193.38	980.7	

Table 8. City Water Supply Distribution by Customer Type

		Percent of City's Water Supply			
Type	**Percent Used Outdoors**	**Arroyo Grande**	**Pismo Beach***	**Oceano**	**Grover Beach****
Single Family	37	70.9		40.0	57.8
Multi-Family	10	7.0	5.0	40.0	17.4
Commerical/Industrial	10	14.5		10.0	20.9
Irrigation	100	3.6		5.0	0.0
Losses	100	4.0		5.0	4.0
TOTAL		100.0		100.0	100.2

Table 9. Assigned Hydraulic Conductivity (K) Values

Formation	Abbreviation	Assigned K-Value (gpd/ft^2)
Alluvial Deposits	Qal	200
Older Dune Sand	Qos	350
Paso Robles Formation	QTpr	100
Careaga Formation	Tpc	50
Squire Member, Pismo Formation	Tpps	50
Undifferentiated Tertiary Deposits	Tu	0*
Franciscan Complex	KJf	0*

* Highly consolidated units are considered non-conductive in this analysis

Table 10. Well Pairs Used for Calculation of Groundwater Gradient

State Well Number	
Upgradient	**Downgradient**
Inflow	
011N035W05G001	011N035W06J001
012N035W29R003	012N035W29N001
012N035W33L001	012N035W32G001
Outflow	
011N035W06J001	012N036W36L001
012N035W30K003	032S013E31R001
032S013E29F001	032S013E30F002
032S013E29M004	032S013E30K011
032S013E32D003	032S013E30N002

Table 11. Information on Municipal Pumping Wells

Wells

City	Well Name	State Well No	Lat	Long	Elevation (ft msl)	Year Drilled	Depth (feet)	Approx Location
Grover Beach	Well 1	032S013E29E001	35.1147	-120.6119	50.0	1951	178	
Grover Beach	Well 2	032S013E29E002	35.1148	-120.6114	50.0	1951	180	
Grover Beach	Well 3	032S013E29E003	35.1147	-120.6105	55.0	1959	178	
Grover Beach	OBS	032S013E29E006	35.1141	-120.6108	56.0	1978	300	
Grover Beach	Well 4	032S013E29E007	35.1141	-120.6108	56.0	1978	549	
Pismo Beach	Well 5	032S013E19Q002	35.1211	-120.6213	58.0	1973	500	
Pismo Beach	Huber 22/23	032S013E30K019				1990	285	
Arroyo Grande	Well 9	032S013E17K001				1990	389	Oak Park
Arroyo Grande	Well 1	032S013E29G001	35.1128	-120.6010	83.0	1940	175	375 Ash St
Arroyo Grande	Well 5	032S013E29F001	35.1147	-120.6060	75.0	1967	200	375 Ash St
Arroyo Grande	Well 3	032S013E29G002	35.1144	-120.6013	84.0	1954	233	375 Ash St
Arroyo Grande	Well 6	032S013E29G003	35.1130	-120.6013	80.0	Irrigation		375 Ash St
Arroyo Grande	Well 4	032S013E29G014				1964	233	375 Ash St
Arroyo Grande	Well 7	032S013E29G015				1982	580	375 Ash St
Arroyo Grande	Well 8	032S013E29G016				1990	251	375 Ash St
Arroyo Grande	Well 2					Inactive		375 Ash St
Oceano CSD	OCSD #4	032S013E32D003	35.1052	-120.6104	90.3	1984	200	
Oceano CSD	OCSD #6	032S013E32D011	35.1053	-120.6103	87.3	1979	607	
Oceano CSD	OCSD #7	032S013E31H008	35.1022	-120.6162	39.6	1984	162	
Oceano CSD	OCSD #8	032S013E31H009	35.1020	-120.6165	35.0	1984	525	

Table 12. Distribution of Crops in the Northern Cities Area

Crop Type	Percent of Crop Land
Lettuce	40.3
Cole Crops	13.3
Strawberries	11.2
Miscellaneous Truck Crops	33.5
Pasture	1.1
Grain	0.5

Source: 1996 DWR Land Use Map

Table 13. Agricultural Applied Water by General Crop Type

	Applied Water AF per Acre	Irrigated Land (acres)		Harvested Land (acres)		TOTAL WATER USE (AFY)		
Crop Type	**Avg**	**1985**	**1996**	**1985**	**1996**	**1985**	**1996**	**AVG**
Grain	0.46	0	8	0	8	0	3.6	2
Pasture	2.81	13	50	13	50	36.2	141.2	89
Truck	0.95	1,748	1,594	3,496	3,188	3,329	3,036	3,183
Citrus / Subtropical	2.40	13	0	13	0	30.9	0	15
Total		1,774	1,652	3,521	3,246	3,396	3,181	3,289

FIGURES

Figure 1
Northern Cities Study Area

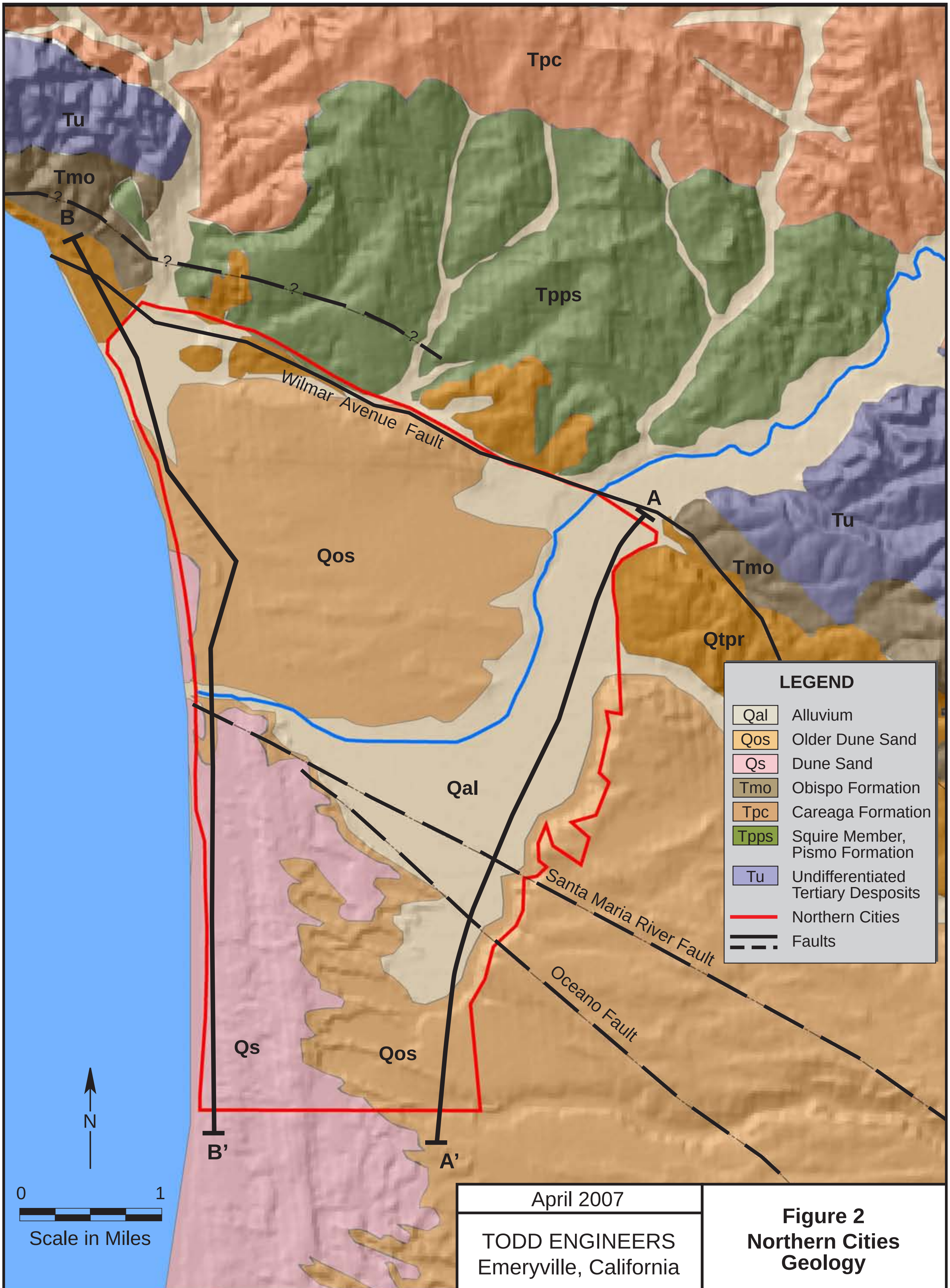

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Figure 2
Northern Cities Geology

