Appendix 7A
Groundwater Model Documentation

7A.1 Introduction

The impacts on groundwater in the Delta Region and the SWP and CVP Export Service Areas due to the project were analyzed with two variations of the Central Valley Hydrologic Model (CVHM) (USGS, 2009). CVHM is a three dimensional groundwater flow model based on the widely used MODFLOW code (USGS 2000, 2005a) and incorporates a number of modeling packages to simulate stream flow routing and crop demand, in addition to the saturated groundwater flow process.

CVHM is a calibrated historical model which spans a 42-year simulation period between water years 1962 and 2003. The model domain encompasses the entire Central Valley, including Sacramento Valley, San Joaquin Valley, and the Sacramento-San Joaquin Delta. CVHM simulates primarily subsurface and limited surface hydrologic processes over the entire Central Valley at a uniform grid-cell spacing of 1 mile (mi). This model was used with minor modifications to simulate impacts from changes in groundwater pumping in the Export Service Areas, and also to provide boundary conditions for a refined model in the Delta Region, CVHM-Delta (CVHM-D).

CVHM-D was developed by CH2M HILL with assistance from the USGS. CVHM-D is essentially a local scale model of the Delta Region that simulates hydrologic processes in the Delta Region at a more refined grid-cell spacing of 0.25 mi (as compared with a grid-cell spacing of 1 mi with CVHM). Other enhancements were also incorporated into CVHM-D, as is described in later subsections of this appendix.

7A.2 Modeling Objectives

As part of the BDCP EIR/EIS development, impacts on groundwater resources in the Delta and in the Export Service Areas were evaluated for each conveyance alternative. Modeling objectives included the evaluation of the following potential impacts:

1. Effects on groundwater level changes and recharge
2. Effects on groundwater flow patterns and existing agricultural drainage
3. Effects on nearby municipal and domestic well yields
4. Inducement of migration of poor-quality groundwater
5. Potential of groundwater level induced land subsidence

CVHM was used to evaluate these potential impacts in the SWP and CVP Export Service Areas, and CVHM-D was used to evaluate these potential impacts in the Delta Region.

Each model was run over the 42-year hydrology period, and boundary conditions were modified to reflect anticipated changes in surface water availability, including the effects of climate change. Surface water flows from operations models (CALSIM II and DSM2 – refer to Surface Water Modeling Technical Appendix 5A) were used to define boundary conditions for CVHM, as well as to develop refined physical features in CVHM-D to allow for improved representation of the various conveyance alternatives proposed for the Delta.

7A.2.1 Near-Term Objectives during Facilities Construction

In the near-term, groundwater impacts would be due to the construction of the proposed project in the Delta, which is anticipated to last about 5 years. Facilities to be constructed include canals, pipelines, siphons, pumping plants, and forebays, among others. Impacts to groundwater would primarily be due to construction dewatering operations, which would lower the water table in certain areas and could potentially affect domestic and municipal well yields, as well as influence groundwater flow patterns. Modeling objectives for the near-term focused on the assessment of impacts on groundwater levels from construction dewatering operations and on developing proposed mitigation measures for potential impacts.

CVHM-D was used to simulate construction dewatering operations for the three different conveyance alignments proposed in the Delta:

1. Pipeline/Tunnel through the center of the Delta
2. Eastern Canal Alignment
3. Western Canal Alignment (including a pipeline/tunnel portion in the middle section)

Each alignment would require the construction of up to 5 intakes and pumping plants on the Sacramento River, as well as one or two forebays. In addition, multiple under-crossings of existing streams, canals, and sloughs would be required, most of which would be accomplished by constructing siphon structures beneath the surface water features.

7A.2.2 Long-Term Objectives during Facilities Operation

Groundwater impacts that would occur during operation of the project after the construction phase were also evaluated with consideration of climate change effects anticipated to occur 40 years after the completion of the new conveyance facilities. Impacts to groundwater would be due to the operation of the conveyance facilities in the Delta, and changes in water deliveries in the Export Service Areas. Modeling objectives during this time frame included the assessment of potential impacts to groundwater levels, well yields, and flow patterns during the operation of the new facilities, both in the Delta – using CVHM-D, and in the Export Service Areas – using CVHM.

7A.3 Model Function

To fulfill the objectives of the groundwater modeling effort, a calibrated regional flow model was used to provide a regional framework, but was also further modified to develop a local scale model focused specifically on the Delta Region. This local scale model was developed to provide higher resolution in the Delta Region and to allow for better representation of the proposed conveyance alignments, but also to develop more accurate depictions of agricultural water balances within the agricultural regions of the central Delta.

CVHM was the regional scale model used to evaluate groundwater level changes and other impacts to groundwater due to the changes in surface water deliveries from the SWP and CVP into the

Export Service Areas located south of the Delta. More specifically, surface water operational changes due to project implementation along with the effects of climate change were incorporated into CVHM as modified boundary inflows into the model domain and as non-routed surface water deliveries to Water Balance Subregions (WBSs) 10, and 13-21.

CVHM-D was used to evaluate changes in groundwater levels and groundwater flow patterns in the Delta Region. Two main types of impacts were evaluated using CVHM-D:

1. Groundwater impacts due to construction dewatering occurring in the near-term.
2. Groundwater impacts due to the long-term operation of the new conveyance facilities.

As described above, the groundwater impacts analysis was performed using a combination of the regional CVHM developed by the USGS in conjunction with a more local scale model of the Delta, termed CVHM-D develop by CH2M HILL. The overall construction and calibration of CVHM was unchanged during this analysis. The only modifications to CVHM involved the prescribed surface water inflows and deliveries, which were modified based on simulations performed using the surface water operations model CALSIM II. CALSIM II flows reflect changed operations in the Delta based on recent biological opinions and modified future inflows based on assumptions related to future operations of the project (see Chapter 5, Water Supply, Chapter 6, Surface Water, and the Surface Water Modeling Appendix 5A).

The active CVHM domain is subdivided into 21 WBSs (Figure 7A-1), as originally defined by the California Department of Water Resources (DWR). During model simulations, applied water requirements for each WBS are computed based on crop type and available water from precipitation, shallow groundwater, and surface water (limited by surface water rights).

The major streams flowing through the Central Valley are explicitly represented in CVHM. Observed USGS gage flows are used as inflows into the model domain for natural, unregulated rivers and streams. Reservoir releases on regulated rivers are also used as boundary inflows into the model domain. The reservoir releases are modified for each alternative due to operational changes and are represented by modified flow time series obtained from the CALSIM II model runs. Surface water deliveries to meet a portion of the crop irrigation demands are diverted directly from the rivers, based on water rights. Additional surface water is delivered through "non-routed" methods in the model. Non-routed surface water deliveries represent water transfers or surface-water deliveries to a WBS not connected to a stream or major canal. This conveyance typically occurs through small canals or diversion ditches (USGS, 2009). Some irrigation canals and aqueducts are not included in CVHM, such as the California Aqueduct, and the Delta-Mendota Canal. The water delivered through these conveyances is simulated in CVHM as non-routed deliveries, directly added to the destination WBS. The deliveries to WBSs south of the Delta from the SWP and CVP and associated conveyance losses were estimated from CALSIM II simulations and included in CVHM.

To develop CVHM-D, a portion of the CVHM representing the Delta was refined and additional surface water features were defined to better assess groundwater impacts in the Delta. Refinements include a finer discretization of the original model grid, and the subdivision of what was a single WBS in the CVHM representing the central Delta, into 23 individual WBSs, each roughly representing the main Delta islands, as shown on Figure 7A-2. A detailed description of the CVHM-D construction is given in Section 7.6.

7A.4 Computer Code Description

CVHM is a regional groundwater modeling application based on the MODFLOW-2000 computer code (USGS, 2000) and incorporates a variety of additional modules that were specifically developed to interact with MODFLOW-2000 (MF2K) and to increase the capabilities of the overall modeling package. The additional modules incorporated into the CVHM application are summarized in Table C1 of USGS Professional Paper 1766 (2009). The package that is responsible for simulating the majority of the agricultural water balance is the Farm Process (FMP) (USGS 2006). As part of the FMP, the WBSs are often referred to as farms; WBS and farms are used interchangeably in this text. FMP computes the crop water demand for each farm based on crop types specified in each model cell and determines the availability of water from “natural” sources such as precipitation and shallow groundwater. After the available natural water is allocated, FMP computes the amount of water that needs to be delivered from other sources, such as surface water deliveries (routed and non-routed) and groundwater pumping.

