Site Water Budget

List of Tables

List of Figures

Charts

F2-1.0 Introduction

This Attachment to Appendix F of the Final Remedial Investigation Report describes the input and results of a combined surface and groundwater budget constructed to assist in characterization of groundwater flow at Casmalia Resources Superfund Site (the Site). The water budget was constructed in accordance with the approach specified in the RI/FS Workplan.

The water budget objectives approach and scope including descriptions of the budget components and flow rates are summarized below and detailed in Section F2-2.0 of this Attachment. Section F2-3.0 presents the water budget results including sitewide Zone 1 and subarea budgets and inflow and outflow differences.

F2-1.1 Water Budget Objectives

The objectives of the water budget are to provide a summary of groundwater and hydrologic data collected at the Site since 1997, and assess the state of the Site water balance with regard to groundwater inflows, outflows and changes in storage. The data summarized in this section consists of available groundwater water-level data and associated aquifer storage changes, and hydrologic data used to aid in characterization and evaluation of groundwater flow conditions, including groundwater sources and sinks. These data were used to evaluate groundwater flow and storage conditions for Remedial Investigation purposes, and will be used to evaluate the potential effectiveness of potential final site remediation measures as a part of the Feasibility Study.

F2-1.2 Water Budget Scope of Work

The CSC constructed an historical site hydrologic water budget, which was presented in the Groundwater Data Summary Report (HLA, 2000). The hydrologic budget was developed to aid in estimating fluid fluxes into and out of the Zone 1 aquifer system. The original mass balance was performed for the period from October 1992 through March 2000 for the combined site surface and groundwater system. Measured or estimated volumes for each identified system inflow, outflow, and storage component were tabulated monthly. The Zone 1 hydrologic system consists of the following components:

Inflows	**Outflows**	**Changes in Storage**
Precipitation	Pond Evaporation	Surface Water (Ponds)
Surface Water Run-on		Groundwater
Dust Control (from ponds)	**Evapotranspiration**	
Irrigation (from ponds)	Groundwater Extraction	
Groundwater Underflow	Pond Dewatering	
	Surface Water Run-off	
	Groundwater Underflow	

Figure F2-1 illustrates the Zone 1 Site area, budget components, and distribution of sources and sinks. Monthly and cumulative budgets were developed for Zone 1 as well as two site subareas: north and south of the PSCT Trench. Monthly and cumulative budgets were evaluated to assess system dynamics and potential net system inflow/outflow. Monthly and cumulative "errors" (difference between total inflow, outflow, and change in storage) were calculated to assess potential gain or loss of liquids from the site groundwater system.

USEPA comments on the original hydrologic balance presented in the Groundwater Data Summary Report stated:

- The period of the water budget should be revised;
- Runoff rates should be revised;
- Evapotranspiration rates should be revised;
- Pond storage relationships should be documented; and
- The northern/southern subareas should be revised such that the northern subarea includes the PSCT capture area only.

The updated water balance includes each of these revisions. As proposed in the RI/FS Work Plan, the CSC reconstructed the hydrologic budget using EPA-approved methods for quantifying evapotranspiration and rainfall runoff, and revised the historical period evaluated to correspond with the transient MODFLOW model calibration. To address USEPA's comments and to update the hydrologic model, the CSC will also modified the water budget as follows:

- **Historical Budget Period** - The site water budget includes data from January 1997 through June 2004, corresponding to the period of the transient HELP model and MODFLOW model simulation periods. Budget analysis of historical periods prior to 1997 was not performed due to limited and unverifiable hydrologic data.

- **Runoff** – The historical water budget estimated runoff rates using a simple ratio method. For the updated water budget, runoff for 35 polygonal site subareas was estimated for the 1997-2004 period using the HELP model. Several rainfall-runoff-evaportanspiration models were evaluated by the CSC in 2006 and this approach was recommended and subsequently approved by the EPA The HELP model accounts for daily precipitation and soil moisture conditions and provides.

- **Evapotranspiration** – The historical water budget estimated evapotranspiration (ET) rates using the California Irrigation Management Information System (CIMIS) reference evapotranspiration (ET_o). For the updated water budget, ET was estimated as a part of the HELP model analysis. The HELP model accounts for more realistic soil moisture and with plant uptake rates at the site than ET_o.

- **Pond Storage** - The topographic map(s) and survey date(s) used to develop the stage-area-volume relationships are referenced.

- **Subarea Budgets** - Water budgets for two site subareas were segmented differently than the previous water balance. Subarea budgets were developed for an "upper" (Northern Zone 1) area where water intended to be captured by the PSCT, Sump 9B, and Gallery Well originates, and a second "lower" (South of the PSCT) area where liquids are not intended to be captured by these extraction facilities but are intended to be captured by the PCTs.

