Appendix K. Water Quality Assessment Model

BACKGROUND

Changes in Mono Basin export volumes will alter the dilution of high mineral content waters of Hot Creek and other geothermal sources entering Lake Crowley reservoir. These changed dilution effects will be transferred from Lake Crowley reservoir to Tinemaha Reservoir and down the Los Angeles (LA) Aqueduct system and will ultimately affect the quality of water delivered to the City of Los Angeles. The incremental effects of these changes can be estimated using a mass balance approach that includes major sources of water for each constituent of concern.

LOCATIONS FOR WATER QUALITY ESTIMATES

The LA Aqueduct Mass Balance Model estimates the water quality at three locations identified as key hydrologic points in the LA Aqueduct system: the East Portal of the Mono Craters Tunnel, Lake Crowley reservoir outflow, and the terminus of the aqueduct at the LA filtration plant. The major tributaries and water bodies affecting East Portal concentrations are Lee Vining, Walker, Parker, and Rush Creeks and Grant Lake reservoir. The major tributaries and water bodies affecting Lake Crowley reservoir outflow concentrations are the Upper Owens River at Big Springs; Mammoth-Hot Creek; Convict, McGee, Hilton, Crooked, and Rock Creeks; and Lake Crowley reservoir. Water sources affecting the LA Aqueduct filtration plant concentrations are runoff and pumped groundwater from Owens Valley and Lake Crowley reservoir outflow.

CONSTITUENTS OF CONCERN

Constituents of concern were identified based on analyses of historical water quality data. Following are the criteria for selecting constituents of concern for analysis in the model:

- the constituent was consistently measured and detected in substantial concentrations at the three locations;

- the constituent is of concern for drinking water quality;

the constituent is of concern for aquatic habitat quality; and

a relationship was identified between the constituent and flow, or with another selected constituent.

Conductivity was selected as the primary water quality parameter because it is a general indicator of salinity and is directly related to the concentrations of other water quality parameters. Chloride, fluoride, arsenic, and phosphate were identified as constituents of concern because their concentrations were correlated with conductivity and they are related to drinking water quality and aquatic habitat value. Examples of these relationships are presented in Figure K-1. These graphs illustrate the relationship between flow and conductivity and conductivity and arsenic at Hot Creek. Similar relationships are identified for all other sources of LA Aqueduct water.

The selected constituents of concern are indicators of water quality changes in the LA Aqueduct system resulting from different hydrologic conditions and Mono Basin export regimes. Chloride, fluoride, and arsenic are of concern in drinking waters; maximum contaminant levels (MCL) have been established by the California Department of Health Services for these constituents. Arsenic is also of concern in aquatic habitats because of its potential toxicity to aquatic organisms; a U.S. Environmental Protection Agency (EPA) water quality criterion for the protection of aquatic life has been established. Phosphates are of concern because they can cause algae growth and eutrophication, which can result in aquatic habitat degradation. EPA has suggested criteria for phosphates to prevent eutrophication in lakes and streams, but they have not been established as national criteria.

MASS BALANCE MODEL DESCRIPTION AND OPERATION

Model Concept

Incremental changes in conductivity and other constituents of concern resulting from alternative patterns of Mono Basin exports will be estimated at the three selected locations; East Portal, Lake Crowley reservoir outlet, and the LA Aqueduct filtration plant. The model uses mass balance equations to calculate total mass units of conductivity and other constituents for each water source or water body included with the selected location. The equations are of the form:

$$EC \times Q = \text{mass (load)}$$

where

Q = flow volume (acre-feet [af]/month), and
EC = electrical conductivity (microsiemens per centimeter [FS/cm])

Conductivity mass units, or loads, are the product of a flow volume multiplied by a conductivity value and are given in FS/cm multiplied by af. The term load is used to describe calculated conductivity mass units. The total calculated conductivity load of each water source is divided by the total flow volume to give the resulting conductivity at the outflow location. An example equation is given below where Q = flow volume, EC = conductivity, and Q1 through Q3 are individual streamflows with known conductivities contributing to an outflow (Q4):

$$Q1 + Q2 + Q3 = Q4$$

$$Q1 \times EC1 + Q2 \times EC2 + Q3 \times EC3 = Q4 \times EC4 \text{ (total mass load)}$$