Another important module integrated into CVHM is the Stream Flow Routing (SFR) package. This package simulates the routing of surface water through the model domain, accounts for surface water diversions and deliveries to individual farms, tracks the flow and associated stage in surface water features, and computes the flow interaction between surface water and groundwater throughout the model domain.

CVHM was chosen to simulate the impacts of the BDCP alternatives for three main reasons:

1. Readily available and peer-reviewed. CVHM was developed, calibrated, and tested by the USGS and is based on a widely recognized groundwater computer code. It is publicly available and extensive documentation has been published describing CVHM as well as all the modules and packages that make up the model.
2. Geographic extent. The potentially impacted areas to be evaluated as part of this project include the Sacramento-San Joaquin Delta, as well as the Export Service Areas located in the San Joaquin Valley. Surface water operational changes resulting from project operations are defined at the margins of the Central Valley. The CVHM domain covers the entire Central Valley and allows for the efficient imposition of boundary conditions throughout the Basin.
3. Model subareas and discretization. CVHM is divided into 21 WBSs that correspond to the historic water balance regions identified by DWR. Water balances are computed for each WBS by the model. This distribution of areas in the Central Valley is consistent with models used by other resource teams, and provides for consistent model reporting with the other teams, and allows for efficient sharing of data with other models. In addition, the MODFLOW platform allows for simple re-sampling, and re-discretization of the original model parameters, with minimal loss of fundamental input parameters that were defined during the CVHM construction and calibration. This resulted in the ability to create a refined local-scale model that can be readily related back to the original CVHM construction and boundary conditions.

7A.5 General Numerical Model Descriptions

7A.5.1 CVHM

CVHM simulates surface-water flows, groundwater flows, and land subsidence in response to stresses from water use and climate variability throughout the entire Central Valley. It utilizes the MF2K (USGS, 2000) groundwater flow model code combined with the FMP to simulate groundwater and surface-water flow, irrigated agriculture, and other key processes in the Central Valley on a monthly basis from April 1961 through September 2003. CVHM is discretized laterally over a 20,000 square mile (mi^2) area and vertically into 10 layers ranging in thickness from 50 feet (ft) near the land surface to 400 feet at depth. Layers 4 and 5 represent the Corcoran Clay member where it exists in portions of the San Joaquin Valley. In the Sacramento Valley, the Corcoran Clay member is not present, and therefore the model layering effectively consists of eight layers. The thicknesses of the eight layers, from surface to depth, are 50 ft, 100 ft, 150 ft, 200 ft, 250 ft, 300 ft, 350 ft, and 400 ft., for a total model thickness of 1,800 feet.

The FMP allocates water, simulates processes, and computes mass balances for the 21 WBSs (or farms) in CVHM. The FMP was developed for MF2K to estimate irrigation water allocations from conjunctively used surface water and groundwater. It is designed to simulate the demand components representing crop irrigation requirements and on-farm inefficiency losses, and the supply components representing surface-water deliveries and supplemental groundwater pumpage. The FMP also simulates additional head-dependent inflows and outflows such as canal losses and gains, surface runoff, surface-water return flows, evaporation, transpiration, and deep percolation of excess water. Unmetered pumpage and surface-water deliveries for the 21 WBSs are also included within the FMP.

Calibration of CVHM was accomplished using a combination of trial-and-error and automated methods. An autocalibration code called UCODE-2005 (USGS 2005b) was used to help assess the ability of CVHM to estimate the effects of changing stresses on the hydrologic system. Simulated changes in water levels, streamflows, streamflow losses, and subsidence through time were compared to those measured in wells, at streamflow gages, and at extensometer sites. For model calibration, groundwater levels and surface-water stages were screened to obtain a calibration-target data set that is (1) distributed spatially (both geographically and vertically) throughout the Central Valley; (2) distributed temporally throughout the simulation period (1961–2003); and (3) available during both wet and dry climatic regimes. From the available wells records, a subset of 170 comparison wells was selected on the basis of perforation depths, completeness of record, and locations throughout the Central Valley (USGS, 2009). No changes were made to physical parameter values in CVHM for this project. A more detailed description of CVHM can be found in USGS Professional Paper 1766 (USGS, 2009).

For each alternative simulation, the surface water inflows at specific locations are updated based on time series computed by CALSIM II. Table 7A-1 lists the CVHM inflow locations at which updated CALSIM II flows were applied based on simulation results from the corresponding CALSIM II nodes.

Table 7A-1. CVHM Modified Inflow Locations

CVHM Node ID	Description	CALSIM II Equivalent Nodes
AMER_374	American River Downstream of Lake Natoma + South Folsom Canal	C9 + D9
MOKE_173	Mokelumne River below Comanche Reservoir	I504 + Original CVHM Diversions on Mokelumne River
CALV_161	Calaveras River (release from New Hogan Reservoir)	C92
STAN_146	Stanislaus River (below Goodwin + Oakdale Canal + SSJ Canal)	C520 + D520B + D520C
TUOL_135	Tuolumne River (Don Pedro Reservoir Release)	C81
SACR_205	Sacramento River (Keswick Reservoir Release)	C5
STON_263	Stony Creek (Black Butte Reservoir Release)	C42
FEAT_341	Feather River below Oroville + Palermo Canal	C6 + D6
YUBA_349	Yuba River below Englebright + Deer Creek inflow + French Dry Creek inflow	C230 + D230
MERC_116	Merced River (Lake McClure outflow)	C20
CHOW_080	Chowchilla River (Eastman Lake outflow)	C53
FRES_069	Fresno River (Hensley Lake outflow)	C52
SANJ_054	SJR at Friant Dam (Millerton Lake outflow)	C18

7A.5.2 CVHM-D

The application of CVHM to evaluate the potential impacts of the proposed project alternatives on groundwater resources in the Delta Region required certain modifications. A refined submodel was developed and is referred to as CVHM-D. Four fundamental modifications were made during construction of CVHM-D for application to this project. These modifications are as follows:

1. Model domain extent of CVHM was reduced to only include the Delta Region
2. Model grid-cell spacing was reduced from 1-mi to 0.25-mi centers
3. WBSs were subdivided into smaller areas
4. Additional streams, sloughs, and canals were incorporated into the SFR package

The additional refinements that were made to develop CVHM-D, and the approach that was taken to construct the numerical model is described in the following section.

7A.6 CVHM-D: Numerical Model Construction

7A.6.1 Model Domain

To more accurately simulate the effects of the construction and operation of the project facilities on groundwater resources in the Delta, a greater resolution of modeling analysis was necessary. This higher resolution was achieved by reducing the area of the original CVHM domain and only retaining the portions of the model domain that directly pertain to the Delta Region, and the portions of the Sacramento and San Joaquin Valleys directly adjacent to the Delta. Five of the original DWR WBSs were retained for the development of CVHM-D: WBSs 6, 7, 8, 9, and 11 (see Figure 7A-2). To improve the resolution of the agricultural water balance in the central Delta Region, WBS 9 was further subdivided into 23 subregions, or "farms", to more closely represent the distribution of islands in the Delta (see Figure 7A-3). The characteristics of the 23 individual farms as represented in CVHM-D are listed in Table 7A-2.

The overall resolution of the model grid increased by a factor of 16, which improved the depiction of the physical configuration of the surface water features that exist within the Delta, and the precision of estimates of potential impacts to groundwater resources due to construction and operation of the project facilities.

7A.6.2 Topography

During the development of CVHM-D, the modeled land surface topography was refined with available Digital Elevation Model (DEM) data from the following two sources:

- Delta area DEM based on 2007 LiDAR mapping by DWR (2 meter re-sampling of the source 1 meter posting from LiDAR)
- Suisun Bay and Delta Bathymetry (USGS, 2004)

The elevation data from these two sources were merged to create a more detailed surface elevation for Model Layer 1. An average elevation from this data set was computed over each 1/16th square mile grid cell and assigned to each cell.

7A.6.3 Hydrologic System

The hydrologic system represented in CVHM-D depicts the complex interaction between surface water features such as streams, sloughs, and reservoirs, the interaction between surface water and groundwater systems, and the effects of climate on agricultural resources. Several hydrologic features in CVHM-D were modified from the original CVHM depiction, and these features are discussed in more detail below.