F2-2.0 Budget Components and Data Sources

The 1997-2004 site water budget elements (inflows, outflows, and storage) and hydrologic data sources are summarized in Tables F2-1 through F2-9, and Figures F2-1 through F2-23. The Zone 1 hydrologic system, illustrated conceptually on Figure F2-1, consists of system inflows (precipitation, total water spreading [irrigation and dust control], and groundwater inflow), system outflows (liquids extraction and offhaul, evaporation, evapotranspiration, and groundwater outflow), and two storage systems (ponds and groundwater). Figures F2-2 and F2-3 show the locations of the recharge polygons and two Zone 1 budget subareas, and extraction facilities, respectively.

Monthly and cumulative budgets were developed for Zone 1 as well as two site subareas: north and south of the PSCT Trench (Figure F2-2). The hydrologic basin area for Zone 1 was previously estimated at 252 acres; this area was used in the analyses. The northern area was delineated based on groundwater flow modeling (Attachment F-3) and includes the area from the North Ridge to the PSCT and recharge polygons contributing inflow to the PSCT. The acreages of the north and south subareas are approximately 95 and 157 acres, respectively.

Monthly volumes (gallons) associated with each system inflow, outflow, and change in storage component were tabulated and accumulated in a database, and monthly and cumulative "errors" (difference between total inflow, outflow, and change in storage) were calculated to assess potential gain or loss of liquids from the site groundwater system. The following sections discuss the data for each identified budget component.

F2-2.1 Precipitation

Monthly onsite and offsite precipitation data were collected and used to calculate the total pond and groundwater system recharge for the Site. Precipitation totals are recorded from the onsite meteorological station (Figures F2-1), and offsite precipitation data are collected at the Santa Maria and Lompoc airports. These data are summarized in Table F2-1 and illustrated on Figures F2-4 through F2-6. As illustrated on Figures F2-5 and F2-6, correlation between the onsite and Santa Maria airport precipitation rainfall is good. Rainfall varies seasonally, with most precipitation occurring between November and March. The largest precipitation volumes occurred during El Niño years (e.g.: 1997-98).

F2-2.2 Rainfall-Runoff Evapotranspiration and Net Recharge Analysis

Rainfall runoff, evapotranspiration, and net recharge for different Zone 1 areas were estimated using the USEPA Hydrologic Evaluation of Landfill Performance (HELP) model. Net recharge is one of the critical water budget components with respect to groundwater flow and chemical fate and transport at the site.

For the Zone 1 area, HELP simulations were performed for different polygonal areas using estimated surface slopes and soil properties. Figure F2-2 shows the locations of the HELP polygons, which were the same polygonal areas used in the MODFLOW Model (Attachment F-3). Thirty five polygons were simulated for the MODFLOW model, which encompasses a larger area than Zone 1, and not all of these polygons were used in the water budget analysis. In addition, several polygons located on or adjacent to the alignment of the PSCT trench were subdivided to construct the northern and southern subarea water budgets (Figure F2-2).

The following Sections describe the HELP model features, input parameters, and estimated runoff, evapotranspiration, and recharge components.

F2-2.2.1 HELP Model

HELP was used to estimate the some components of the Casmalia site water budget. HELP uses weather, soil design data, and solution techniques that account for the effects of surface storage, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, and net recharge to the water table.

HELP models the following pertinent processes on a daily frequency:

- Precipitation (input);
- Surface runoff using the Soil Conservation Service (SCS) curve-number method (USDA SCS 1972);
- Evapotranspiration: potential evapotranspiration using a simplified Penman approach; actual evapotranspiration (ETa) using a model of plant growth and decay for perennial and annual crops; ETa consists of the following components: evaporation of surface water, soil evaporation, and plant transpiration; ETa is then restricted to the evaporative zone depth input by the user;
- Net vertical percolation/recharge;

Table F2-2 lists the common input data used for each HELP polygon. Common input parameters include soil properties such as porosity; weather data including daily precipitation, mean daily air temperature, daily solar radiation; and parameters for the calculations of evapotranspiration, such as growing season and leaf area index. Table F2-3 lists the input parameters specific to each polygon, including surface slope, soil thickness, and hydraulic conductivity, along with overall results including total net recharge as a percentage of rainfall.