To solve for outflow conductivity (EC4):

$$EC4 = (Q1 \times EC1 + Q2 \times EC2 + Q3 \times EC3)/Q4$$

Calculation of Other Constituent Concentrations

Analysis of historical data at each source location indicated that the concentrations of chloride, fluoride, arsenic, and phosphate are directly correlated with conductivity. This relationship is relatively linear, with the concentration of each constituent increasing with increasing conductivity. The correlations of the four constituents with conductivity at Hot Creek are illustrated in Figures K-1b and K-2. These relationships allow the concentration of each constituent to be estimated at each location using a constant ratio of the constituent concentration to conductivity. For example:

Chloride concentration = EC x chloride/EC ratio

Ratios between each constituent and conductivity were calculated based on historical data at each location. The constituent concentration at each location was divided by the corresponding conductivity, and the average of the ratios was used in each module. The ratios used in the mass balance model are presented in Table K-1. Ratios for chloride ranged from 0.008 to 0.11, arsenic ratios ranged from 0.0009 to 0.35, ratios for fluoride ranged from 0.0004 to 0.04, and phosphate ratios ranged from 0.00001 to 0.003.

Model Description

The model comprises three individual modules for the three hydrologic locations described above and uses 50 years of historical hydrology data from 1940 to 1989. The three modules are the Grant Lake reservoir water quality module, the Lake Crowley reservoir (Long Valley) water quality module, and the LA Aqueduct filtration plant water quality module.

Grant Lake Reservoir Module

The first module is called Grant-WQ. This module calculates the four tributary conductivity loads, Grant Lake reservoir outlet conductivity, and the resulting East Portal conductivity. A conceptual diagram of the Grant-WQ module is presented in Figure K-3.

The conductivity of Rush Creek inflow to Grant Lake reservoir is a function of dilution and mixing of Rush Creek surface runoff with a higher conductivity base flow (Figure K-3). The conductivity and flow volume values for base flow and runoff were estimated based on historical Grant Lake reservoir conductivity data. The Rush Creek conductivity load is the sum of the base flow and runoff loads divided by the Rush Creek flow. An estimated mixing volume of 10,000 af for the upper Rush Creek lakes was required to simulate the observed pattern increasing conductivity during low-flow periods.

Conductivity loads for Lee Vining, Parker, and Walker Creeks are calculated using constant flow regression equations and historical flow data. Details of the regression equations and their calibration are discussed below. The calculation of Grant Lake reservoir outlet conductivity is adjusted for storage and dilution by dividing the initial conductivity load plus the inflowing tributary conductivity load minus the outflowing load by the end of month Grant Lake reservoir storage volume.

East Portal conductivity is calculated using West Portal flows, the estimated Grant Lake reservoir outlet conductivity, and an estimated constant "tunnel make" flow and conductivity of 1,000 af/month and 425 FS/cm, respectively. Tunnel make is the groundwater inflow to the Mono Craters Tunnel. When there are no exports from Mono Basin, the East Portal flow is estimated as 1,000 af/month with an EC value of 425 FS/cm.

Long Valley Module

The second module, known as Long-WQ, incorporates all Lake Crowley reservoir inflows, including the Owens River above East Portal, five tributaries, Rock Creek diversions, and East Portal flows calculated in the Grant-WQ module. The Owens River above East Portal (Big Springs) and the five tributary conductivity loads are calculated using regression equations and historical flows. A conceptual diagram of the Long-WQ module is presented in Figure K-4.

Because gains and losses are significant between the tributary streamflow gages and Lake Crowley reservoir, the effects of gains and losses must be accounted for. The measured tributary inflows are compared with Lake Crowley reservoir inflow estimated from the outflow and storage charge. Sometimes the sum of measured tributary inflow is different than estimated inflow to the reservoir. If Lake Crowley reservoir inflow is less than tributary flows, the difference is assumed to be irrigation diversions and evapo-transpiration losses. If reservoir inflow is greater than tributary flows, the difference is assumed to be local runoff. When measured Lake Crowley reservoir inflow is less than total tributary inflow, the total estimated tributary load is assumed to enter the reservoir. When measured Lake Crowley reservoir inflow is greater than tributary inflow, the inflow conductivity load is increased by local runoff with an assumed conductivity of 950 FS/cm that was estimated by calibration.