7A.1.1.1 Climate

The climate data incorporated into CVHM include monthly estimates of precipitation and crop evapotranspiration over the calibration period (April 1961 through September 2003). The precipitation data were compiled from Parameter-Elevation Regressions on Independent Slopes Model (PRISM) data and the monthly crop evapotranspiration estimates were derived utilizing the PRISM data as outlined by the USGS Professional Paper 1766 (2009). In CVHM-D, the same PRISM data used in CVHM are used, but they are re-sampled over the 1/16th square mile grid cells to obtain greater resolution.

Table 7A-2. CVHM-D Farm Characteristics

CVHM-D Farm ID	Area (Acres)	Irrigated Fraction	Irrigated Area (Acres)	Average Annual Simulated Maximum Diversions (Acre-Feet)
22	222,789	0.50	111,395	348,981
23	9,546	1.00	9,546	26,480
24	17,896	1.00	17,896	57,380
25	10,082	1.00	10,082	33,724
26	81,006	0.75	60,755	225,285
27	17,410	0.50	8,705	35,072
28	4,303	1.00	4,303	12,507
29	9,330	1.00	9,330	21,003
30	11,083	0.75	8,312	31,194
31	22,532	0.25	5,633	38,533
32	14,938	0.75	11,204	37,460
33	8,615	0.75	6,461	21,885
34	49,296	0.50	24,648	112,546
35	9,797	1.00	9,797	32,597
36	50,773	0.75	38,080	174,957
37	26,643	0.67	17,851	95,967
38	100,856	0.33	33,282	195,587
39	22,115	0.25	5,529	52,765
40	43,060	0.00	0	0
41	3,662	0.00	0	0
42	1,608	0.00	0	0
43	3,856	0.00	0	0
44	14,733	0.00	0	0
23 farms	**755,929**		**392,809**	**1,553,923**

7A.6.3.1 Surface Water

The surface water system in CVHM-D includes streams, canals, sloughs, reservoirs, and other water bodies such as flooded Delta islands. The original CVHM represents a large portion of the Delta as flooded, and only the San Joaquin River, the Sacramento River, and the Mokelumne River are represented in the model. A much greater resolution of features were added into CVHM-D as described below, and the boundary conditions assigned to each surface water feature are described in Section 7.6.5.

7A.6.3.1.1 Streams

CVHM includes explicit representation of only the primary rivers that enter the Delta, and conceptualizes the remainder of the Delta as a large groundwater discharge area, which is simulated using a General Head Boundary (GHB). To more accurately evaluate the effects of the proposed project on stream flows and surface-water/groundwater interaction, a more detailed representation of the stream, slough, and canal networks in the Delta was required. The additional water courses were digitized from USGS maps and included in CVHM-D. The additional explicitly modeled streams include Old River (combined with Grant Line Canal), Middle River, Georgiana Slough, and the South Fork Mokelumne River. Figure 7A-3 shows the refined stream network modeled in CVHM-D.

7A.6.3.1.2 Water Bodies

The Delta Region contains many flooded areas and extensive open water bodies. The flooded areas incorporated into CVHM-D are the Clifton Court Forebay, Franks Tract, Mildred Island, the flooded portions of Sherman Island, the flooded area southwest of Sherman Island at the confluence of Sacramento River and San Joaquin River, and the Suisun Marsh area. These water bodies act as constant recharge areas to the groundwater system, and were simulated accordingly, as described in Section 7.6.5.2.4.

7A.6.3.2 Groundwater

The physical parameter values of the modeled groundwater system were left unchanged from the original CVHM calibrated model. The overall subsurface aquifer configuration such as model layering and extent, and the assumed hydrogeologic parameters such as hydraulic conductivity and storativity are documented in detail in Professional Paper 1766 (USGS 2009).

7A.6.4 Land Use

The land use maps from CVHM were re-distributed over the 1/16th square mile cells in CVHM-D to create a suite of refined land-use arrays for the CVHM-D analysis. In addition, several areas were assigned a revised land-use code of "water", such as Franks Tract, Mildred Island, and Clifton Court. These flooded areas do not receive any irrigation water, and lose water to evaporation and seepage to underlying groundwater. The Suisun Marsh area was also assigned a land use code of "water".

7A.6.5 Boundary Conditions

Boundary conditions are mathematical statements (rules) that specify hydraulic head and flux at selected locations within the model domain. The following three types of boundary conditions were used with CVHM-D:

1. Prescribed-flux: Surface water and/or groundwater flux is specified.
2. Head-dependent flux: Given a specified head, and conductance values in some cases (depending on the type of head-dependent boundary selected), groundwater flux is internally computed across the boundary using an appropriate governing flow equation.
3. No-flow: Groundwater can flow parallel to the boundary but not across it.

7A.6.5.1 Prescribed-Flux Boundaries

Prescribed-flux boundaries are used to assign time-series flows as inputs to the model domain. For CVHM-D, most of the time-series flows were obtained from CALSIM II model simulations or from CVHM. Time series flows were utilized as boundary inflows at the perimeter of the model domain, and to define diversions in the Delta. Other prescribed flux boundaries include groundwater pumping, mostly representing groundwater production from municipal and industrial wells within the model domain.

7A.6.5.1.1 Surface Water Inflows

Five streams flow into the northern and southern boundaries of the CVHM-D domain: the Sacramento River, the Colusa Basin Drain, Cache Creek, Feather River, and the San Joaquin River. The stream flows along these drainages at the CVHM/CVHM-D domain boundary were extracted from the CVHM simulations for each alternative and used as input flows in CVHM-D at the location where the streams enter the model domain. The SFR gage package was used within CVHM to assign a gage node at the CVHM/CVHM-D boundary cells on the five streams. The gage package then compiled the simulated time-series flows for the CVHM runs that were used as boundary inflows for CVHM-D. Other stream inflows were obtained directly from CALSIM II time series. Inflows for the new streams incorporated into CVHM-D also needed to be defined. Some of the new stream inflow locations are not simulated by CALSIM II, but are simulated by DSM2. The so-called “split-flows” (where a single stream splits into two separate streams) were computed for four locations based on CALSIM II and DSM2 simulated time series, as described in Section 7.6.5.1.2.

The surface water inflow locations defined as boundary conditions along the CVHM-D boundary are shown in Table 7A-3.

Table 7A-3. CVHM-D Inflow Locations

CVHM-D Node ID	Type of flow	Description	CALSIM II Equivalent Nodes
AMER_374	Inflow (existing)	American River Downstream of Lake Natoma + South Folsom Canal	C9 + D9
MOKE_173	Inflow (existing)	Mokelumne River below Comanche Reservoir	I504 + Original CVHM Diversions on Mokelumne River
CALV_161	Inflow (existing)	Calaveras River (release from New Hogan Reservoir)	C92
STAN_146	Inflow (existing)	Stanislaus River (below Goodwin + Oakdale Canal + SSJ Canal)	C520 + D520B + D520C
TUOL_135	Inflow (existing)	Tuolumne River (Don Pedro Reservoir Release)	C81
YOLO_157	Inflow (new)	Yolo bypass, non-routed flows, including Fremont and Sac weirs, and Putah and Cache Creeks	C157
SACI_408	Inflow (new)	North Delta flows that get diverted to the export pumps + net DICU from CALSIM II (agricultural demand)	negC409 + D409B - I409
DXCI_401	Inflow (new)	Delta cross channel inflow into Mokelumne river upstream of the South Fork split	C401B_DXC
GEOB_401b	Inflow (new)	Inflow into Sacramento River split segment for Georgiana slough	C401B_GEO
OMRS_417b	Inflow (new)	Inflow into San Joaquin River split segment for Old River	C417B
SFOM_024b	Inflow (new)	Inflow into Mokelumne River split segment for South Mokelumne River	fraction of (C504+C401B_DXC) based on DSM2 flow splits
MIDR-041b	Inflow (new)	Inflow into Old River split segment for Middle River	fraction of (C417B + negC409 + D409B - I409) based on DSM2 flow split

7A.6.5.1.2 Surface Water Diversions

Four types of surface water diversions were simulated in CVHM-D: 1) agricultural surface water diversions to meet crop demand; 2) municipal and industrial diversions for the urban centers in and around the Delta; 3) total south Delta exports to agricultural and municipal contractors south of the Delta, and 4) split flows from streams in the Delta.