F2-2.2.2 Runoff

Runoff in Zone 1 is limited to runoff across/within the Site; significant run-on and runoff across the Zone 1 boundaries does not occur and is not budgeted for the Zone 1 area. The HELP model was used to simulate runoff for each polygon. The HELP model uses the U.S. Department of Agriculture Soil Conservation Service (SCS) Runoff Curve Number (CN) method to predict surface-water runoff. The curve number, CN, is a function of Hydrologic soil group type of ground cover (e.g., type of plants covering the soil), and other soil properties to estimate runoff. The hydrologic soil group is the most important factor determining CN. Site-specific hydraulic conductivity data, free water occurrence, ground cover, and hydrologic condition were used to determine the hydrologic soil group for the Site. The estimated rainfall runoff for each HELP polygon is shown on Charts R1 through R35, attached. Within Zone 1, runoff from the Northern Subarea was applied as runon to the Southern Subarea, and included in the subarea and sitewide budgets. .

F2-2.2.3 Evapotranspiration

Evapotranspiration estimates were developed using the HELP model. The estimated evapotranspiration rates for each HELP polygon are shown on Charts R1 through R35. For comparison, the HELP-estimated ET rates and volumes were compared with reported ET rates and volumes provided by CH2M Hill and with potential evapotranspiration rates and volumes obtained from the California Irrigation Management Information System (CIMIS - Figure F2-10). CH2M Hill developed an annual cycle of monthly evapotranspiration rates double quotes split evenly between ‘bare ground’ and ‘weeds and grasses’. Based on independent estimates available from research agencies, the CH2M Hill evapotranspiration values are low for the Casmalia area. CIMIS is a network of more than 80 computerized weather stations located at key agricultural and municipal sites throughout California. Six of these stations are located in Santa Barbara County. Each weather station automatically reads and collects information on wind speed and run, average vapor pressure, air temperature, relative humidity, dew point, solar radiation, soil temperature, and precipitation. The information is transmitted to a central computer database that converts the data into reference evapotranspiration, or Eto. Eto is the combined value of the water needs of cool-season grass and soil evaporation. CIMIS Eto data from Station #38 in Santa Maria were also compared with HELP-estimated monthly Site evapotranspiration rates (Figure F2-10). These CIMIS monthly rates represent estimated actual evapotranspiration; however, evapotranspiration may be limited if soil moisture is not available. As illustrated in figure F2-10, the HELP-estimated ET volumes are significantly lower than the reference Eto rates obtained from CIMIS, but larger than the average ‘bare ground’ and ‘weeds and grasses’ rates provided by CH2M Hill.

F2-2.2.4 Net Recharge

Based on the HELP model, the amounts of runoff and ET and resulting net recharge vary significantly for the different HELP polygons. For the overall simulation period of 1997-2004, between less than three to around 50 percent of total rainfall becomes net recharge. The largest rates of net recharge occur in areas of high hydraulic conductivity and low surface slope (Table F2-3). These findings are consistent with the recharge rates and distribution obtained during calibration of the groundwater flow model (Attachment F-3).

F2-2.3 Irrigation and Dust Control

Water extracted from the RAP wells and pumped from the ponds is used for site irrigation and dust control. Irrigation operations began in 1998, whereas monthly dust control volumes began prior to 1997. This water is re-applied to the ground surface and is therefore accounted for as site recharge. Monthly irrigation and dust control data are summarized in Table F2-4 and illustrated on Figure F2-8.

F2-2.4 Pond Evaporation

Free-surface evaporation from the Zone 1 ponds is a relatively large component of the water budget. Pond evaporation was estimated using two sets of pan evaporation data. Onsite pan evaporation data have been collected at the Site since 1992, and the pan evaporation data between 1997 and 2004 were used in this water budget. Onsite pan evaporation data collected by the CSC were corroborated with data provided by CH2M Hill. The monthly evaporation data are summarized in Table F2-5 and illustrated on Figures F2-9 and F2-10.

F2-2.5 Extracted Groundwater Offhaul and Pond Discharge

Groundwater has been continuously extracted from the aquifer system since the 1980's. Monthly extraction volumes from the Gallery Well, Sump 9B, PSCT –1, PSCT-4, RAP-1A, RAP-2A, RAP-3A, RAP-1B, and RAP-1C are listed in Table F2-6 and illustrated on Figures F2-11 through F2-20.

The majority of extracted groundwater (from wells PSCT -1 and PSCT-4, and RAP-1A, RAP-2A, RAP-3A, RAP-1B, RAP-1C, and C-5) is discharged to the ponds and/or used as irrigation/dust control; this water is accounted for as pond storage or as irrigation/dust control recharge. Liquids extracted from the Gallery Well and Sump 9B currently are trucked offsite for treatment and disposal; these volumes represent a site discharge and are listed in Table F2-7.