The output from Long-WQ is the estimated Lake Crowley reservoir outlet conductivity. The outlet conductivity from the reservoir is calculated by adding the initial reservoir load to the estimated inflow load, subtracting the outflow load, and dividing by the end of month storage volume. The outlet conductivity estimates are equal to the average mixed lake concentrations.

LA Aqueduct Filter Plant Module

The third module is called LAA-WQ. This module includes the estimated Lake Crowley reservoir outlet data from Long-WQ, Owens Valley groundwater pumping above and below Tinemaha Reservoir, and Owens Valley runoff above and below Tinemaha Reservoir. These sources comprise the inflow to Haiwee Reservoir and the LA Aqueduct filtration plant. A conceptual diagram of this module is presented in Figure K-5. Tinemaha Reservoir outlet concentrations were used to calibrate the model because of the availability of an extensive data set collected by LADWP and USGS at this location.

The average conductivity for groundwater pumping was estimated from historical data. The combined average of historical conductivity for groundwater pumped from the Laws Ditch, Bishop Canal, and Big Pine Creek well fields was used for groundwater pumping from Long Valley to Tinemaha Reservoir. The historical average conductivity of groundwater pumped from Tinemaha Reservoir to Haiwee Reservoir well fields was used for groundwater pumping in this reach.

Owens Valley runoff includes flow from Long Valley to Tinemaha Reservoir and Tinemaha Reservoir to Haiwee Reservoir. Runoff above Tinemaha Reservoir includes historical flows from Round Valley (minus Rock Creek diversions), Laws Ditch, Bishop Canal, and Big Pine Creek. Runoff below Tinemaha Reservoir includes historical flow values from Tinemaha Reservoir to Haiwee Reservoir. Runoff conductivities for these locations were estimated using monthly flow regressions, which are discussed further under "Model Calibration".

The LAA-WQ module first calculates the Tinemaha Reservoir outlet conductivity using the historical Lake Crowley reservoir flow and conductivity and the runoff and groundwater flows and conductivities described above. The combined historical Tinemaha Reservoir inflow from the runoff and groundwater sources often exceeds the historical measured inflow due to diversions and evapotranspiration losses. The module accounts for this difference by assuming that a portion of the total net conductivity (salt) load in the diverted inflow enters Tinemaha Reservoir, as described above for Lake Crowley reservoir inflows. This "salt return" fraction was estimated during calibration.

The conductivity load from Tinemaha Reservoir outflow is added to the groundwater and runoff conductivity loads below Tinemaha Reservoir to give the total load in the LA Aqueduct. The estimated LA Aqueduct filtration plant conductivity is calculated by dividing the total LA Aqueduct load by the LA Aqueduct filtration plant inflow. No adjustment was made when added LA Aqueduct inflows exceeded measured LA Aqueduct inflows. The output of the LAA-WQ module reflects the cumulative change in water quality predicted for a given Mono Basin export alternative.

Model Calibration

Two steps were used to calibrate each module. The first step of model calibration estimated flow regression equations for conductivity based on historical data for individual streams. Historical conductivity and flow data were plotted for each location, regression curves were analyzed, and regression equations were calculated using the following formula:

$$\text{Conductivity} = a \times Q^{-b} = a/Q^{b}$$

where

a = conductivity at base flow of 1,000 af (TAF)/month,
Q = flow (TAF/month), and
b = regression curve exponent

Historical flows and these flow regressions were used to generate a 50-year time series of monthly conductivity values at each location. The 50-year time series of estimated monthly conductivity at each location were compared graphically and statistically to available historical data. The mean, minimum, and maximum values of modeled data were compared with historical data at individual stream locations, and adjustments were made, if necessary, by changing the appropriate regression coefficients. Calibrated flow regression equations for each location are discussed below and shown in the conceptual diagrams for each module (Figures K-3, K-4, and K-5).

The second calibration step involved estimating unknown conductivity values for specific source terms in each module to calibrate the module output calculations with historical data. The calibration results for each module are described below.