Agricultural Diversions

The islands in the Delta obtain the majority of their irrigation water by diverting surface water from adjacent streams, canals, and sloughs. Hundreds of diversion locations are present in the Delta to provide water to agricultural lands. CVHM-D does not incorporate the diversion points along all of these canals and sloughs, thus diversion locations for each farm are consolidated into a limited number of locations. A total of 24 diversion locations were incorporated over the CVHM-D stream network to simulate the conveyance of irrigation water to the 18 irrigated farms (five of the 23 farms are not irrigated). The locations were chosen at a downstream reach along the stream flowing through or adjacent to each farm. Some farms were assigned two diversion locations if surrounded by more than one stream, and if it was known that diversions occurred from several streams, each of which was explicitly simulated in CVHM-D.

In CVHM-D it was necessary to define a time series describing the maximum surface water diversion flows that can occur within each stress period. During each stress period, the FMP computes the total crop water demand required to meet irrigation needs, computes the portion of the total crop demand satisfied by precipitation and shallow groundwater, and then diverts any unmet demand via specified surface water deliveries from nearby streams. Additional surface water might also be provided to the farms via non-routed deliveries. However if the applied water demand for a given farm is still not met after water is supplied from precipitation, shallow groundwater (direct consumption in the root zone), and stream diversions, then the remaining applied water demand is met by agricultural (groundwater) pumping. To develop estimates of the maximum diverted surface water deliveries available for each farm simulated in CVHM-D during each stress period, estimates of yearly crop water demand for each farm were computed based on the acreage of irrigated farmland. The farm irrigated acreages were estimated from the land use arrays incorporated in CVHM-D. An irrigation efficiency of 65 percent was used for demand estimates. Table 7A-2 shows the average annual simulated maximum diversion quantities for each farm.

Municipal and Industrial Diversions

Several urban centers surrounding the Delta Region divert surface water and convey it through aqueducts to water treatment plants and to their customers. In addition to existing Municipal and Industrial (M&I) diversions, new projects are anticipated to be built within the next few years. A total of twelve surface water M&I diversions were included in the model, lumped into six diversion locations. Table 7A-4 shows the type of prescribed diversions that were included in CVHM-D and which CALSIM II node they correspond to. Similar to the surface water inflows at the model boundaries, the M&I diversion time series were obtained from CALSIM II simulations. The location of each M&I diversion point is shown on Figure 7A-3. Water diverted for M&I purposes is not further routed in CVHM-D but taken out of the overall available surface water balance.

South Delta Exports

Two pumping plants located in the South Delta near Clifton Court divert surface water from the Delta surface water system that is then conveyed through the California Aqueduct and the Delta-Mendota Canal to the SWP and CVP Export Service Areas in Southern California. When the pumps are turned on, water from several rivers is drawn towards the South Delta (Sacramento River through Georgiana Slough, Mokelumne River, San Joaquin River, Old River, and Middle River). In particular, the flows in Old and Middle River are temporarily reversed, causing the water to flow upstream towards the pumps, instead of downstream towards the San Joaquin River and the Delta outflow.

Table 7A-4. CVHM-D Prescribed Diversions

CVHM-D Node ID	Type of flow	Description	CALSIM II Equivalent Nodes
DXCO_401	Diversion_non-routed (new)	Delta cross channel diversion on Sacramento River upstream of Georgiana Slough	C401B_DXC
EXPO_409	Diversion_non-routed (new)	Total South Delta Exports - simulated on San Joaquin River at the Mokelumne River confluence	D409
GEOB_401	Diversion_routed split flow (new)	Georgiana Slough diversion on Sacramento River	C401B_GEO
OMRS_417	Diversion_routed split flow (new)	Old River diversion on San Joaquin River	C417B
SFOM_024b	Diversion_routed split flow (new)	South Mokelumne River diversion on Mokelumne River	fraction of (C504+C401B_DXC) based on DSM2 flow split
MIDR-041b	Diversion_routed split flow (new)	Middle River on Old River	fraction of (C417B + negC409 + D409B - I409) based on DSM2 flow split
NBAV_403	M&I Diversion_non-routed (new)	North Bay Aqueduct and Vallejo M&I diversion out of model	D403A + D403B + D403C + D403D
ANTI_406	M&I Diversion_non-routed (new)	Antioch water works diversion on SJR U/S of Sac confluence	D406B
CCWI_408	M&I Diversion_non-routed (new)	Contra Costa water intake (on Rock Slough) simulated at Old River, where Rock Slough diverts	D408_RS
CCOV_408	M&I Diversion_non-routed (new)	Contra Costa water intakes on Old River and Victoria Canal (lumped)	D408_OR + D408_VC
STOC_514	M&I Diversion_non-routed (new)	City of Stockton diversions on SJR at South Mokelumne confluence	D514A + D514B
FRPT_168	M&I Diversion_non-routed (new)	Freeport Regional water project diversions	D168B + D168C

The SFR package used in CVHM-D does not have the capability of reversing the direction of stream flow during the simulation. In order to account for all the water present in the Old and Middle Rivers at any time during a simulation, the amount of water estimated to flow upstream in CALSIM II was added into CVHM-D at a location downstream of the Old River split from San Joaquin River. If this quantity of water is not added back into the model, simulations will underestimate the amount of surface water that is available for agricultural and M&I diversions. The total Delta exports diversion location also needed to be situated in the model at a location where water from the correct rivers was diverted. If the export diversion were placed on Old River in the vicinity of Clifton Court, the model would have only simulated the withdrawal of water from Old River and, to some extent from San Joaquin River, because no reversal of stream flows is possible in the model. Therefore, the selected location in CVHM-D for this diversion is at the confluence of the Mokelumne River with the San Joaquin River. This export location ensures that less water flows out into the Ocean from the Delta, while leaving enough water in the streams to satisfy agricultural irrigation demand and M&I diversions. The simulated export time series from CALSIM II was used for each alternative simulation in CVHM-D. Because CVHM-D does not explicitly incorporate the California Aqueduct and Delta-Mendota Canal in the model simulations, the water diverted for South Delta exports was taken out of the overall available surface water balance of the model at the diversion locations described above.

Split Flows

The four streams added to the Delta surface water system originate from larger streams that were already included in CVHM. The current configuration of the SFR package in CVHM and CVHM-D requires inflow time series to be specified for each stream at its upgradient reach. In the model, the split segments receive stream inflow from a “parent” stream. The time series for these four stream inflows were developed from CALSIM II and DSM2 data. For Georgiana Slough branching off of the Sacramento River, and Old River branching off of the San Joaquin River, CALSIM II time series were readily available (the appropriate nodes are shown in Table 7A-4). For the South Mokelumne River branching off of the Mokelumne River and Middle River branching off of Old River, such time series do not exist in CALSIM II as the model does not explicitly include these streams. DSM2 includes these flows, but it only simulates a 16-year time frame, which is not enough to populate the 42-year simulation period of CVHM-D. To develop these necessary split flow quantities, a flow relationship equation was developed for the split segment flows based on the fractional DSM2 flow in these streams. The flow relationship equation was then applied to the parent stream time series from CALSIM II to develop the time series for the split segments over the 42-year simulation period.

7A.6.5.1.3 Groundwater Pumping

Groundwater well construction and pumping information was collected during the construction of CVHM (USGS, 2009). Municipal and industrial wells in the model domain were assigned specified pumping flows based on available historical data over the model simulation period, developed by the USGS for the CVHM construction.

Agricultural pumping was estimated by the FMP based on crop water demand and available water resources for each farm. Agricultural pumping is set up with “virtual” pumping wells assigned to each irrigated cell in a CVHM-D farm (WBS) and is managed interactively and iteratively through the FMP process.

7A.6.5.2 Head-Dependent Boundaries

Head-dependent flux boundaries are used in CVHM-D to represent various surface water features such as streams, flooded islands, and areas to be drained. These boundaries also represent areas of subsurface inflow and outflow as described below.

7A.6.5.2.1 CVHM-D Lateral Boundaries

The delineation of the CVHM-D domain within the larger CVHM required assignment of boundary conditions on the northern and southern edges of the CVHM-D grid. These boundary conditions were specified as GHBs with associated groundwater heads that reflect groundwater levels consistent with monthly model output from CVHM for each respective model run. Thus, CVHM was run initially to define transient groundwater levels at the locations of the GHBs on the northern and southern boundaries of CVHM-D, and these transient head values were then used as input to parameterize the border GHBs of CVHM-D.