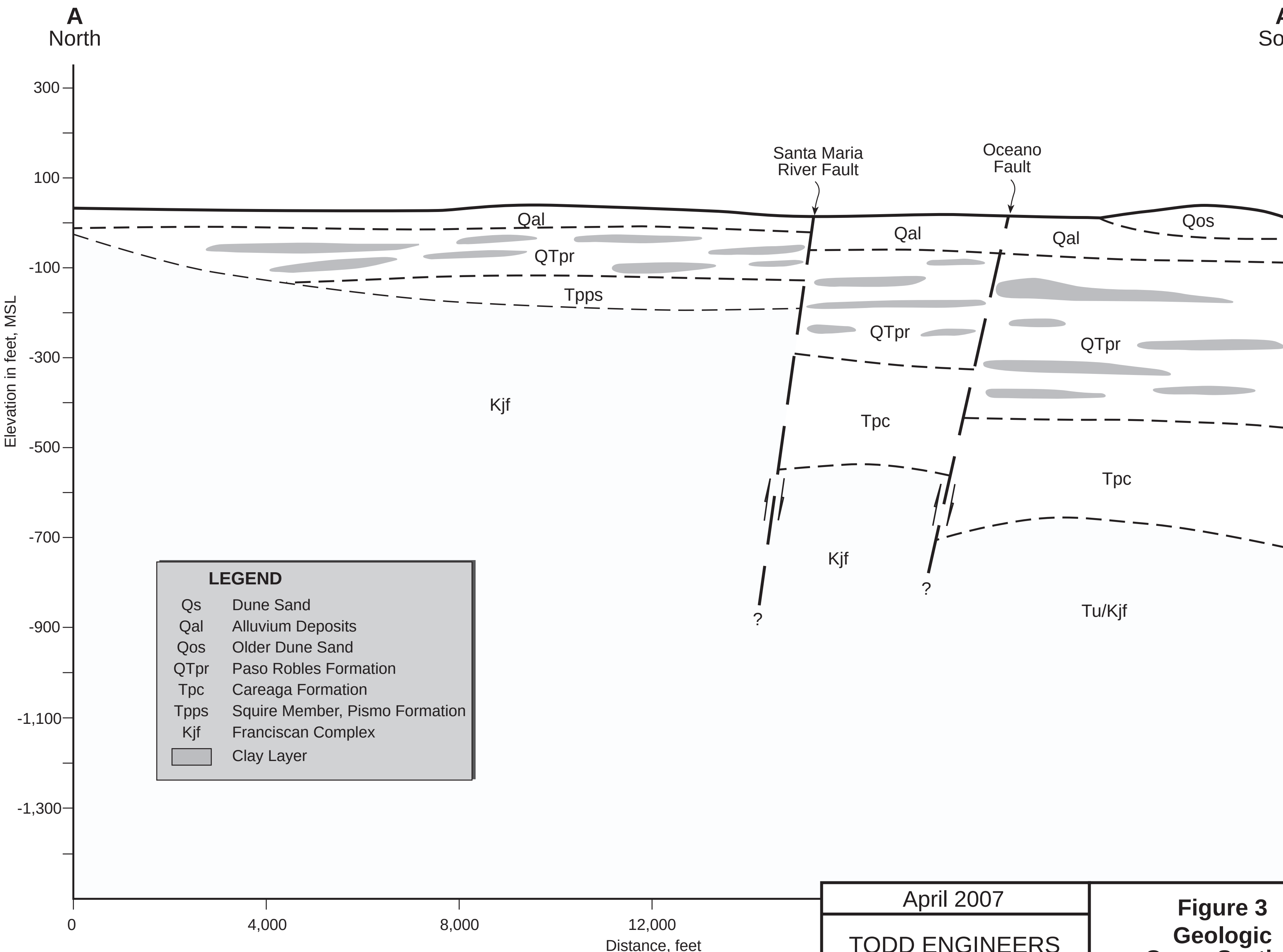

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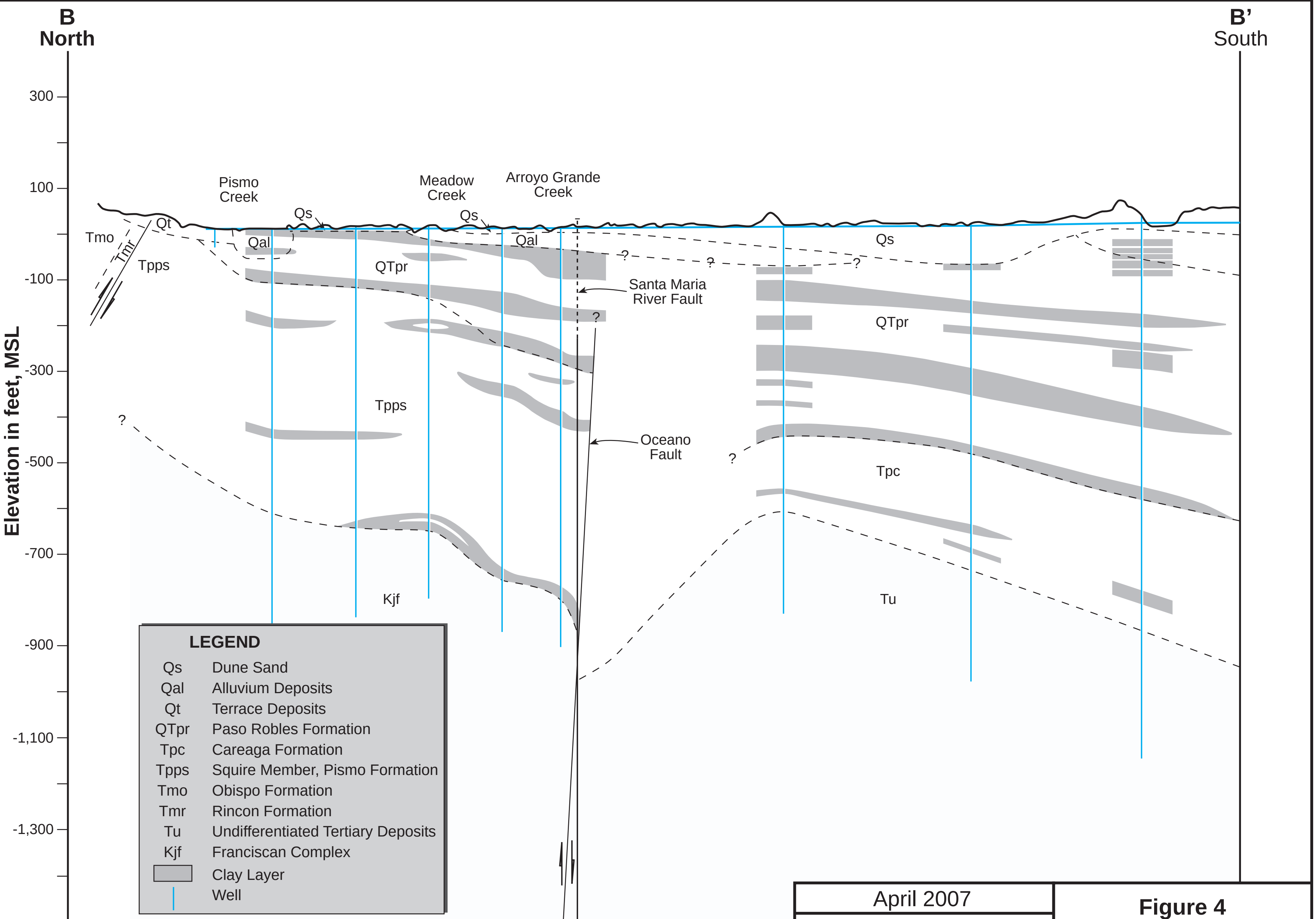
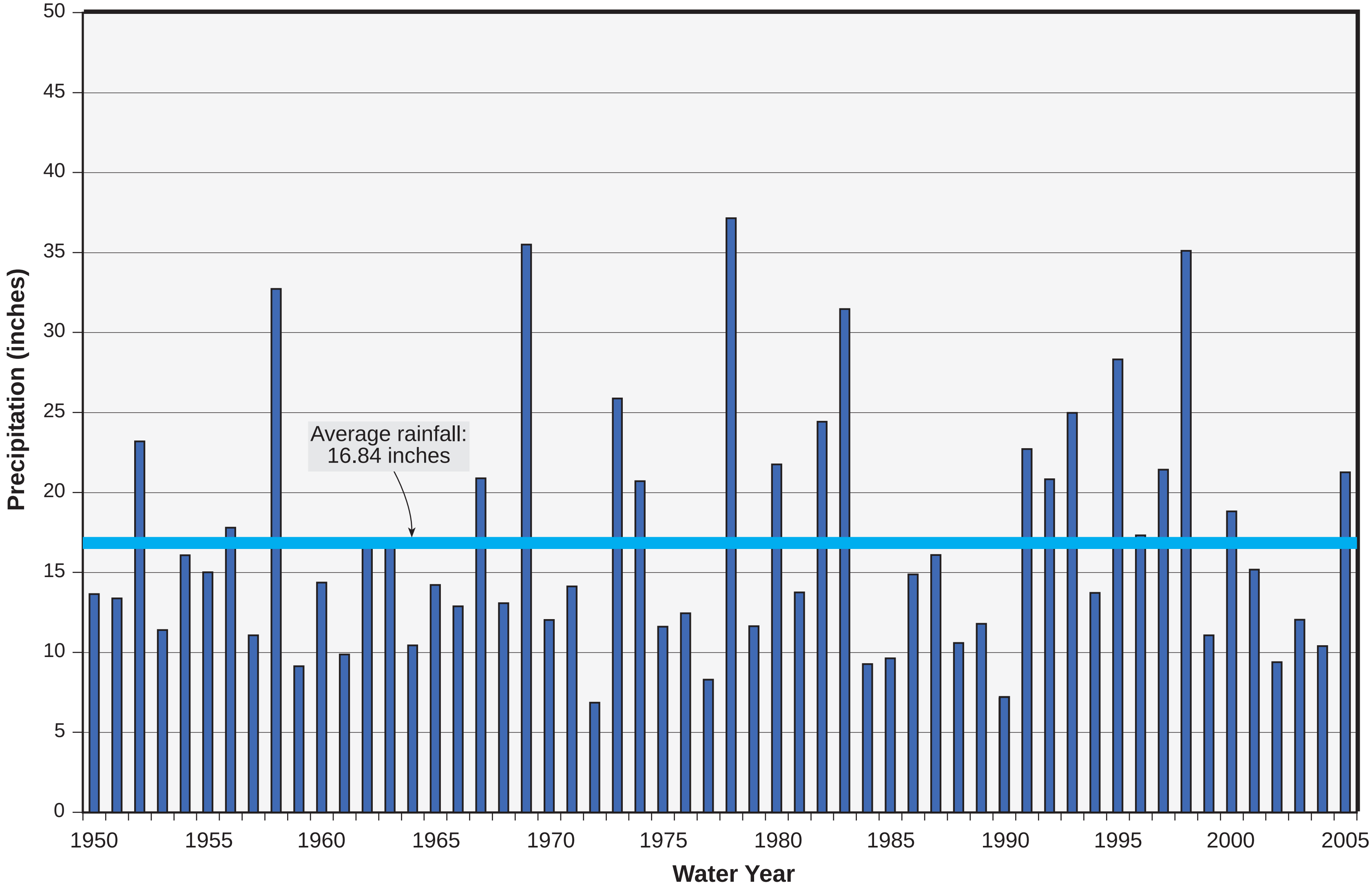
Figure 3
Geologic Cross Section A- A'

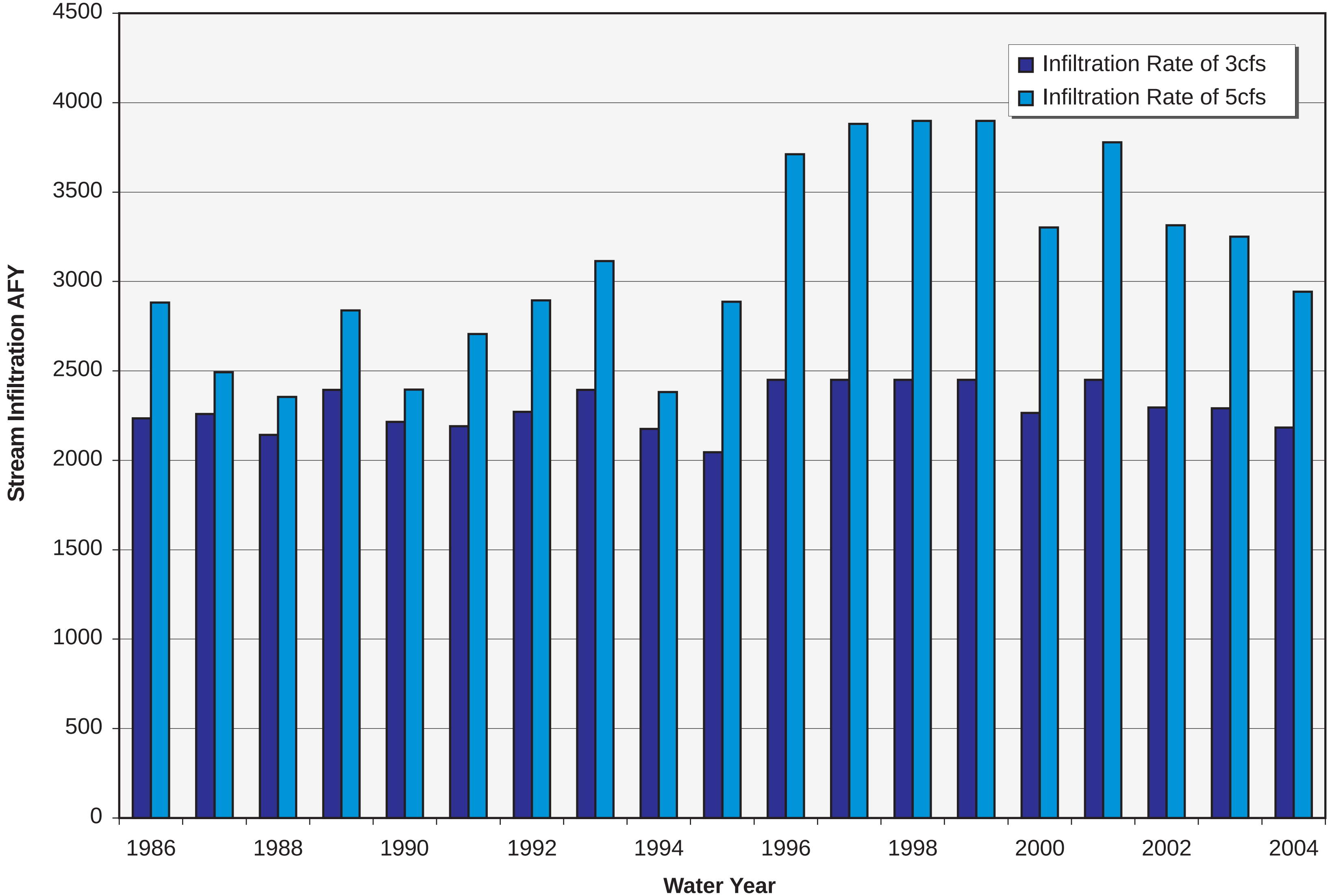


Note: Adapted from DWR, 2002b.

April 2007	**Figure 4**
TODD ENGINEERS Emeryville, California	**Geologic Cross Section B- B'**



April 2007	**Figure 5**
TODD ENGINEERS Emeryville, California	**Rainfall at Pismo Beach**



April 2007	**Figure 6**
TODD ENGINEERS Emeryville, California	**Annual Stream Infiltration**