F2-2.6 Pond Storage

Five ponds store site runoff and extracted groundwater, and serve as discharge points through free-surface evaporation and withdrawals for site irrigation. Pond stage data from staff gages are recorded monthly by site personnel (Figure F2-21). Stage-area-volume relations for the RCF Pond, A-Series Pond, Pond A-5, Pond 18, and Pond 13 were developed using several historical topographic maps. Dry-pond condition topographic contours at 2-foot intervals were digitized and associated areas calculated. Linear and polynomial elevation-area and elevation-volume relations were developed as shown in Tables F2-8 and F2-9 and Figures F2-22 and F2-23. Monthly pond staff gauge measurements were then used to calculate volumes over time for each pond. For the purposes of the Site water budget, the surface and groundwater systems are treated as an essentially combined system.

F2-2.7 Groundwater Storage

As described in the main Section of Appendix F, monthly storage volume fluctuations were estimated by calculating average water-level changes. The average groundwater elevation change in 14 wells monitored monthly was calculated and multiplied by the Zone 1 area. A rigorous area integration of the well points was not performed, rather the mean monthly change was applied to the entire Site area.

F2-2.7 Groundwater Underflow

Groundwater flow rates in and out of the Zone 1 system were estimated using the MODFLOW model described in Attachment F-3. Limited groundwater inflow occurs into Zone 1 along the North Ridge. Along the North Ridge, a MODFLOW general head boundary was used to simulate underflow. However, based on volumetric flow rates estimated by MODFLOW along with MODPATH flowpath analysis, only very limited groundwater underflow occurs into and out of the Zone 1 system. For the March 2004 steady-state MODFLOW model, only around 60 cubic feet per day (around 450 gallons per day, or approximately 14,000 gallons per month) of inflow occurs through both the North Ridge and Model Layer 7 general head boundaries, combined). This small flow rate is insignificant compared to all other water budget components, and therefore was not included in the overall site water budget.

F2-3.0 Water Budget Results

Table F2-10 lists the water budget results, and Figures F2-24 through F2-35 show the sitewide, north of PSCT, and south of PSCT cumulative recharge discharge and total budget/error, as well as monthly error by zone. For each zone, the largest recharge component is rainfall recharge and the largest discharge components are evapotranspiration and pond evaporation. The cumulative error propagated through time, as well as the month-to-month error, indicates the relative balance of the surface/groundwater system and the potential capture effectiveness of the pumping systems in removing recharged water.

F2-3.1 Sitewide Balance

Figures F2-24, F2-27, and F2-30 show the cumulative sitewide recharge, discharge, and balance charts. To better illustrate where and when the balance errors are occurring, then CSC constructed a sitewide water balance based solely on monthly values for each variable (Figure F2-31). This monthly approach effectively eliminates the cumulative “mask” that may interfere with a clear understanding of the Site water budget.

As shown on the sitewide cumulative balance chart (Figure F2-30), the overall cumulative “error” on the sitewide budget is negative, indicating more water is being removed from the system than is being recharged. At the end of the study period (January 1997 through June 2004), the cumulative error represents a system discharge of over three hundred million gallons. Using the monthly approach (Figure F2-31), it is much more readily apparent that seasonal precipitation controls when the system error swings from positive to negative. In any given year, most months indicate that more groundwater is being removed from the system than is entering the system (a negative error). Months when the opposite is true include those with high precipitation events. Positive errors are calculated each water year during the wettest winter months. During the El Niño water years (i.e., 1997-98), the positive monthly errors are greater than during normal precipitation years.

Despite the rainy season positive errors calculated for each water year, it is clear that throughout most periods of the year more groundwater is being removed than is entering the Site. This result is reflected by the monthly error chart (Figure F2-31), which illustrates that most of the monthly errors since 1997 are negative. This conclusion is consistent with the overall Site conditions that are conducive to discharge (relatively low soil permeability and infiltration rates; arid conditions; locally shallow groundwater available for evapotranspiration; locally upward hydraulic gradients, especially in the southern portion of the Site; large pond surface areas; and active groundwater extraction).

F2-3.2 Subarea Budgets

The site was partitioned into two halves to better delineate the amount of groundwater capture by the PSCT. Figures F2-25 and F2-26 show the cumulative recharge north and south of the PSCT, respectively, while Figures F2-28 and F2-29 show the cumulative discharge north and south of the PSCT, respectively. The cumulative and monthly balance/errors for north and south of the PSCT are shown on Figures F2-32 through F2-35.

North of the PSCT, only minor total error (less than 2 million gallons) is calculated for the 1997 through 2004 simulation period (Figure F2-32). This indicates the groundwater system is roughly in balance, with recharge sources (precipitation, irrigation) roughly equaling discharge sinks (ET, pumping). South of the PSCT, minor positive errors are calculated for a few of the wettest months during each water year (Figure F2-34), but these are offset by the strong negative errors estimated during the remaining months. The cumulative error for the South of the PSCT subarea represents most of the error calculated for the entire Site (Figure F2-35).