7A.6.5.2.2 Drains

The Yolo Bypass area is an area of known groundwater discharge. To incorporate the hydraulic influence of this hydrologic feature on the groundwater system, it was simulated by imposing a drain boundary condition in the vicinity of the bypass, with the drain elevations defined by the land surface elevation within each model cell. The Deep Water Ship Channel and the sloughs in the Yolo Bypass area were also simulated with similar drain boundary conditions. This configuration allows for the simulation of groundwater discharge to surface features in the referenced areas.

Most of the islands in the Central and South Delta are located below sea level, and are surrounded by levees that prevent the various streams and sloughs from flooding the islands. As a consequence, groundwater is very shallow beneath these Delta islands. To accommodate irrigated agriculture in these areas, extensive subsurface agricultural drainage systems are operated to maintain groundwater levels beneath the root zone of the crops. Given the resolution of the CVHM-D grid, it was not possible to explicitly simulate the configuration of these subsurface agricultural drainage systems. Instead, in areas of very shallow groundwater, generalized drainage networks were assigned in CVHM-D to allow for capture and diversion of shallow groundwater to nearby surface streams. These generalized drains were incorporated in 9 farms within CVHM-D. These drains (simulated as streams within the SFR package) were assigned an invert elevation at the minimum ground surface within a particular model grid cell, and a high permeability to allow for groundwater to be drained into these structures. As configured, these drains collect the excess shallow groundwater within the agricultural areas, and discharge the captured groundwater into adjacent streams. The SFR parameters used to simulate the drains were as follows: channel bottom hydraulic conductivity of 3.3 feet per day (ft/day), roughness coefficient of 0.03, bottom width of 164 ft, channel depth of 0.01 ft, and a wetted perimeter of 328 ft.

7A.6.5.2.3 Stream and Canal Network

The new streams and canal segments, described in Section 7.6.3.2.1 and the discussion sections of the alternatives analysis that were added to CVHM-D were simulated using the SFR package and thus are consistent with the methodology used to represent other streams that were included in the original CVHM.

Table 7A-5 shows the SFR parameters used to simulate the new streams and canal conveyances in CVHM-D.

Table 7A-5. CVHM-D Simulated Stream and Canal Parameters

	Delta Streams	Unlined Canal	Lined Canal	Tunnel Portion (within Canal Conveyance)
Channel Bottom Hydraulic Conductivity (ft/day)	0.033	0.28	0.0028	0.000029
Roughness Coefficient	0.03	0.022	0.013	0.013
Bottom Width (ft)	344	340	340	340
Channel Depth (ft)	30	23.5	23.5	23.5
Approximate Wetted Perimeter (ft)	400	500	500	500

Notes: For characteristics of the main channels in the Delta, refer to USGS PP 1766 (2009).
Simulated conveyance feature parameters were obtained from the respective Conceptual Engineering Reports (DWR 2010a).
The pipeline/tunnel conveyance feature is not explicitly simulated in CVHM-D.

7A.6.5.2.4 Water Bodies

The open water bodies that were simulated in CVHM-D were configured as GHBs with a specified head and conductance. The head for each water body was assigned based on a typical water level over the entire surface of the water body as follows:

- Clifton Court: 1.6 feet NGVD29
- Franks Tract: 1.6 feet NGVD29
- Mildred Island: 4.9 feet NGVD29

The hydraulic head assigned to the Delta outflow area in the vicinity of Suisun Bay was set at sea level for the near-term simulations, whereas sea level rises were incorporated into the long-term simulations, as discussed in Section 7.8.1.2. These areas are always flooded, do not receive any diverted irrigation water, and provide continuous recharge to the underlying aquifer.

7A.6.5.2.5 Groundwater Evaporation and Transpiration

Groundwater evapotranspiration is computed interactively by the FMP based on crop type and shallow groundwater levels computed by the model during each stress period.

7A.6.5.3 No-Flow Boundaries

The east and west boundaries of CVHM-D in all model layers, as well as the bottom of Model Layer 10, were simulated as no-flow boundaries. No lateral inflows into the model domain were specified for the east and west edges of the model. No-flow boundaries were also assigned to areas of a layer where bedrock is present, making the grid inactive in some areas of the model domain.

7A.7 Overview of Model Results of Historical Hydrology with Modified Operations

7A.7.1 CVHM

CVHM is based on the original calibrated model released by the USGS. Boundary conditions include historical quantities for surface water diversions, historic municipal groundwater pumping, observed stream flows, and historical land use and hydrology encompassing the 1962 to 2003 water years. Surface water inflows at the model boundaries were updated to account for recent operational changes influencing reservoir outflows. Non-routed deliveries to the Service Areas south of the Delta were also updated with CALSIM II time series to reflect current operational modifications. The Service Area time-series deliveries for the SWP and CVP contractors south of the Delta were compiled from CALSIM II and used as non-routed surface water inputs within CVHM. Figures 7A-4a and 7A-4b show typical CVHM deep groundwater level contour maps for the summer (August 1980) and the winter (December 1980) simulation periods in the Export Service Areas, for the model layer directly below the Corcoran Clay. Conditions in this model reflect those that would exist under historic land use and hydrology, but given the modified water management practices resulting from recent operational modifications.

CVHM farm inflows for the SWP and CVP Export Service Areas are presented in Table 7A-6. These inflows represent the average annual water usage for all the farms in the SWP and CVP Export Service Areas (WBSs 10 and 12 through 21).

7A.7.2 CVHM-D

CVHM-D includes the features described in Section 7.6 as well as historical values for surface water diversions outside of the Delta islands, groundwater pumping, observed stream flows, and historical land use and hydrology encompassing the 1962 to 2003 water years. Surface water inflows at the model boundaries were updated to account for recent operational changes influencing reservoir releases. Delta export estimates were incorporated from CALSIM II simulations. Figures 7A-5a and 7A-5b show typical CVHM-D shallow groundwater level contour maps for the summer (August 1980) and the winter (December 1980) simulation periods.

CVHM-D water inflows for the Delta Region farms are also presented in Table 7A-6. These inflows represent the average annual water usage for the 23 farms located in the Delta Region.

Table 7A-6. CVHM and CVHM-D Annual Average Farm Inflows for Selected Areas

Farm Inflow Component	CVHM CVP/SWP Export Service Areas (acre-ft) [a]	CVHM-D Delta Region (acre-ft) [b]
Precipitation	5,668,444	972,165
Shallow Groundwater in Root Zone [c]	982,088	248,966
Non-routed Deliveries (CVP/SWP) [d]	3,097,085	0
Semi-routed Deliveries (River Diversions)	3,824,589 [e]	1,120,255
Groundwater Pumping Deliveries [f]	7,133,145	280,086
Total Farm Inflows	20,705,351	2,621,472
Total Farm Delivery Requirement [g]	14,054,822	1,400,357

[a] Includes WBSs 10 and 12 through 21 in CVHM.

[b] Includes WBSs 22 through 44 in CVHM-D (formerly WBS 9 in CVHM).

[c] Includes shallow groundwater available for direct consumptive use (via evapotranspiration) by crops within the farms.

[d] Includes time series from CALSIM II simulations that represent the SWP and CVP deliveries to the Service Area farms.

[e] Includes surface water diverted from streams adjacent to farms. Diversion time series are included in the model to provide the maximum allowable diverted flow based on water rights and historical diversions. The data were compiled by the USGS and other agencies, as described in PP 1766.

[f] Includes groundwater pumped by agricultural wells to satisfy crop demand that is not met by other available sources.

[g] Includes total amount of water that needs to be delivered to each farm to meet the applied water demand. Values presented are representative of the simulation period including water years 1962 through 2003.

7A.8 Model Application Methodology

For each simulation scenario (conveyance type and time frame), boundary inflows in both CVHM and CVHM-D, and Service Area farm diversion estimates for CVHM were updated with the appropriate CALSIM II and DSM2 model outputs. The 42-year hydrology for water years 1962 to 2003 was used for each predictive simulation. Thus, predictive impact evaluations assume the same dry to wet hydrology patterns as the calibration simulations. However, operational changes, new infrastructure, and estimated sea level rise were incorporated into the predictive simulations to account for the anticipated ranges of conditions over the 42-year predictive simulation period. The simulated groundwater levels for each alternative were compared to the Existing Conditions and No Action Alternative simulations and the largest differences were chosen to analyze worst case impacts on groundwater. The simulation period did not intend to provide groundwater levels at exact future dates, but rather provide a reasonable range of groundwater level changes that could be expected for each alternative given historic fluctuations in hydrology.