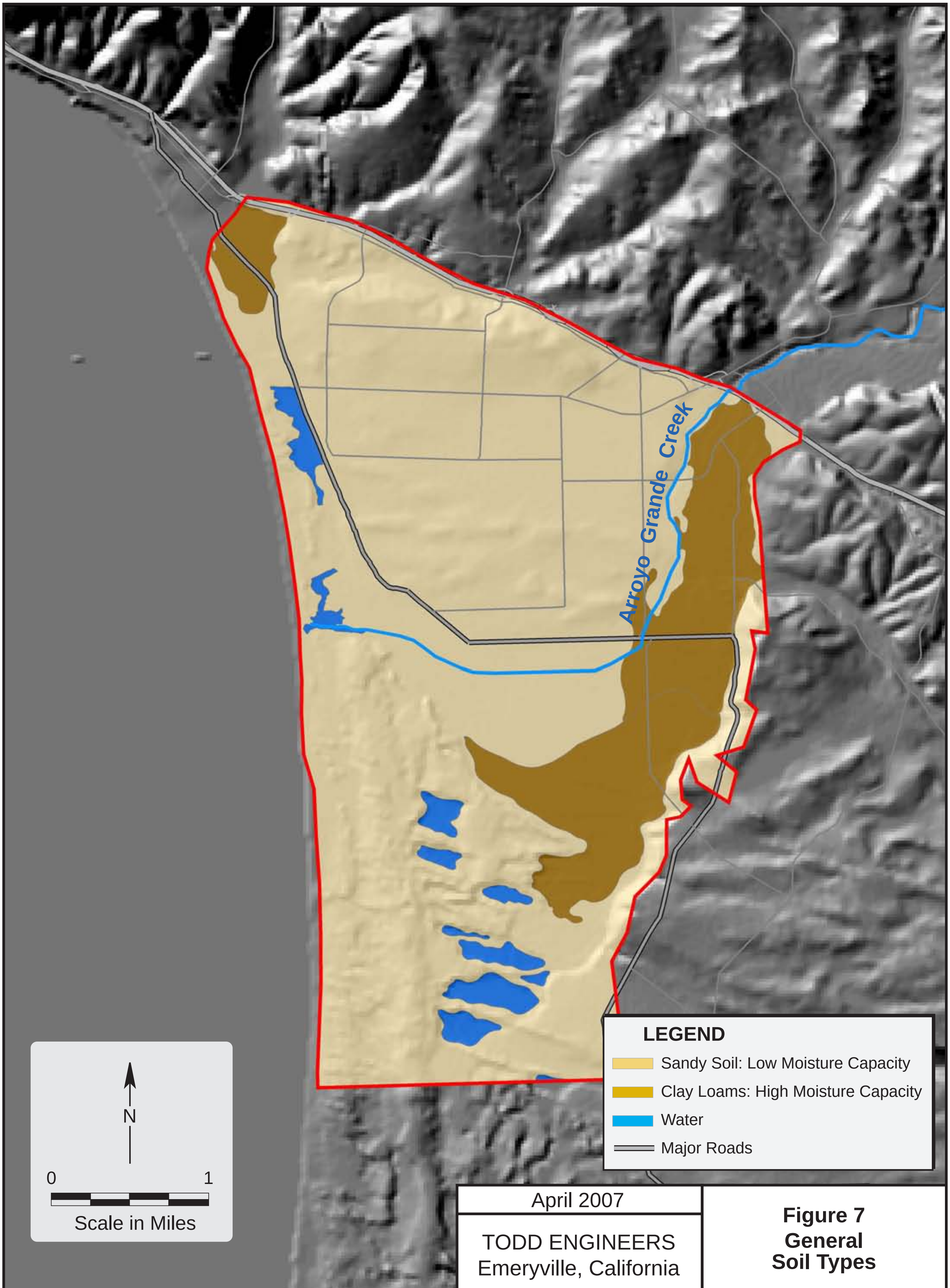


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Figure 7
General Soil Types

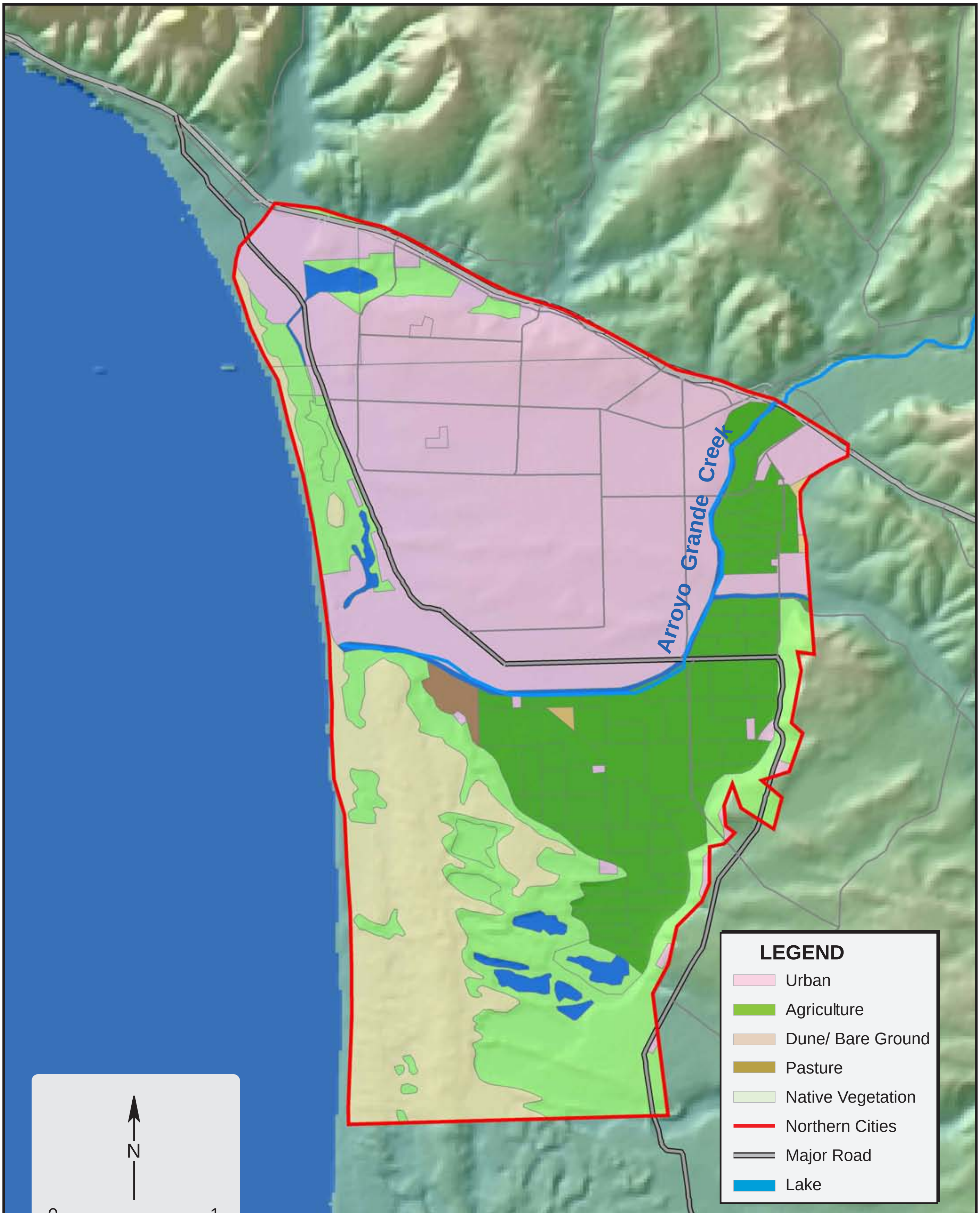

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Figure 8
Land Use in the Northern Cities Area 1996

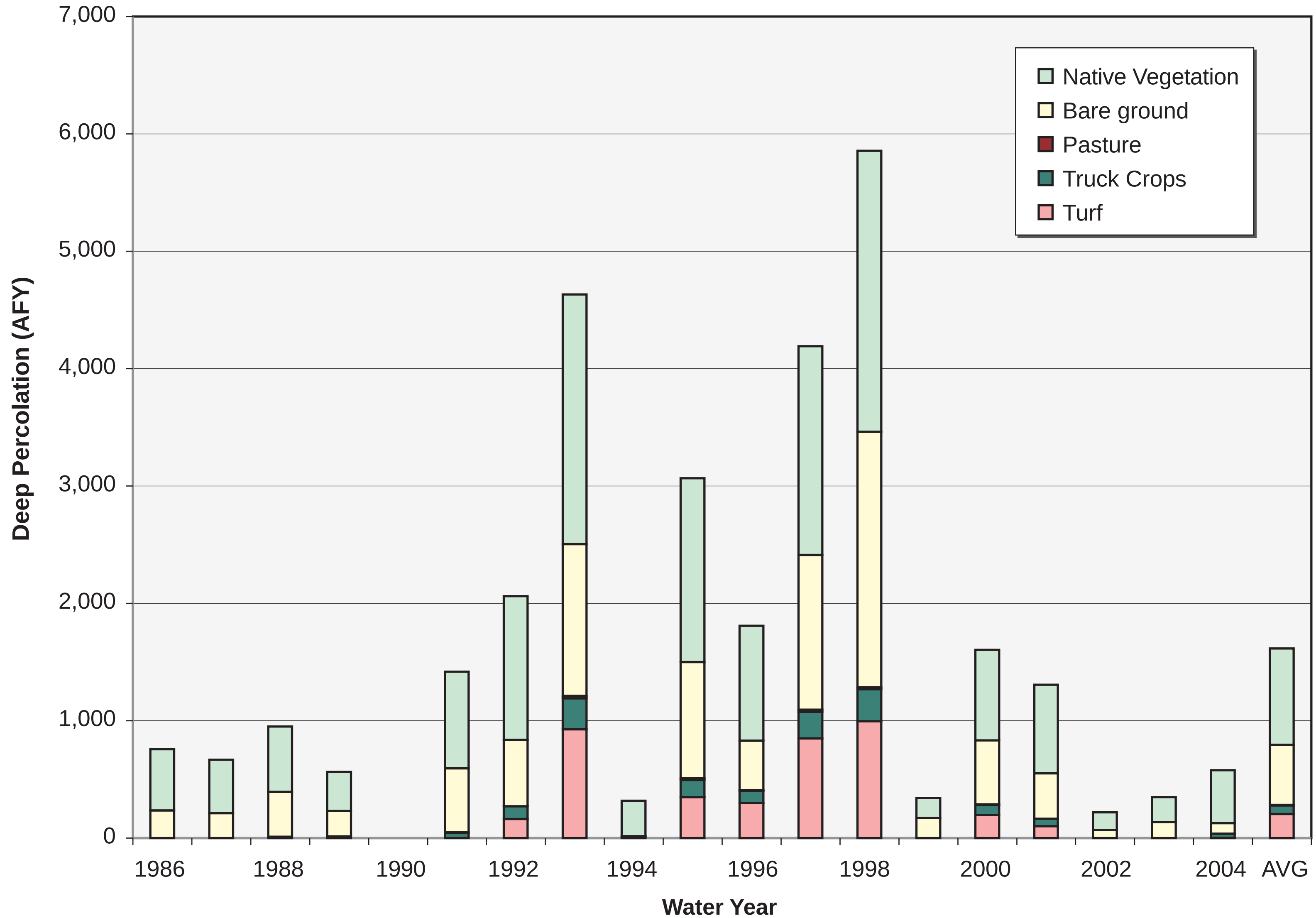

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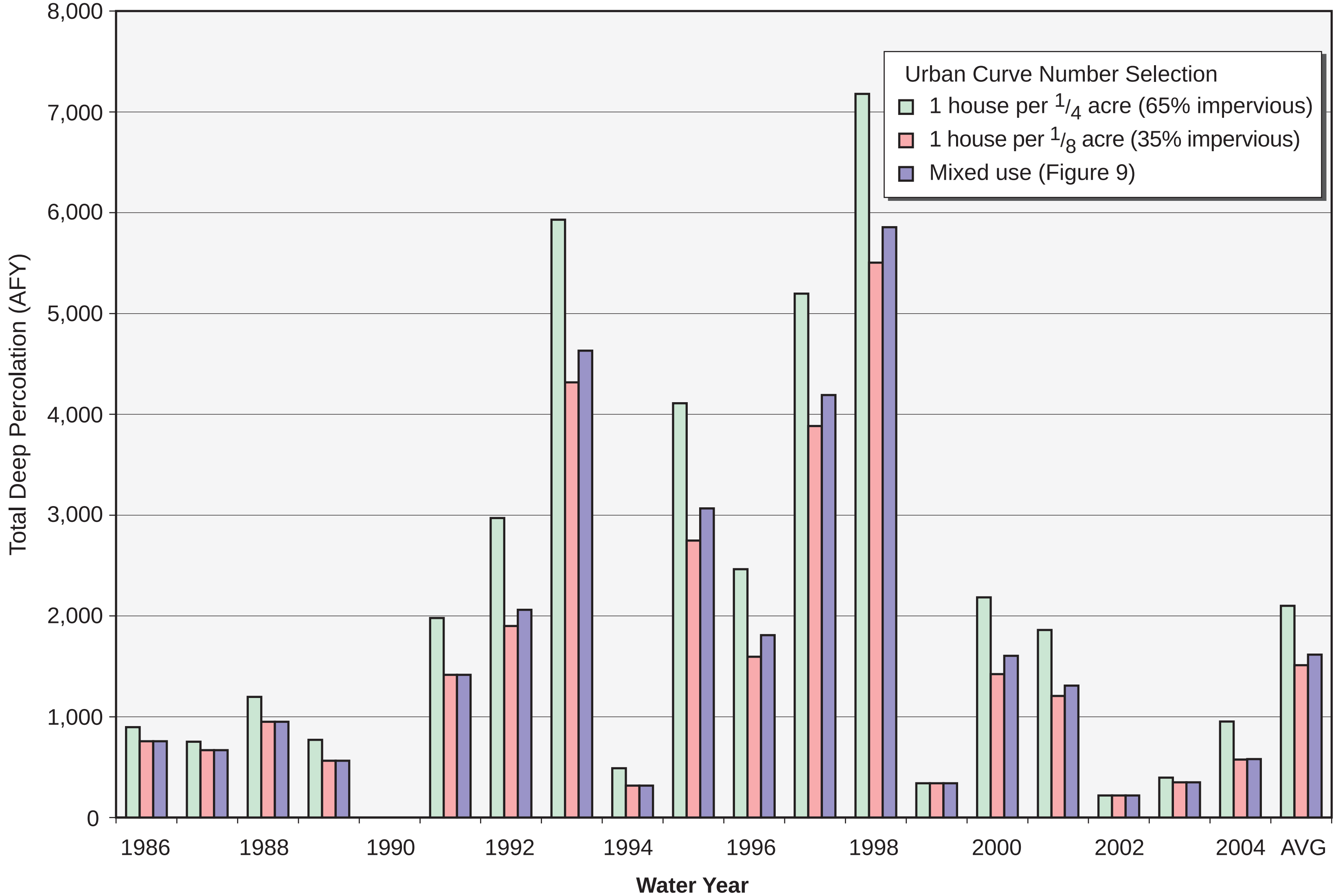
Figure 9
Annual
Deep Percolation



April 2007	Figure 10 Annual Deep Percolation Testing Assumptions
TODD ENGINEERS Emeryville, California	

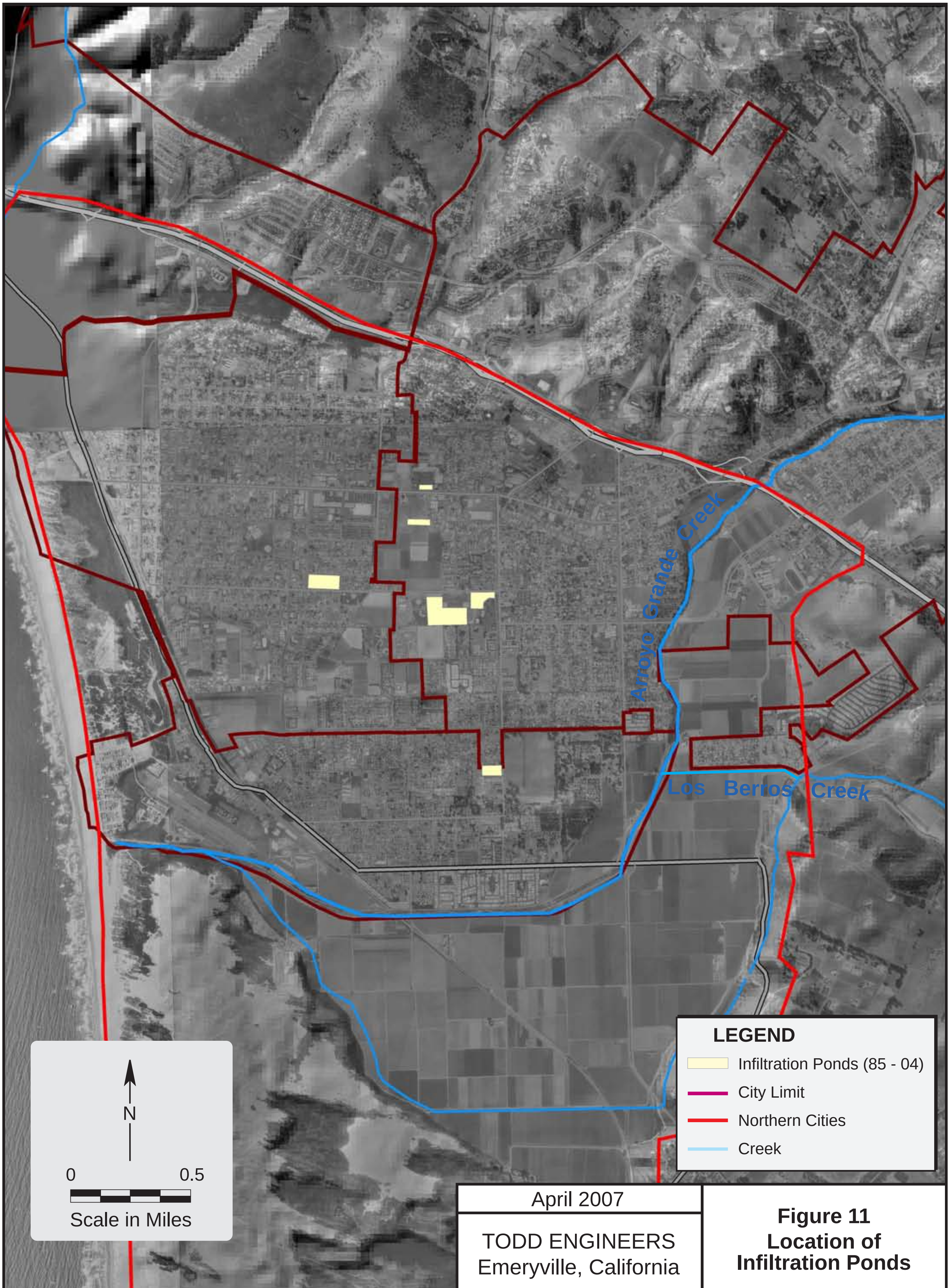


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Figure 11
Location of Infiltration Ponds

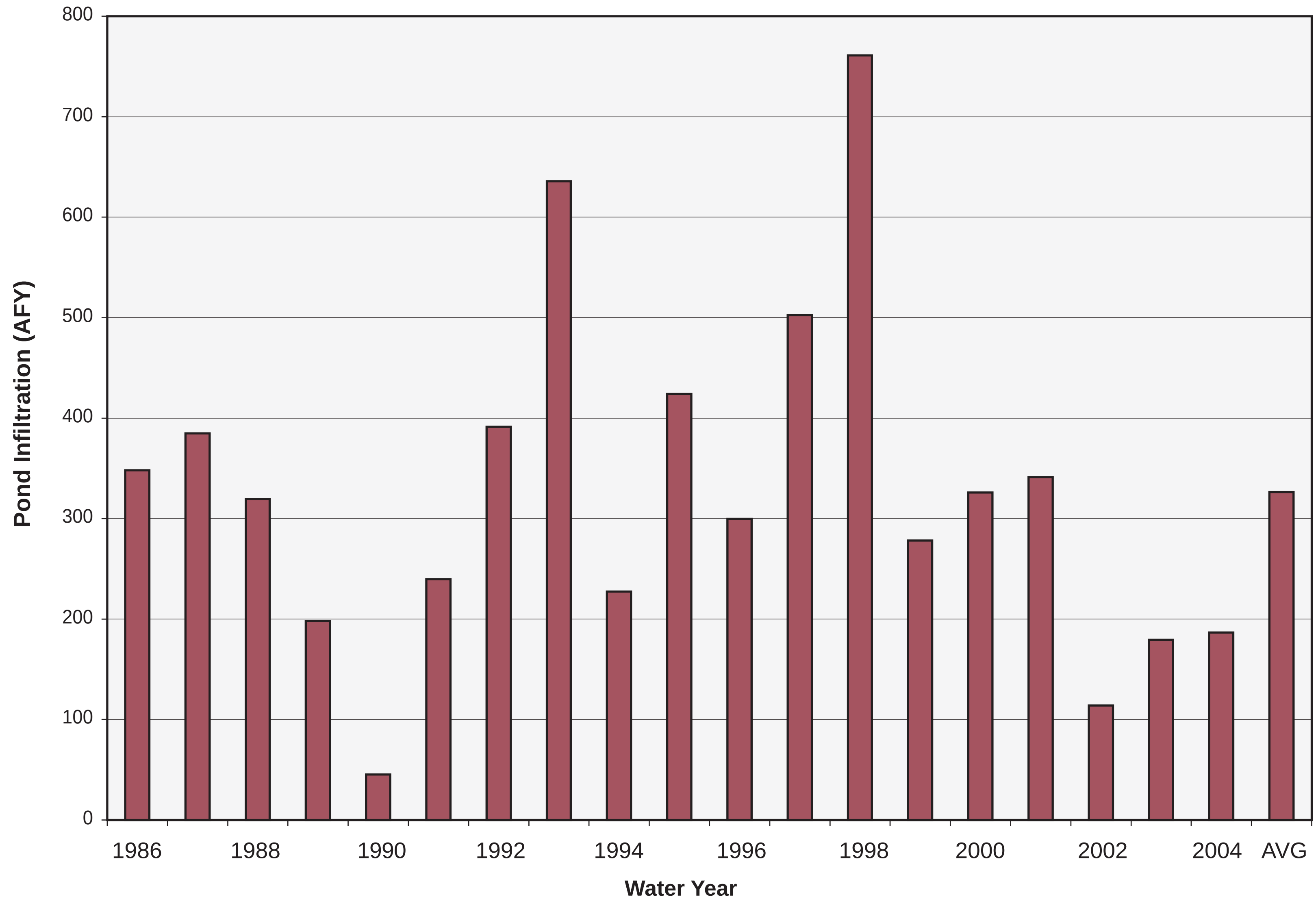

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Figure 12
Annual Infiltration From Ponds

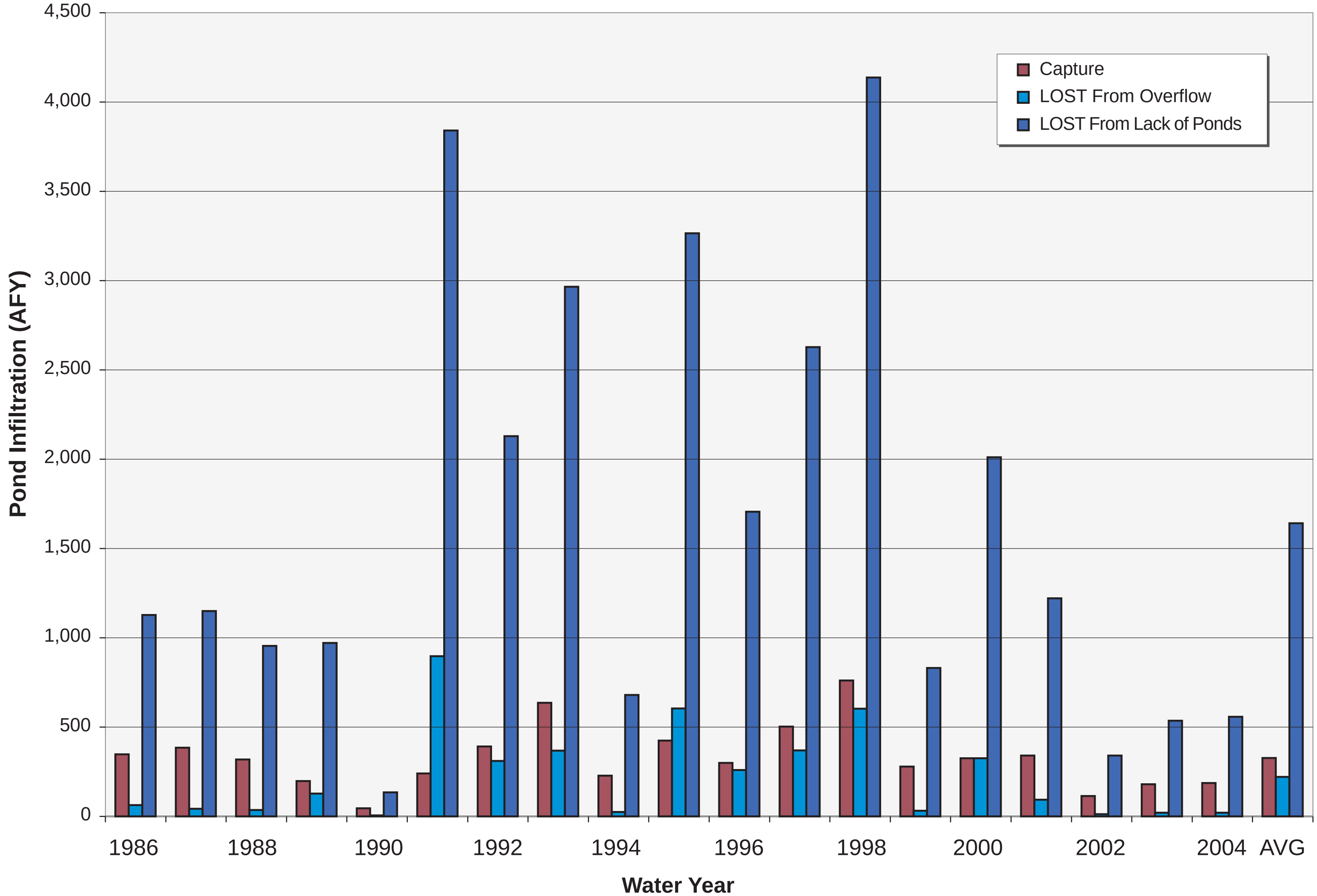

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Figure 13
Annual Runoff Not Captured by Infiltration Ponds