7A.8.1 Baseline Models

The overall purpose of the baseline models is to provide a set of baseline conditions for comparison with the forecasts of the alternative models to determine whether the implementation of the proposed alternatives are likely to result in substantial impacts to groundwater resources.

7A.8.1.1 Existing Conditions and No Action Alternative Models

For CVHM, the development of both the existing conditions model (EC model) and the No Action Alternative model (NAA model) was based on the modified CALSIM II flow time series for the reservoir outflows and the deliveries to the WBSs in the Export Service Areas. Following are additional assumptions inherent in the predictive version of CVHM:

- The groundwater pumping distribution for 2003, the most recent available in CVHM, was assumed for the duration of the 42-year predictive simulation period.
- The 2003 surface water diversions for all WBSs were also assumed for the duration of the predictive simulation.
- The most current land use distribution available from CVHM (approximately year 2000) was kept constant throughout the predictive simulation.
- The hydrologic and climatic data used in the historical model was repeated in the predictive models.

For CVHM-D, it is assumed that simulated groundwater conditions of the NAA model would be very similar to the EC model. The construction of the NAA model is nearly identical to that of the historical CVHM-D model, except for a few input assumptions and boundary conditions that were modified. The groundwater pumping distribution for 2003, the most recent available in CVHM, was assumed to be reasonable for the duration of the 42-year simulation period. The 2003 surface water diversions for WBSs (farms) 6, 7, 8 and 10 were also assumed to be reasonable for the duration of the simulation. The most current land use distribution available from CVHM (approximately year 2000) was also kept constant throughout the no action simulation. The hydrologic and climatic data used in the historical CVHM-D model was repeated in the NAA model. Therefore it was assumed that the water year 1962 though 2003 hydrology is a reasonable representation of the hydrology that could occur over the next 42 years. Groundwater initial conditions and boundary conditions remained consistent for each alternative simulation. However, surface water boundary conditions were modified with the corresponding CALSIM II flows for each alternative simulation.

For the NAA model, only the surface water boundary flows and the estimated farm diversions in the SWP and CVP Export Service Areas were modified from the CVHM and CVHM-D historical models, by incorporating the appropriate CALSIM II flow time series.

7A.8.1.2 No Action Alternative Model "Late Long-Term" (2060)

In the "Late Long-term", the surface water boundary flows and the estimated farm diversions in the SWP and CVP Export Service Areas were modified from the CVHM and CVHM-D historical models, by incorporating the appropriate CALSIM II flow time series. In addition, in the CVHM-D, the Delta GHBs were set to a constant 17.7 inches (45 cm) NGVD29 to account for an estimated 17.7 inch sea level rise by 2060. The simulation descriptions and input assumptions presented in the following sections pertain to CVHM-D only. No model construction changes were made to CVHM. For each alternative simulation, the appropriate time series flows were incorporated in CVHM to assess the impacts on groundwater levels due to changes in surface water deliveries from the Delta to the Export Service Areas. For each alternative and conveyance option, CVHM-D required modifications to provide for more accurate representations of the new infrastructure components. A description of the modifications made to the baseline CVHM-D to represent the new conveyance infrastructure for each of the alternatives is given below.

7A.8.2 Alternative 1A – Dual Conveyance with Tunnel

Alternative 1A is a dual-conveyance alternative. This alternative consists of using existing in-Delta diversions along with a new tunnel for the second conveyance. The second conveyance includes five intakes located on the Sacramento River in the North Delta, each with a maximum pumping capacity of 3,000 cubic feet per second (cfs), to convey water through the Delta via a pipeline/tunnel constructed at a depth of approximately 200 ft to the new forebay located in the South Delta. Additional information regarding this new conveyance is provided in Chapter 3, Description of Alternatives. Simulations for this alternative included construction dewatering simulations as well as long-term conveyance simulations.

7A.8.2.1 Construction Dewatering

Construction dewatering was simulated by adding drains (from the MODFLOW drain package) in the model cells that represent the location of the infrastructure to be built. The NAA model was used as the basis for the construction dewatering model development. Drains were specified for the dewatering of the following infrastructure: the five pumping plants on the Sacramento River, and the Byron Tract Forebay. The drain elevations were set at the dewatering depths specified in the de-watering plan memorandum (DWR, 2010b). For elements of the design for which no de-watering depths were specified, a de-watering depth of 35 ft below ground surface was assumed. The drain conductance values were set to a high value to allow for sufficient water to be removed from the model. The duration of individual dewatering activities was obtained from the conveyance construction schedules contained in the Conceptual Engineering Report (DWR, 2010a). Table 7A-7 lists the dewatering schedule for each component of the alternative along with the target dewatering depth for each component.

Table 7A-7. Construction Dewatering Schedule for the Pipeline/Tunnel Alignment

Component	Dewatering Target Depth (ft bgs)	Feb	Mar	Apr	May	Jun	Jul	Aug
Pumping Plant No. 1	38	X	X	X				
Pumping Plant No. 2	38	X	X	X				
Pumping Plant No. 3	38	X	X	X				
Pumping Plant No. 4	38	X	X	X				
Pumping Plant No. 5	38	X	X	X				
Byron Tract Forebay	35	X	X	X	X	X	X	X

7A.8.2.2 Fully Built Conveyance Operation

For the operations simulations, selected components of the fully built conveyance infrastructure that had the potential to cause impacts on shallow groundwater levels were included in CVHM-D. For Alternative 1A, the five intake locations were included on the Sacramento River as non-routed diversions. This means the water was taken out of the modeled stream flows and was no longer available for use in the Delta. The time series of the pumping plant operations were estimated with CALSIM II and incorporated into CVHM-D. CALSIM II simulates the five intakes as one combined diversion on the Sacramento River. In CVHM-D, five different locations were used for the intakes. For modeling purposes, it was assumed that all five intake pumping plants operate exactly the same way, and have the same pumping schedule. To obtain approximate pumping rates, the original CALSIM II combined pumping rate time series was split into 5 equal time series for each pumping plant simulated in CVHM-D.

The Intermediate and the Byron Tract Forebays were simulated in CVHM-D as GHBs. The groundwater level in the forebay cells was set to a constant elevation of approximately 17.5 feet (5.3 m) NGVD29 for the Intermediate Forebay, and at 7.2 ft (2.2 m) NGVD29 for the Byron Tract Forebay, representing a maximum depth of water in the forebays as reported in the CERs (DWR 2010a). The pipeline/tunnel was not simulated in CVHM-D, as it would be built at an approximate depth of 200 feet and is not anticipated to have any impacts on the shallow groundwater levels in the Delta. Furthermore, the pipeline/tunnel sections are to be fully enclosed in a concrete casing, thus rendering the potential for leakage to be minimal.

In addition, the Delta GHBs were set to a constant 17.7 inches (45 cm) NGVD29 to account for an estimated 17.7 inch sea level rise by 2060.

The operation simulations for this alternative were used to evaluate potential impacts on groundwater from long-term operation of the facility. The potential effects that were simulated include operation of the two new forebays and the diversion of stream flow out of the Sacramento River. Simulation results are presented in the EIR/EIS in Section 7.3, Environmental Consequences.

7A.8.3 Alternative 1B—Dual Conveyance with East Unlined Canal Option

Alternative 1B is a dual-conveyance alternative. This alternative consists of using existing in-Delta diversions along with a new unlined canal along the eastern side of the Delta for the second conveyance. The second conveyance includes five intakes located on the Sacramento River in the North Delta, each with a maximum pumping capacity of 3,000 cfs to convey water around the Delta to a new forebay located in the South Delta. Additional information on this new conveyance is provided in the EIR/EIS in Chapter 3, *Description of Alternatives*.

Simulations for this alternative included construction dewatering simulations as well as long-term conveyance simulations.