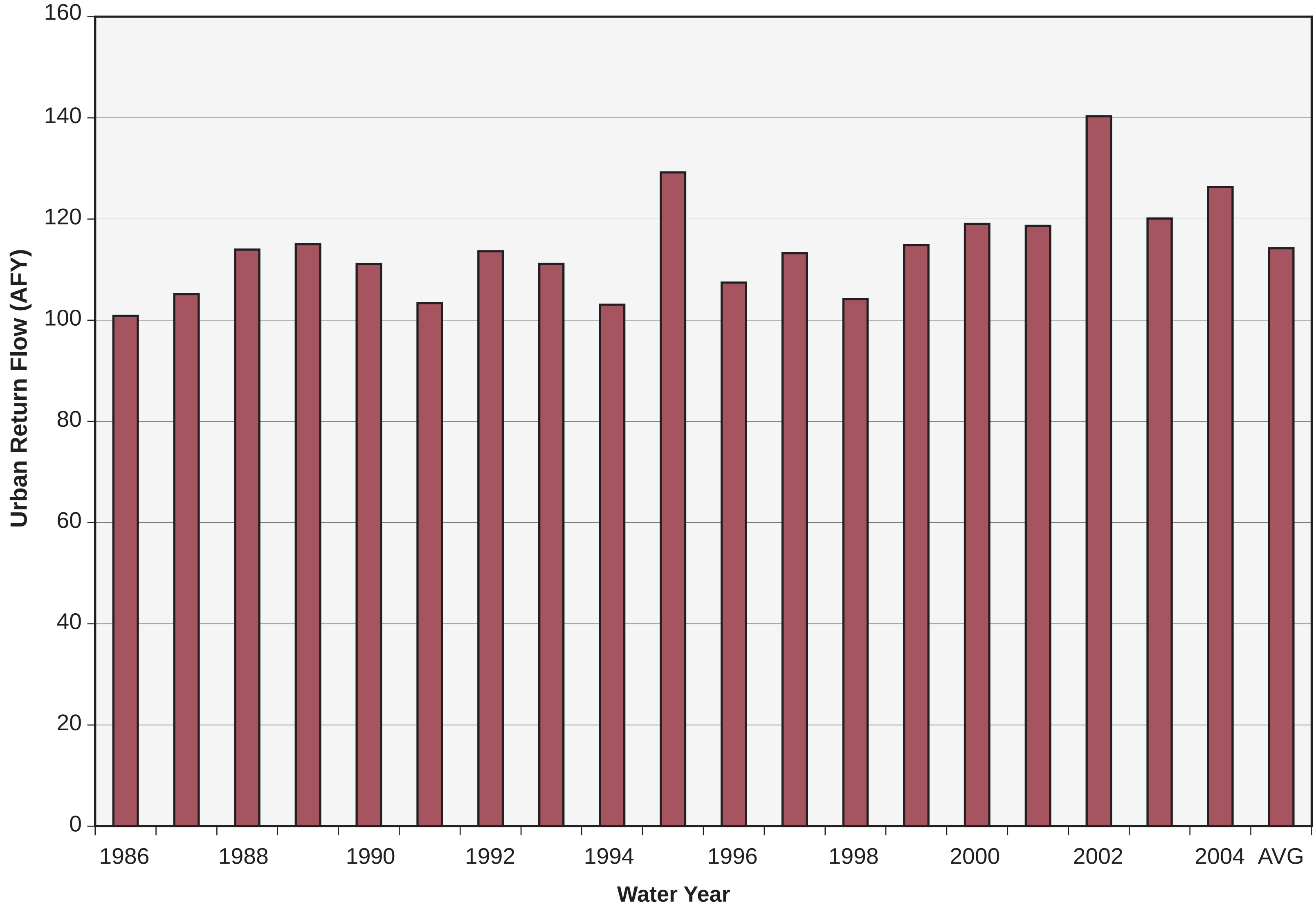

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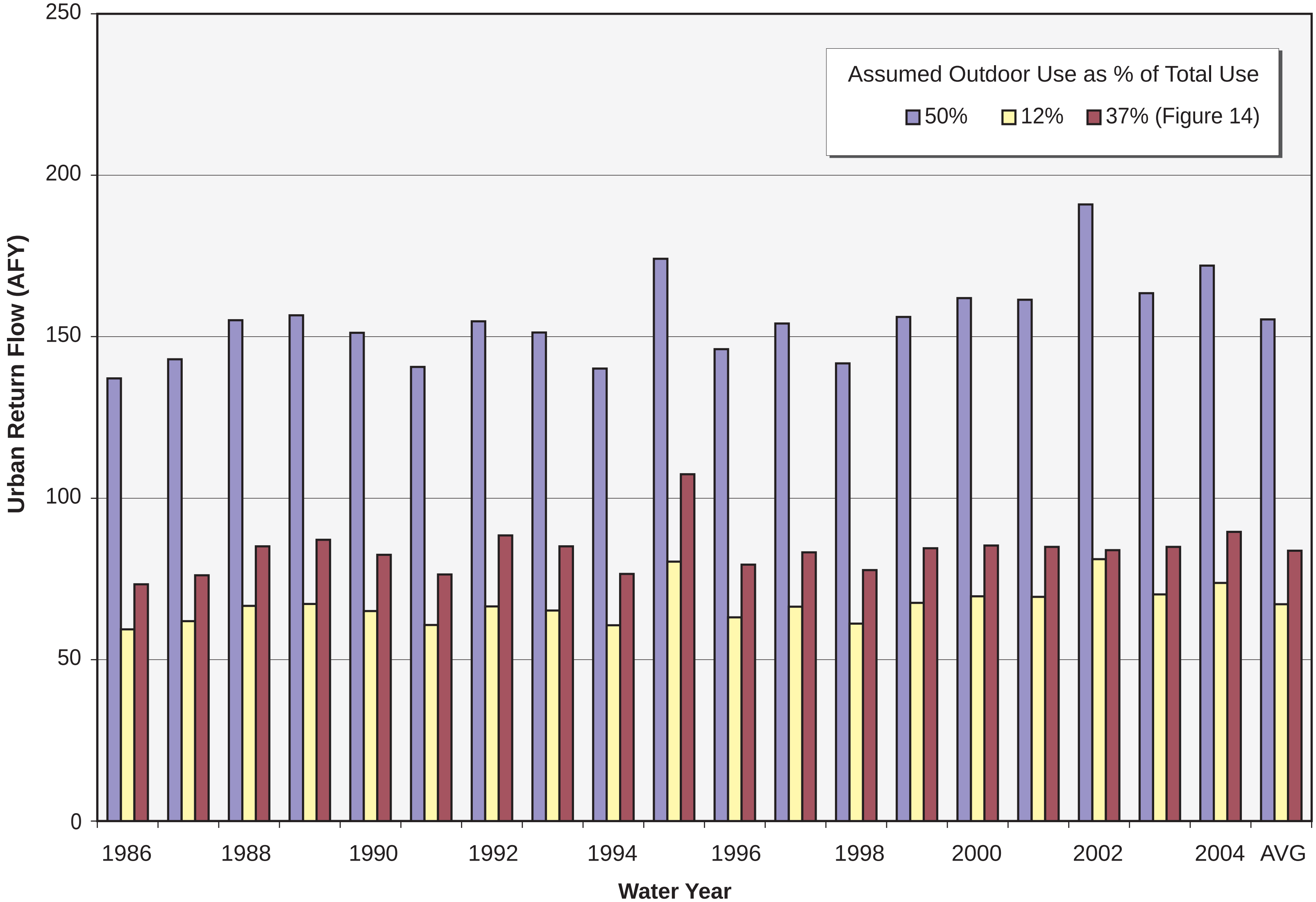
Figure 14
Annual Urban Return Flow Rate



April 2007	**Figure 15** **Annual Urban Return Flow Testing Assumptions at 12, 37,and 50%**
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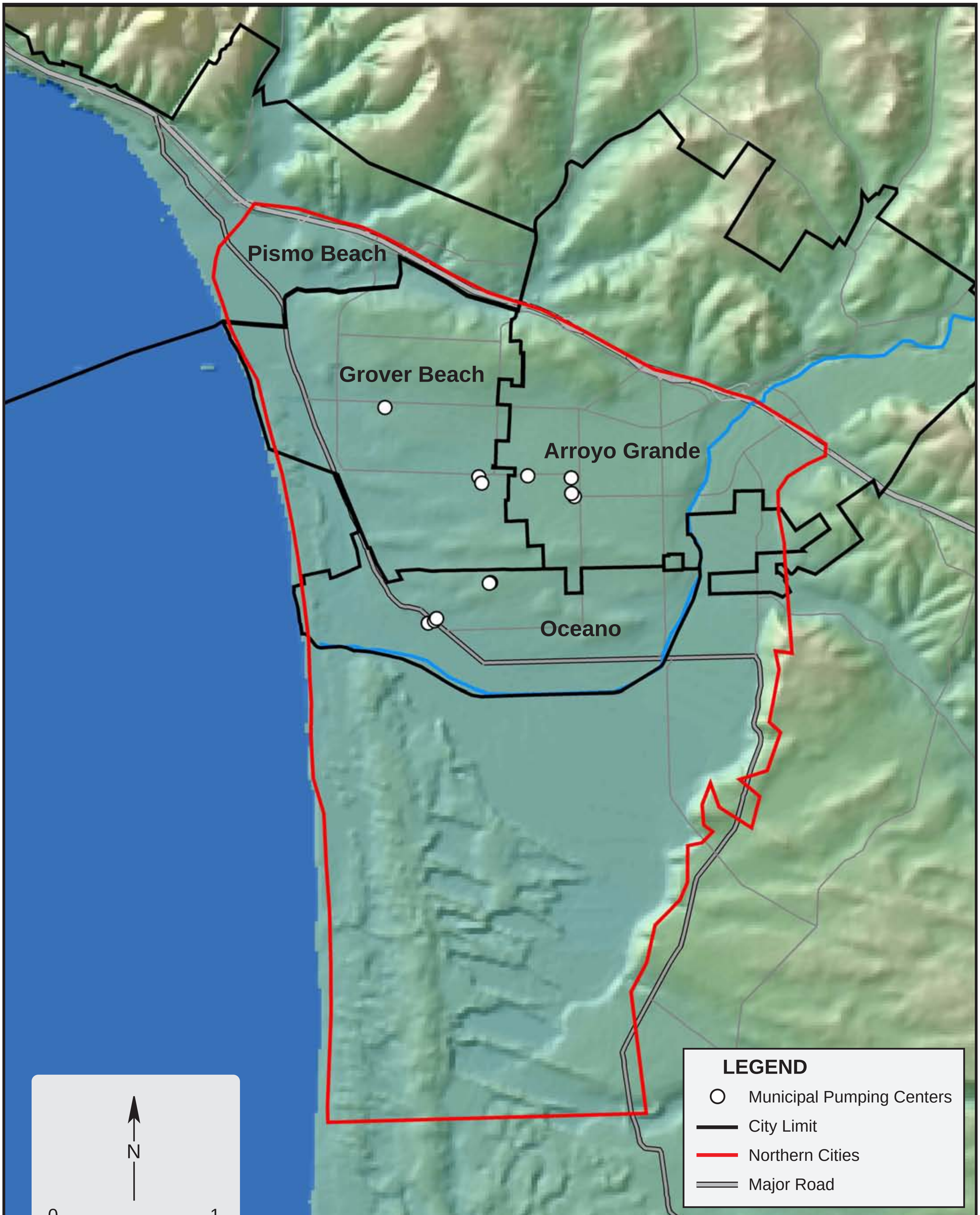

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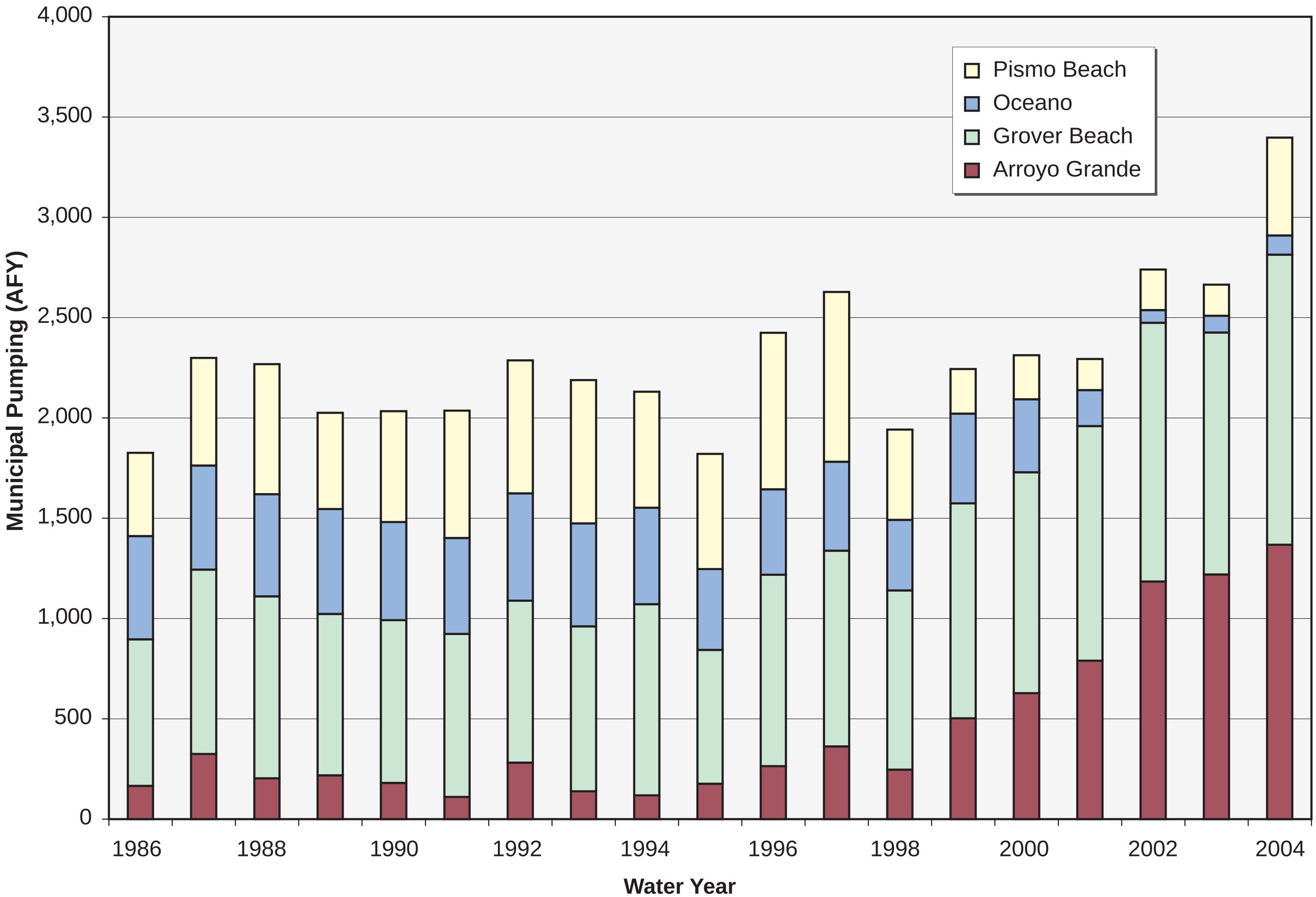
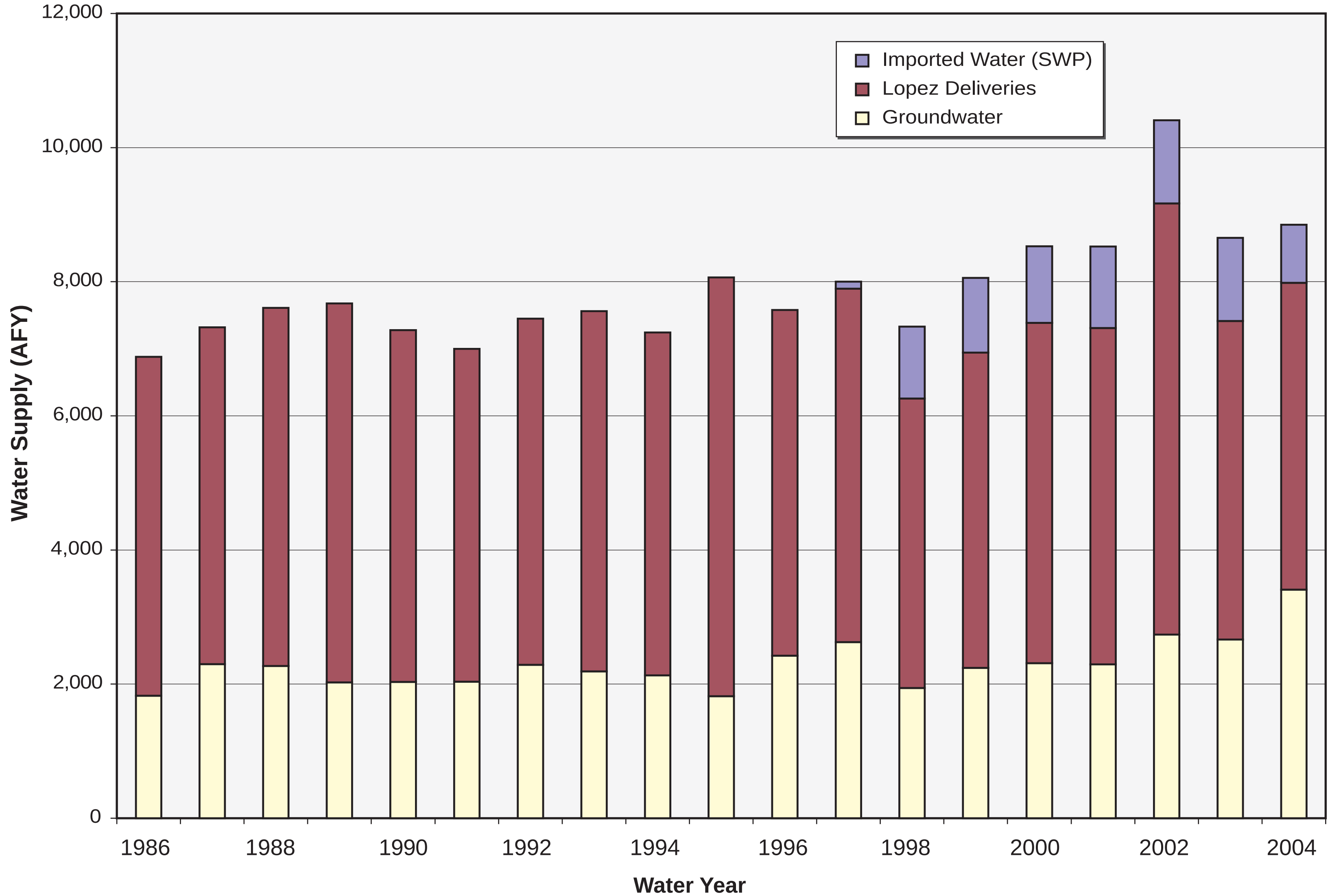
Figure 16
Locations of Cities and Wells



April 2007	**Figure 17**
TODD ENGINEERS Emeryville, California	**Annual Urban Groundwater Pumping**



Water supply for Pismo Beach, Arroyo Grande, Grover Beach, and Oceano.
Note: SWP water to Oceano not included in totals.