7A.8.3.1 Construction Dewatering

Construction dewatering was simulated by adding drains (using the MODFLOW drain package) to the model cells that represented the location of the infrastructure to be built. Drains were specified for the dewatering of the following infrastructure: the five pumping plants on the Sacramento River, the intermediate pumping plant, Byron Tract Forebay, the pipelines to the pumping plants, ten siphons for canal, stream and slough under-crossings, and the canal. The canal was dewatered in three sections as shown on the dewatering schedule. The drains elevations were set at the dewatering depths specified in the dewatering plan memorandum (DWR, 2010b). For elements of the design for which no dewatering depths were specified, a de-watering depth of 35 ft below ground surface was assumed. The drain conductance values were set to a high value to allow for sufficient water to be removed from the model. The duration of the individual dewatering activities was obtained from the conveyance construction schedules contained in the Conceptual Engineering Report (DWR, 2010a). Table 7A-8 lists the dewatering schedule for each component of the alternative along with the target dewatering depth for each component.

Table 7A-8. Construction Dewatering Schedule for the East Canal Alignment

Component	De-Watering Target Depth (ft bgs)	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August
Pumping Plant No. 1	38		X	X	X																																								
Pumping Plant No. 2	38		X	X	X																																								
Pumping Plant No. 3	38		X	X	X																																								
Pumping Plant No. 4	38		X	X	X																																								
Pumping Plant No. 5	38		X	X	X																																								
Intermediate Pumping Plant	68		X	X	X																																								
Byron Forebay	35		X	X	X	X	X	X	X																																				
Pipelines to Pumping Plants	35					X	X	X	X																																				
Canal Section 1	15											X	X	X	X	X	X																												
Canal Section 2	15																X	X	X	X	X	X																							
Canal Section 3	15																						X	X	X	X	X	X																	
Beaver siphon	35											X	X	X	X	X	X	X	X																										
Hog siphon	35											X	X	X	X	X	X	X	X	X																									
Sycamore siphon	35																							X	X	X	X	X	X	X	X	X	X												
White - A siphon	35																								X	X	X	X	X	X	X	X	X												
White - B siphon	35																																				X	X	X	X	X	X	X	X	X
Disappointment - A siphon	35												X	X	X	X	X	X	X	X	X																								
Disappointment - B siphon	35																								X	X	X	X	X	X	X	X	X												
BNSF Railroad siphon	35													X	X	X	X	X	X	X																									
Middle River A siphon	35													X	X	X	X	X	X																										
Middle River B siphon	35																																				X	X	X	X	X	X	X		

7A.8.3.1 Fully Built Conveyance Operation

For the operation simulations of Alternative 1B, selected components of the fully built conveyance infrastructure that had the potential to cause impacts on shallow groundwater levels were included in CVHM-D. For Alternative 1B, the five intake locations were included on the Sacramento River as non-routed diversions, similar to Alternative 1A. The five time-series were then combined into one single inflow to the canal. The canal was represented in CVHM-D with SFR segments that allowed for water to be routed downstream and into the new Byron Tract Forebay. The SFR segments were digitized from a GIS shapefile and overlain on top of the CVHM-D grid to identify the cells that would incorporate the SFR reaches. The canal was split into six distinct segments for modeling purposes: the upper canal section between the intakes and the Mokelumne River, the pipeline portion under-crossing the Mokelumne River, the middle canal section between then Mokelumne River and the San Joaquin River, the pipeline portion under-crossing the San Joaquin River, the lower canal section between the San Joaquin River and Old River, and the pipeline portion under-crossing Old River and ending in the Byron Tract Forebay. The canal portions were all given the same hydraulic properties for a typical unlined canal. The pipeline portions were simulated as deeper canals with hydraulic properties that greatly minimize leakage, as would be expected given the planned pipeline construction methods. Simulated hydraulic properties for the canal and pipeline sections are listed in Table 7A-5.

The Byron Tract Forebay was also included in the model as GHBs. The groundwater level in the forebay cells was set to a constant elevation of 7.2 ft (2.2 m) NGVD29, representing a maximum depth of water in the forebays as reported in the CERs.

In addition, the Delta GHBs were set to a constant 17.7 inches (45 cm) NGVD29 to account for an estimated 17.7 inch sea level rise by 2060.

The operation simulations for this alternative were used to evaluate potential impacts on groundwater from long-term operation of the facility. The primary operations that were simulated include the diversion of stream flow out of the Sacramento River, the unlined canal gain or leakage to the surrounding aquifer, and the Byron Tract Forebay. Simulation results are presented in the EIR/EIS report in Section 7.3, Environmental Consequences.

7A.8.4 Alternative 1B—Dual Conveyance with East Lined Canal Option

This option includes the same infrastructure as the unlined option except that the canal is concrete lined. Dewatering operations would be identical to the ones described for the unlined option and no separate dewatering simulations were performed. For information regarding the potential effects of dewatering on groundwater levels, the reader is referred to the Construction Dewatering section of the east unlined canal option.

The operation simulations were set up similarly to the ones described for the unlined canal option except that the canal hydraulic parameters were modified to reflect a lined concrete channel. These parameters are shown in Table 7A-5. Simulation results are presented in the EIR/EIS report in Section 7.3, *Environmental Consequences*.

7A.8.5 Alternative 1C—Dual Conveyance with West Unlined Canal Option

Alternative 1C is a dual conveyance alternative. This alternative consists of using existing in-Delta diversions along with a new unlined canal along the western side of the Delta for the second conveyance. The second conveyance includes five intakes located on the Sacramento River in the North Delta, each with a maximum pumping capacity of 3,000 cfs, to convey water around the Delta to the new forebay located in the South Delta. Additional information on this new conveyance is provided in Chapter 3, Description of Alternatives.

Simulations for this alternative included construction dewatering simulations as well as long-term conveyance simulations.

7A.8.5.1 Construction Dewatering

Construction dewatering was simulated by adding drains (using the MODFLOW drain package) to the model cells that represent the location of the infrastructure to be built. Drains were specified for the dewatering of the following infrastructure: the five pumping plants on the Sacramento River, the intermediate pumping plant, Byron Tract Forebay, the pipelines to the pumping plants, twelve siphons for canal, stream and slough under-crossings, and the canal. The canal was dewatered in three sections as shown on the dewatering schedule. The drain elevations were set at the dewatering depths specified in the dewatering plan memorandum (DWR 2010a). For elements of the design for which no dewatering depths were specified, a dewatering depth of 35 ft below ground surface was assumed. The drain conductance values were set to a high value to allow for sufficient water to be removed from the model. The duration of the individual dewatering activities was obtained from the conveyance construction schedules contained in the Conceptual Engineering Report (DWR 2010b). Table 7A-9 lists the dewatering schedule for each component of the alternative along with the target dewatering depth for each component.

7A.8.5.1 Fully Built Conveyance Operation

For the operation simulations, selected components of the fully built conveyance infrastructure that had the potential to cause impacts on shallow groundwater levels were included in CVHM-D. For Alternative 1C, the five intake locations were included on the Sacramento River as non-routed diversions, similar to Alternative 1A. The five time-series were then combined into one single inflow to the canal. The canal was represented in CVHM-D with SFR segments that allowed for water to be routed downstream and into the new Byron Tract Forebay. The SFR segments were digitized from a GIS shapefile and overlain on top of the CVHM-D grid to identify the cells that would incorporate the SFR reaches. The canal was split into three distinct segments for modeling purposes: the upper canal section between the intakes and the entrance to the pipeline/tunnel portion, the pipeline portion connecting the two canal segments, and running beneath the Central Delta Region and under-crossing the Sacramento and the San Joaquin Rivers, and the lower canal section ending in the Byron Tract Forebay. The canal portions were all given the same hydraulic properties for a typical unlined canal (same properties as for the east alignment). The pipeline portion was simulated as a deeper canal with hydraulic properties that greatly minimize leakage, as would be given the planned pipeline construction methods. Simulated hydraulic properties for the canal and pipeline sections are given in Table 7A-5.