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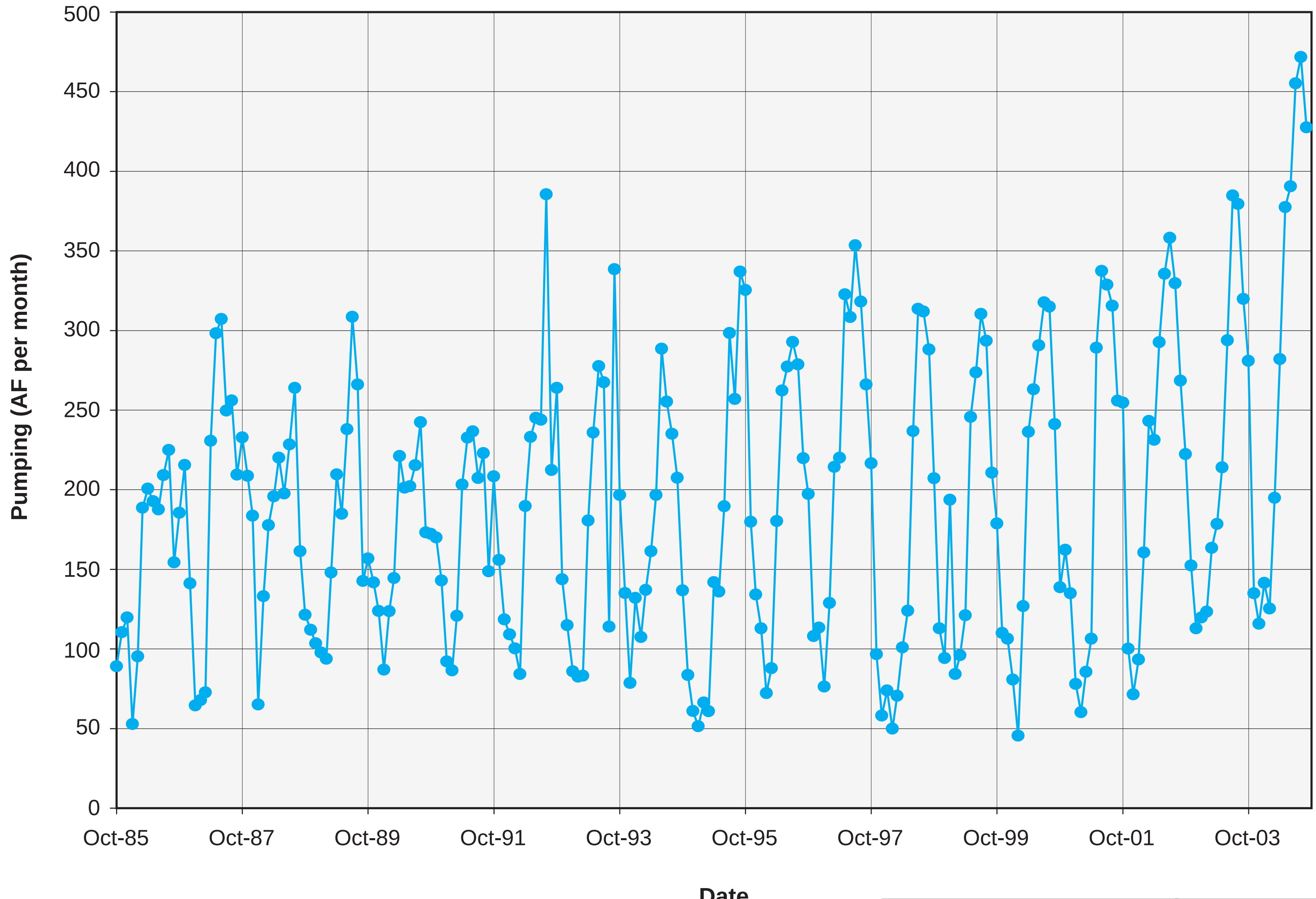
Figure 18
Annual Total Urban Water Supply



April 2007	**Figure 19**
TODD ENGINEERS Emeryville, California	**Monthly Urban Pumping**

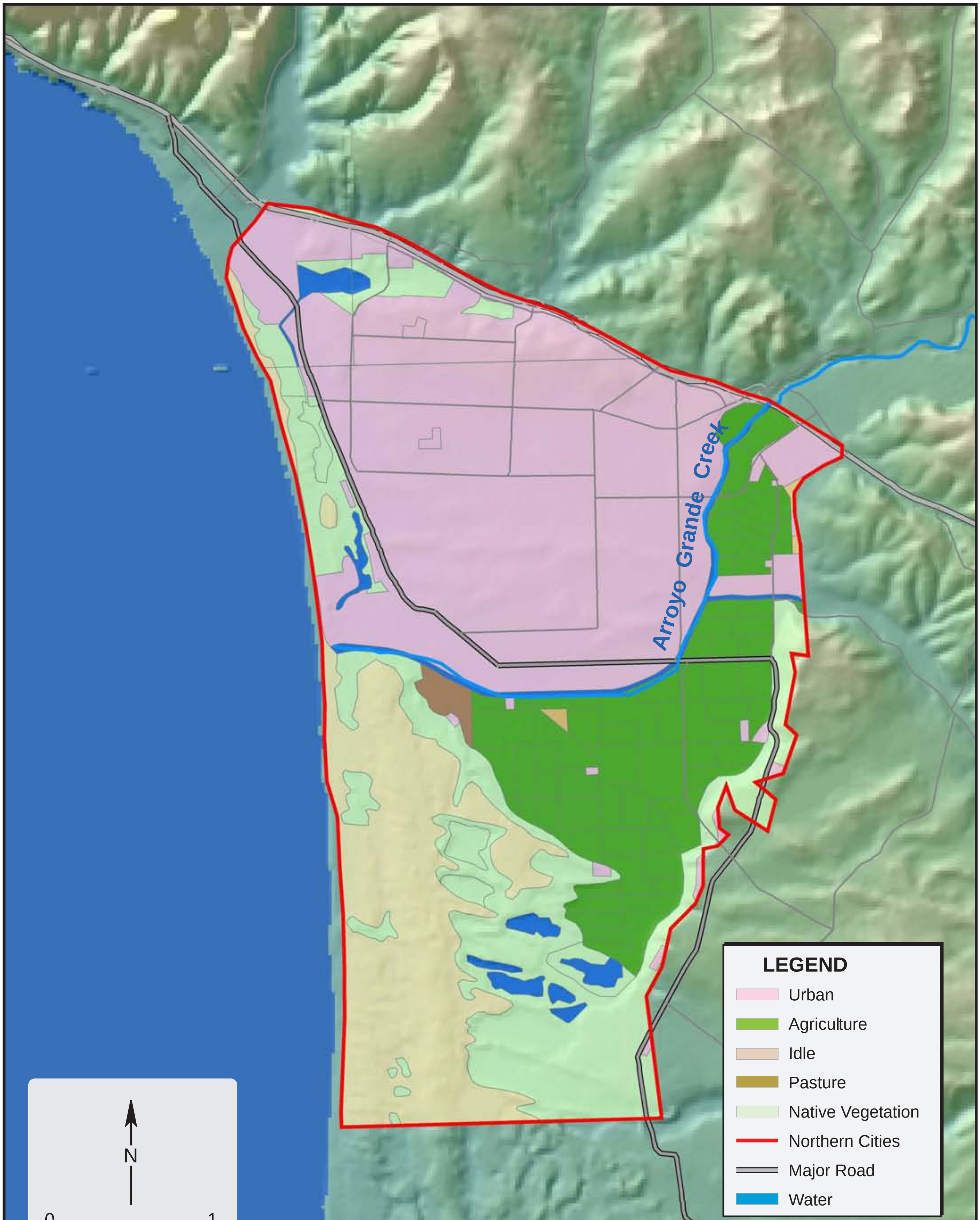


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Figure 20
Land Use in the Northern Cities Area 1985

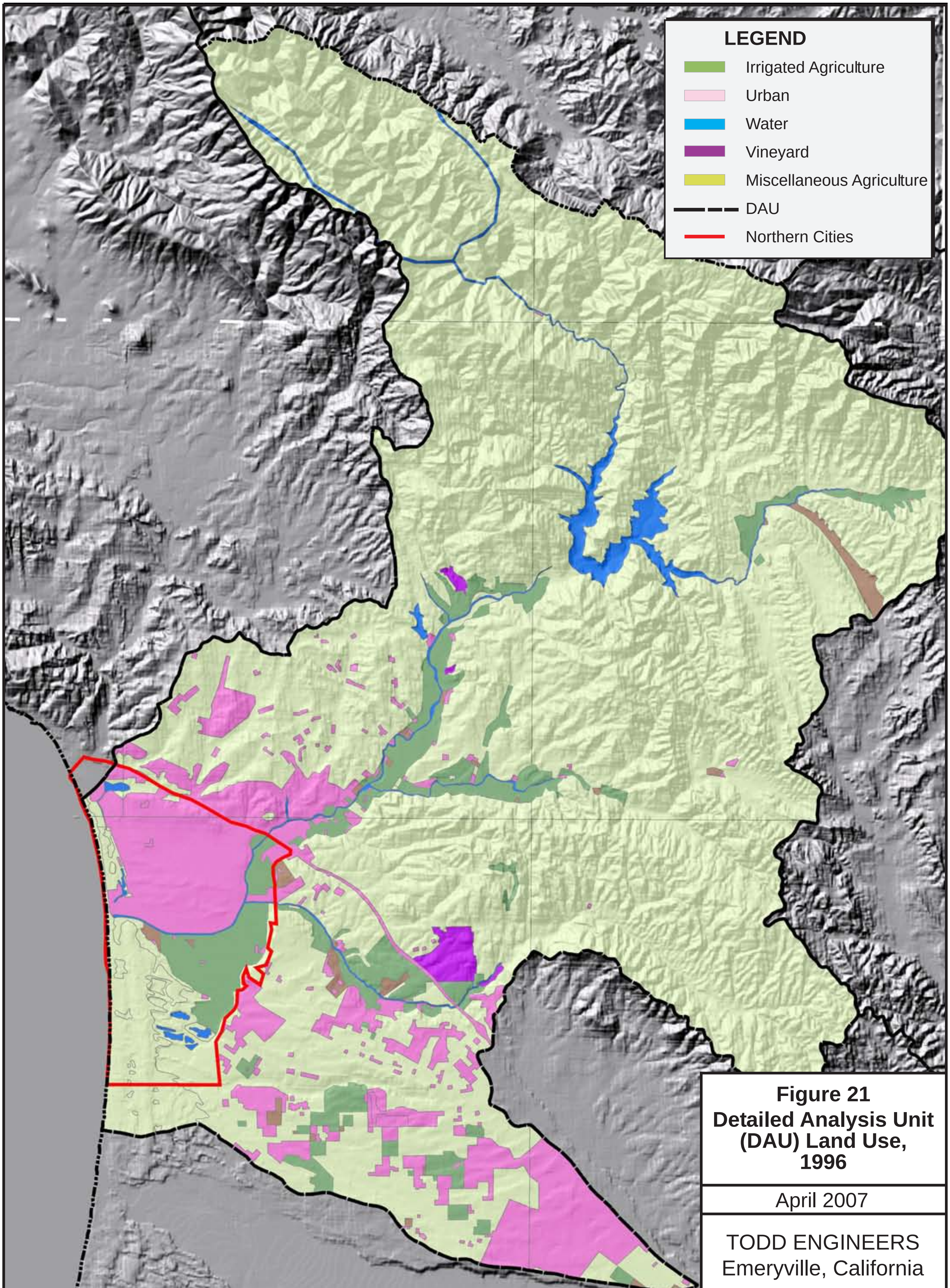

Figure 21
Detailed Analysis Unit (DAU) Land Use, 1996

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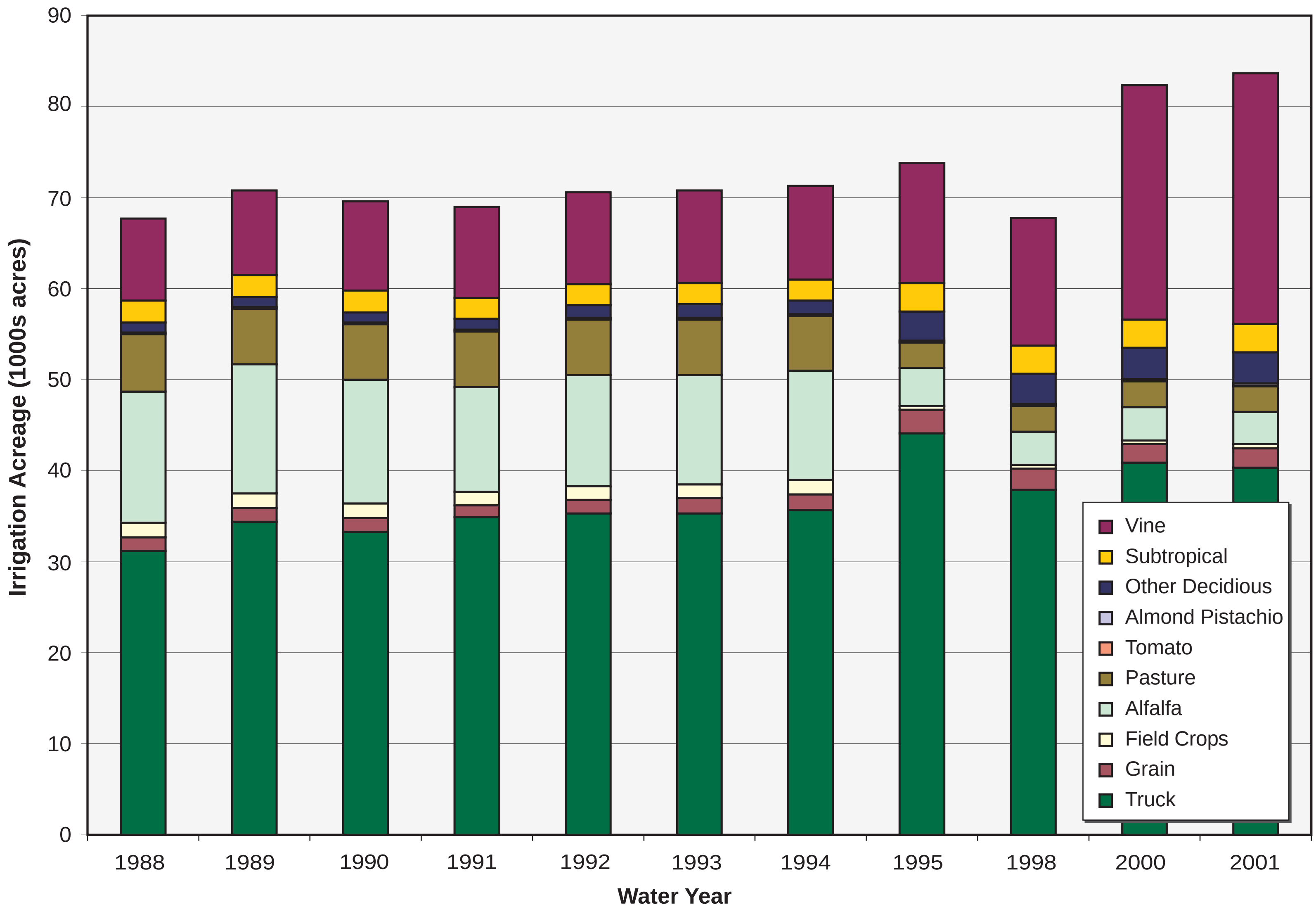
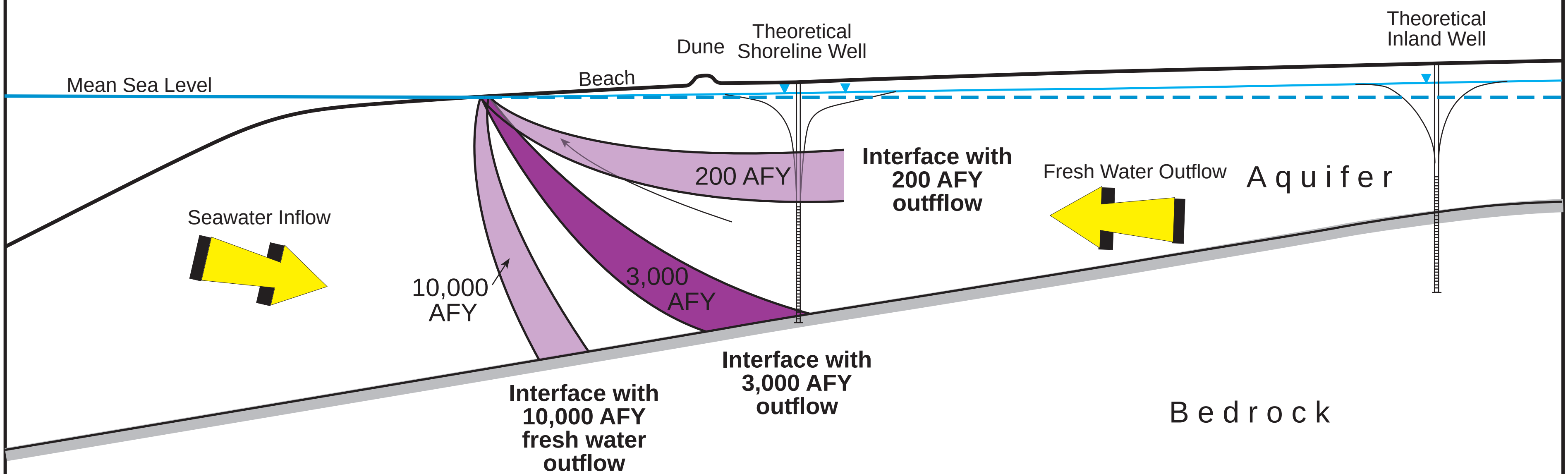


April 2007	**Figure 22**
TODD ENGINEERS Emeryville, California	**Annual San Luis Obispo County Irrigation Acreage**



not to scale
illustrative only

April 2007	**Figure 23**
TODD ENGINEERS Emeryville, California	**Geometry of Seawater/Freshwater Interface**

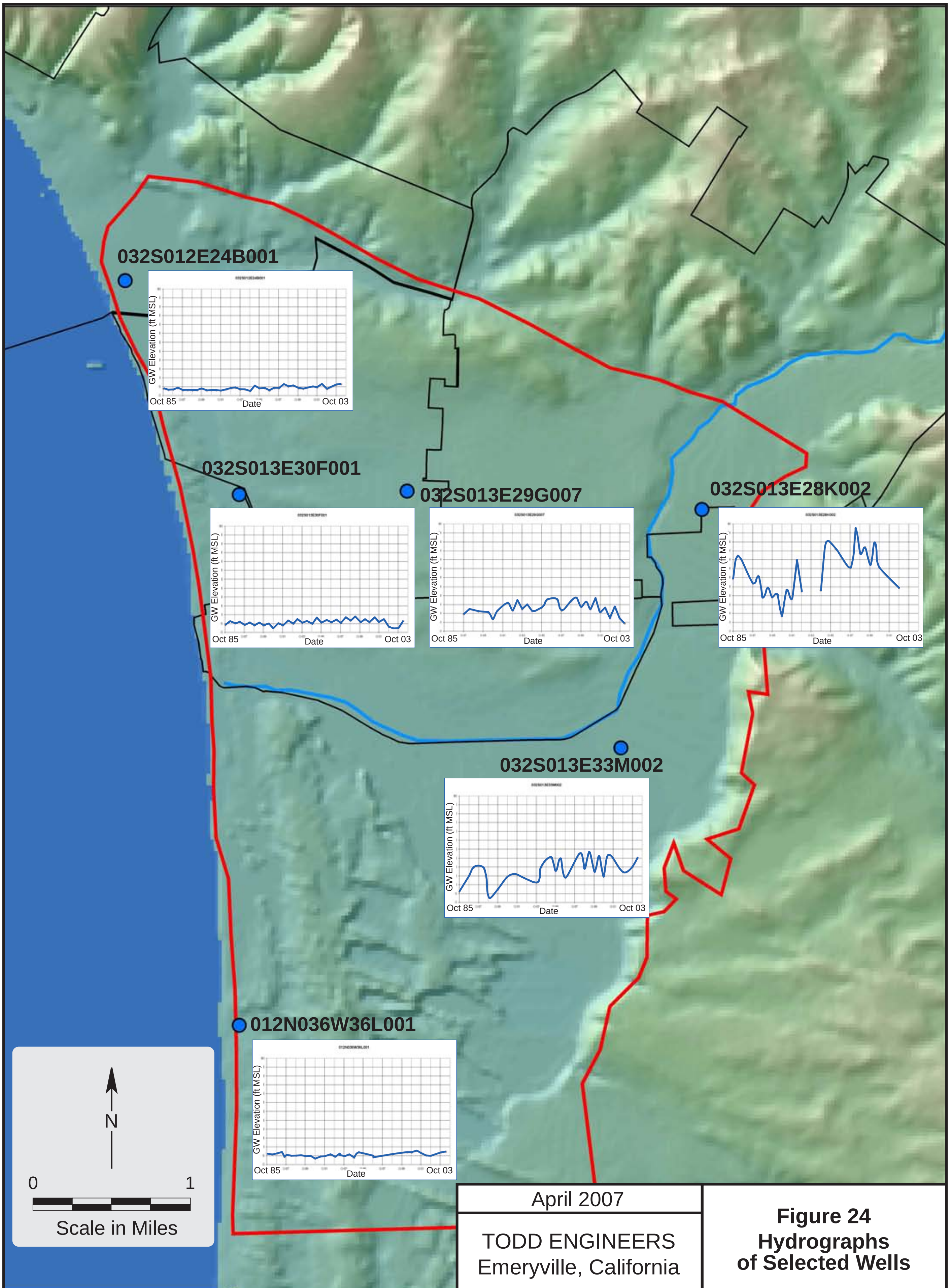


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Figure 24
Hydrographs of Selected Wells