Table 7A-9. Construction Dewatering Schedule for the West Canal Alignment

Component	De-Watering Target Depth (ft bgs)	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October 13	November-13	December-13	January-14	February-14	March-14
Pumping Plant No. 1	38		X	X	X																							
Pumping Plant No. 2	38		X	X	X																							
Pumping Plant No. 3	38		X	X	X																							
Pumping Plant No. 4	38		X	X	X																							
Pumping Plant No. 5	38		X	X	X																							
Intermediate Pumping Plant	68		X	X	X																							
Byron Forebay	35		X	X	X	X	X	X	X																			
Pipelines to Pumping Plants	35					X	X	X	X																			
Canal Section 1	15											X	X	X	X	X	X											
Canal Section 2	15																X	X	X	X	X	X						
Canal Section 3	15																						X	X	X	X	X	X
Unnamed - siphon	35											X	X	X	X	X	X	X	X	X								
Babel - siphon	35											X	X	X	X	X	X	X										
Winchester Lake - siphon	35											X	X	X	X	X	X	X	X	X								
Elk - siphon	35											X	X	X	X	X	X	X										
Duck - siphon	35											X	X	X	X	X	X	X	X	X								
Miner - siphon	35											X	X	X	X	X	X	X	X	X								
Rock - siphon	35											X	X	X	X	X	X	X	X	X								
BNSF Railroad -siphon	35													X	X	X	X	X	X	X								
Main Canal - siphon	35											X	X	X	X	X	X	X										
Kellogg Creek - siphon	35											X	X	X	X	X	X	X										
Kendall Creek - siphon	35											X	X	X	X	X	X	X	X									
Italian Creek - siphon	35											X	X	X	X	X	X	X	X									

The Byron Tract Forebay was simulated in the model using GHBs. The groundwater level in the forebay cells was set to a constant 7.2 ft (2.2 m) NGVD29, representing a maximum depth of water in the forebays as reported in the CERs.

In addition, the Delta GHBs were set to a constant 17.7 inches (45 cm) NGVD29 to account for an estimated 17.7 inch sea level rise by 2060.

The operation simulations for this alternative permitted to evaluate potential impacts on groundwater from the diversion of stream flow out of the Sacramento River, the unlined canal gain or leakage to the surrounding aquifer, and the Byron Tract Forebay. Simulation results are presented in the EIR/EIS report in Section 7.3, Environmental Consequences.

7A.8.6 Alternative 1C—Dual Conveyance with West Lined Canal Option

This option includes the same infrastructure as the lined option except the canal is concrete lined instead of unlined. Dewatering operations would be identical to the ones described for the unlined option and no separate dewatering simulations were performed. For information regarding the potential effects of construction dewatering on groundwater levels, the reader is referred to the Construction Dewatering section of the west unlined canal option.

The operation simulations were set up similarly to the ones described for Alternative 1D except that the canal hydraulic parameters were modified to more closely reflect a lined concrete channel. These parameters are shown in **Table 7A-5**. Simulation results are presented in the EIR/EIS report in Section 7.3, Environmental Consequences.

7A.8.7 Alternatives 2A, 3, 4, 5, 6A, 7, and 8—Dual or Isolated Conveyance with Tunnel

All alternatives that include a tunnel (as part of either a dual-conveyance system or an isolated conveyance system) would be simulated with similar modifications in CVHM-D that were incorporated for Alternative 1A. For the construction simulations, the only changes between alternatives would be due to the number and location of intakes, which would influence the amount of groundwater dewatering required and the footprint of the dewatering impact. Dewatering impacts would increase with each additional intake, assuming they are constructed at the same time. Relative impacts due to construction dewatering for each alternative are described in the EIR/EIS report in Section 7.3, Environmental Consequences.

For operations simulations, the only modifications would be due to operational flows in the Delta and the changes in Delta exports (both north and south) as simulated by CALSIM II. Groundwater impacts due to operations of the tunnel would be very similar between these alternatives (except for Alternative 4), as described in the EIR/EIS report in Section 7.3, Environmental Consequences. Alternative 4 has a different Intermediate Forebay size and location compared to the other alternatives with a tunnel conveyance. The smaller forebay size would result in lesser impacts, as described in the EIR/EIS. Alternative 4 also includes an expanded Clifton Court Forebay as opposed to a separate Byron Tract Forebay adjacent to the existing Clifton Court Forebay. However, the overall footprint would be the same, and therefore impacts in the Clifton Court Forebay area would be similar for all the alternatives using tunnel conveyance.

7A.8.8 Alternatives 2B and 6B—Dual or Isolated Conveyance with East Unlined Canal Option

Alternatives 2B and 6B with the unlined canal option would be simulated with similar modifications in CVHM-D that were incorporated for Alternative 1B with the unlined canal option. The construction simulations would be identical for Alternatives 1B and 6B, since both alternatives use the same 5 intakes. Therefore, impacts on groundwater resources due to construction would be identical as well. For Alternative 2B, the location of 2 of the 5 intakes would be modified, and impact locations due to construction dewatering at the intakes would be different as compared to Alternative 1B.

For operations simulations, the only modifications would be due to operational flows in the Delta and the changes in Delta exports (both north and south) as simulated by CALSIM II. Groundwater impacts due to operations of the east unlined canal option would be very similar between these alternatives, as described in the EIR/EIS report in Section 7.3, Environmental Consequences.

7A.8.9 Alternatives 2B and 6B—Dual or Isolated Conveyance with East Lined Canal Option

Alternatives 2B and 6B with the lined canal option would be simulated with similar modifications in CVHM-D that were incorporated for Alternative 1B with the lined canal option. The construction simulations would be identical for Alternatives 1B and 6B, because both alternatives use the same 5 intakes. Therefore, impacts on groundwater resources due to construction would be identical as well. For Alternative 2B, the location of 2 of the 5 intakes would be modified, and impact locations due to construction dewatering at the intakes would be different as compared to Alternative 1B.

For operations simulations, the only modifications would be due to operational flows in the Delta and the changes in Delta exports (both north and south) as simulated by CALSIM II. Groundwater impacts due to operations of the east unlined canal option would be very similar between these alternatives, as described in the EIR/EIS report in Section 7.3, Environmental Consequences.

7A.8.10 Alternatives 2C and 6C—Dual or Isolated Conveyance with West Unlined Canal Option

Alternatives 2C and 6C with the unlined canal option would be simulated with similar modifications in CVHM-D that were incorporated for Alternative 1C with the unlined canal option. The construction simulations would be identical, because Alternatives 2C and 6C include the same 5 west intakes, like Alternative 1C. Therefore, impacts on groundwater resources due to construction dewatering would be identical as well.

For operations simulations, the only modifications would be due to operational flows in the Delta and the changes in Delta exports (both north and south) as simulated by CALSIM II. Groundwater impacts due to operations of the west unlined canal option would be very similar between these alternatives, as described in the EIR/EIS report in Section 7.3, Environmental Consequences.

7A.8.11 Alternatives 2C and 6C—Dual or Isolated Conveyance with West Lined Canal Option

Alternatives 2C and 6C with the lined canal option would be simulated with similar modifications in CVHM-D that were incorporated for Alternative 1C with the lined canal option. The construction simulations would be identical, because Alternatives 2C and 6C include the same 5 west intakes, like Alternative 1C. Therefore, impacts on groundwater resources due to construction dewatering would be identical as well.

For operations simulations, the only modifications would be due to operational flows in the Delta and the changes in Delta exports (both north and south) as simulated by CALSIM II. Groundwater impacts due to operations of the west lined canal option would be very similar between these alternatives, as described in the EIR/EIS report in Section 7.3, Environmental Consequences.

7A.8.12 Alternative 9—Separate Corridors with Through Delta Channel Modifications

Alternative 9 does not require any new separate conveyance system to be built. It relies on existing streams and channels in the Delta and includes changes to existing SWP and CVP water conveyance infrastructure and operations. This alternative cannot be accurately simulated with CVHM-D because this model does not incorporate every channel and SWP and CVP conveyance in the Delta that would be used for this alternative. However, the impacts to groundwater are not anticipated to be substantial with this alternative, as described in Section 7.3, Environmental Consequences

7A.9 Model Limitations

Although it is impossible to predict future hydrology, land use, and water use with certainty, CVHM and CVHM-D were used to forecast impacts to groundwater resources that could result from implementation of the BDCP alternatives to aid in development of the BDCP EIR/EIS. Mathematical models like CVHM and CVHM-D can only approximate processes of physical systems. Models are inherently inexact because the mathematical description of the physical system is imperfect and the understanding of interrelated physical processes is incomplete. However, CVHM and CVHM-D are powerful tools that, when used carefully, can provide useful insight into processes of the physical system.

CVHM and CVHM-D simulate groundwater conditions in the Delta Region with cells on one-mile and quarter-mile centers, respectively. Therefore, surface water and groundwater features that occur at a scale smaller than one mile and one quarter mile cannot be simulated in CVHM and CVHM-D, respectively.

7A.10 References

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