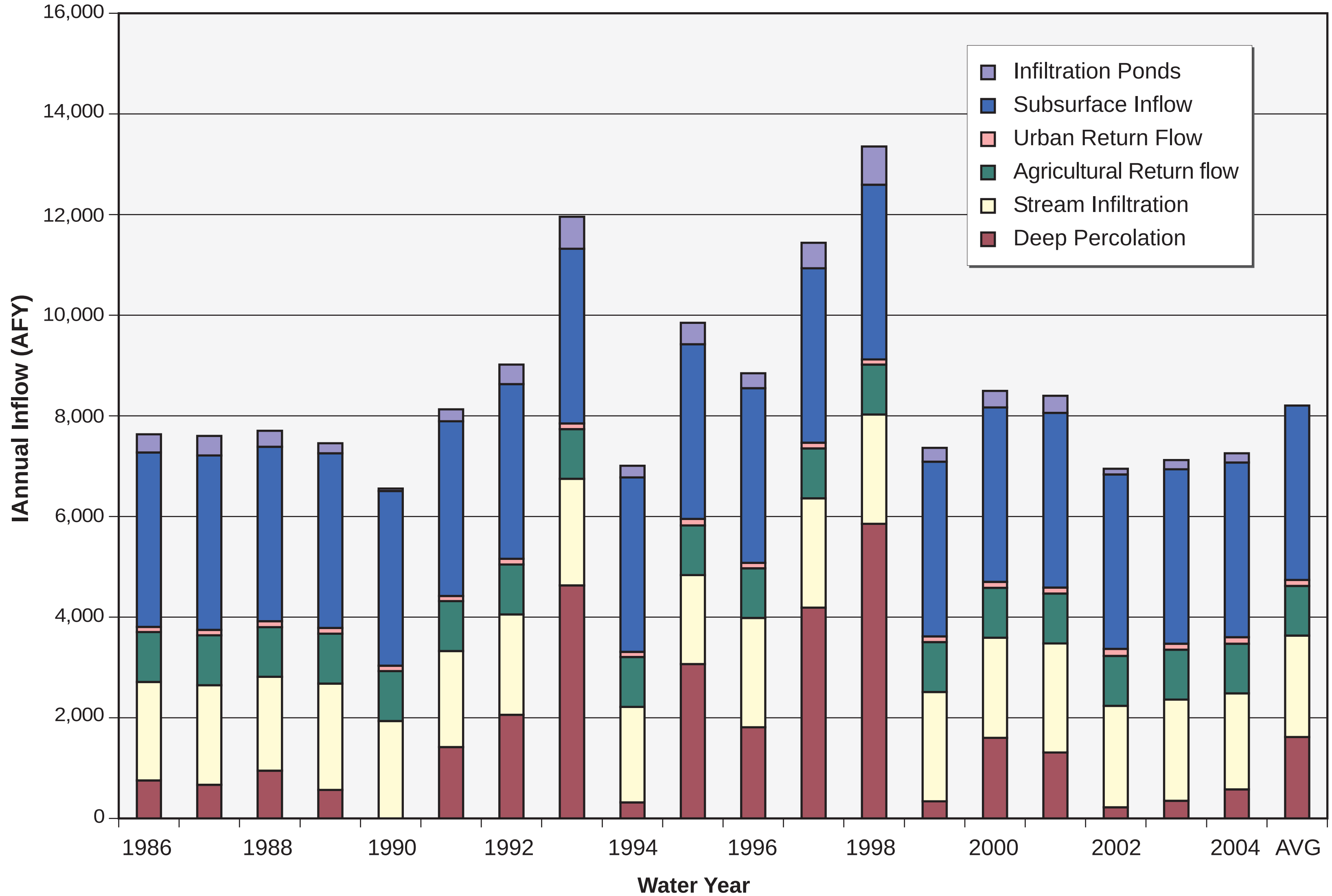

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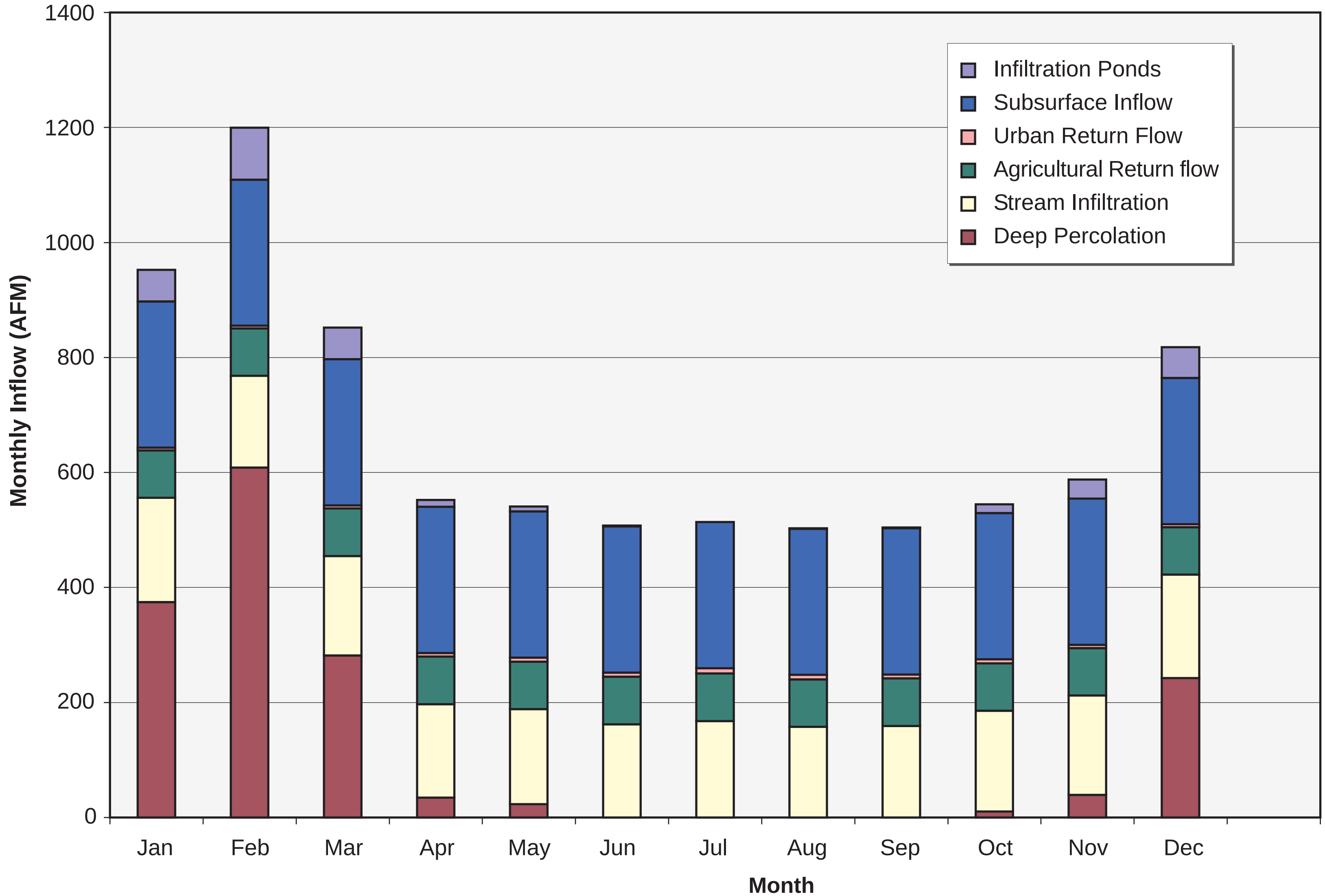
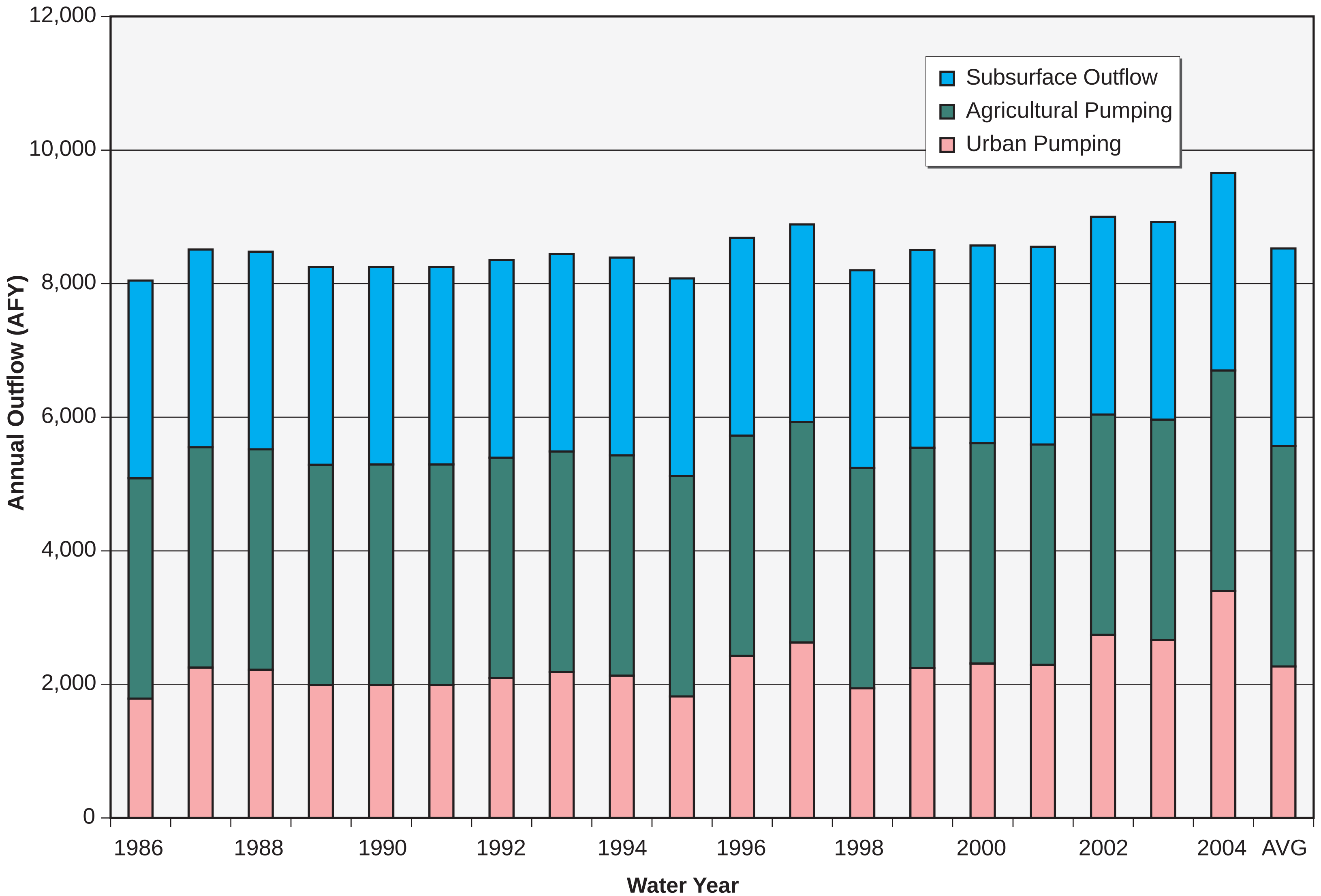
Figure 25
Annual Inflow



Average monthly inflow: October 1985 - September 2004.

April 2007	**Figure 26**
TODD ENGINEERS Emeryville, California	**Monthly Inflow**



April 2007	**Figure 27 Annual Outflow**
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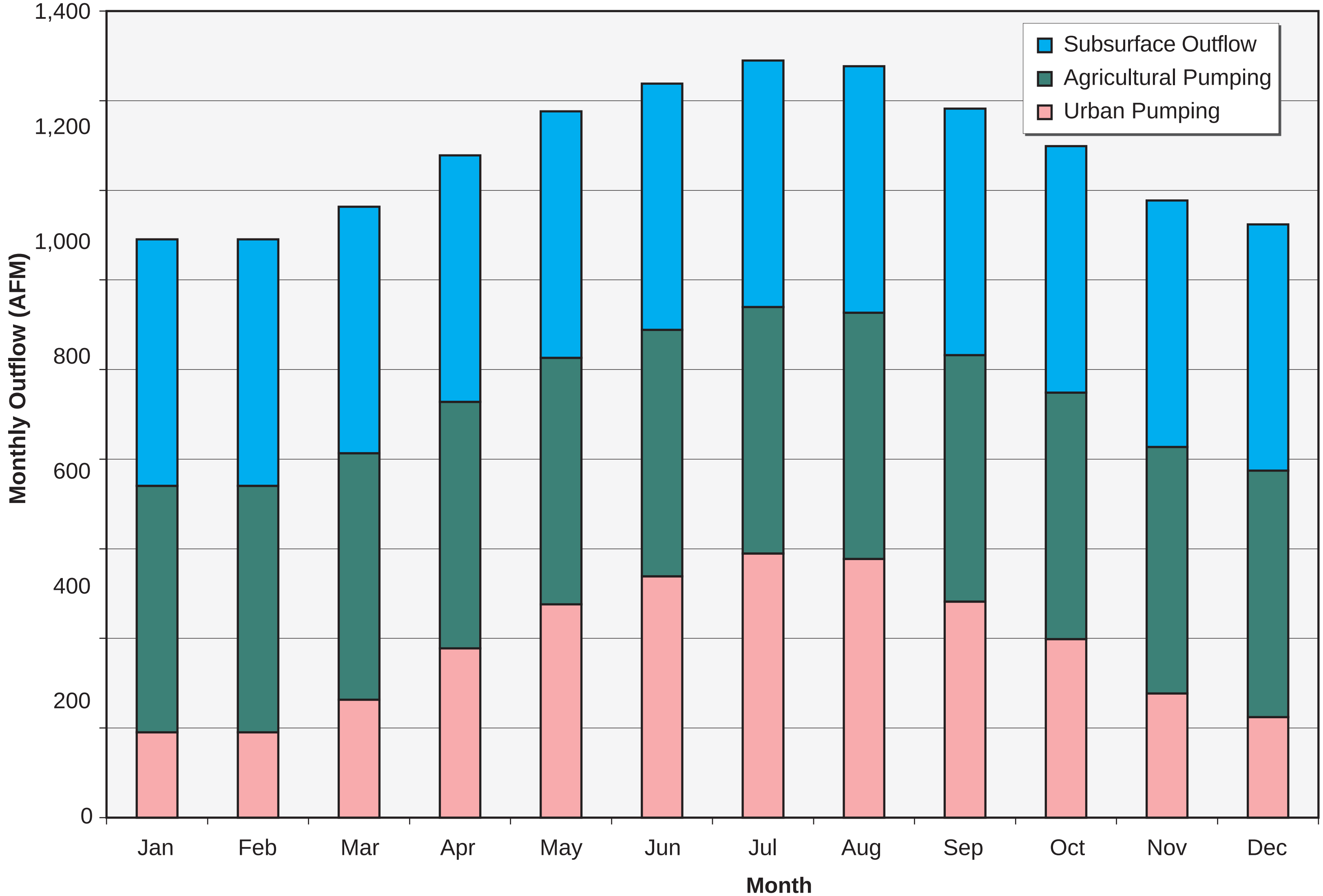

Average monthly outflow: October 1985 - September 2004.

April 2007

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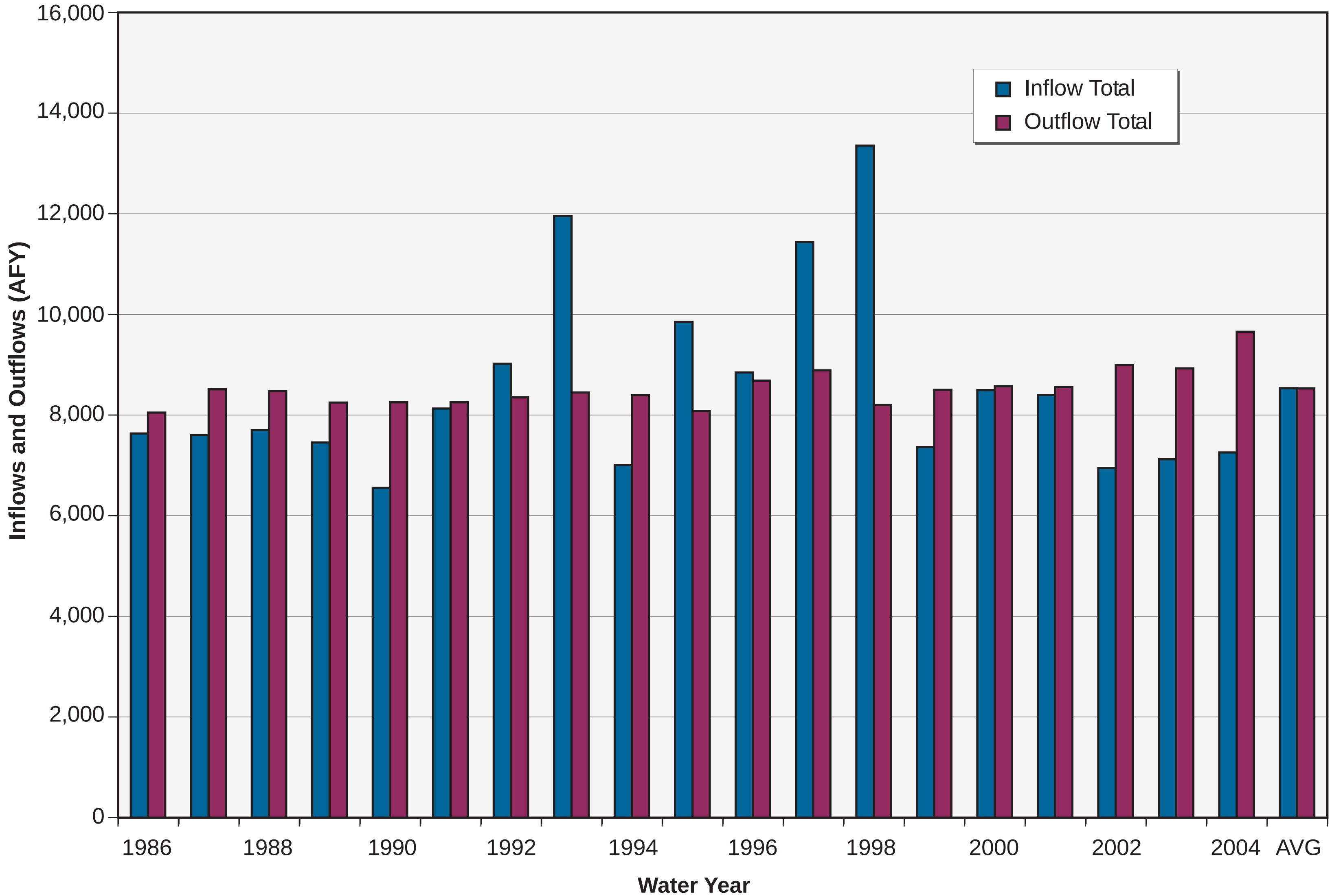
Figure 28
Monthly Outflow



April 2007	Figure 29
TODD ENGINEERS Emeryville, California	**Comparison of Inflow and Outflow**