Grant-WQ Module Calibration

The calibrated regression equations used for each stream location in the Grant-WQ module are presented in Figure K-3. Water quality in Rush Creek above Grant Lake reservoir is affected by upstream storage and dilution and therefore a flow regression was not used to estimate conductivity. Calculations of direct runoff and base flow conductivity using the mass balance techniques described above were used to estimate the conductivity of Rush Creek. The Grant-WQ calibration was conducted using creek flow diversions under the point-of-reference scenario simulated with the LAAMP model. The only potential source of errors would be the estimation of diverted flows entering Grant Lake reservoir from Lee Vining, Walker, and Parker Creeks.

Estimates of constant base flow, monthly runoff, a constant mixing volume, and base flow and runoff conductivities were then used to calibrate the module output with the historical time series of Grant Lake reservoir outlet conductivity. The conductivity and flow values for base flow and runoff were estimated using a combination of 1991 Rush Creek conductivity data and historical conductivities at Grant Lake reservoir outlet. Base flow was estimated at 1,250 af/month with a conductivity of 130 FS/cm. The total mixing volume was estimated at 10,000 af. Runoff conductivity was estimated at 40 FS/cm.

Calibrated Grant Lake reservoir outlet conductivities were compared to historical values during the calibration. The minimum, mean, and maximum of the modeled values were 39, 54, and 75 FS/cm. The minimum, mean, and maximum for historical values were 40, 59, and 165 FS/cm. A graphic comparison of modeled and historical conductivity at the Grant Lake reservoir outlet is depicted in Figure K-6. Some of the scattered high EC historical data values may be inaccurate.

Long-WQ Module Calibration

The mass balance techniques described above for Grant-WQ also were used in this module to estimate conductivity at the Lake Crowley reservoir outlet. Calibrated regression equations used for each water source in the Long-WQ module are presented in Figure K-4. Equations with similar exponents indicate the same basic dilution patterns for the respective water sources.

The mass balance used in the Long-WQ module accounts for the difference between measured total tributary inflow and Lake Crowley reservoir inflow to reflect the greater net conductivity load due to local runoff. The term "gains" is used in the module to estimate this additional conductivity (salt) load entering Lake Crowley reservoir and calibrate modeled Lake Crowley reservoir outlet conductivities with historical values. The conductivity load from gains is added to the total tributary load to obtain the Lake Crowley reservoir outlet conductivity. A conductivity of 950 FS/cm was used for the gains. Gains flows were estimated as the difference between tributary flows and Lake Crowley reservoir inflows.

Calibrated Lake Crowley reservoir outlet conductivities were compared to historical values. The minimum, mean, and maximum of the modeled reservoir outlet values were 156, 316, and 540 FS/cm, respectively. The minimum, mean, and maximum for historical values were 188, 325, and 592 FS/cm, respectively. A graphic comparison of modeled and historical conductivity at Lake Crowley reservoir outlet is presented in Figure K-7.

LA Aqueduct-WQ Module Calibration

Owens Valley runoff conductivities were estimated using monthly flow regressions for runoff from Long Valley to Tinemaha Reservoir and for runoff from Tinemaha Reservoir to Haiwee Reservoir. The regression equations were adjusted to calibrate modeled Tinemaha Reservoir outflow and LA Aqueduct inflow conductivity values with the respective historical values. Calibrated regression equations used for each runoff location are presented in Figure K-5.

The average conductivity of pumped groundwater from Long Valley to Tinemaha Reservoir was calculated from historical data to be 360 FS/cm. It was estimated that 25% of the conductivity load in diverted water entered Tinemaha Reservoir as irrigation return flows. A graphic comparison of modeled and historical conductivity at Tinemaha Reservoir outlet is presented in Figure K-8.

It was assumed that the sources between Tinemaha Reservoir and Haiwee Reservoir were fully mixed and therefore no adjustment in the conductivity load was required. The average conductivity of pumped groundwater from Tinemaha Reservoir to Haiwee Reservoir was estimated to be 290 FS/cm.

Calibrated LA Aqueduct filtration plant inflow conductivities were compared to historical values for the calibration. The minimum, mean, and maximum of the modeled values were 207, 330, and 653 FS/cm, respectively. The minimum, mean, and maximum for historical values were 173, 334, and 618 FS/cm, respectively. A graphic comparison of modeled and historical conductivity at the LA Aqueduct filtration plant is presented in Figure K-9.

Calibration of EC Ratios for Other Constituents of Concern

EC ratios for the other constituents of concern were calibrated by comparing the mean, minimum, and, maximum of the estimated concentrations with historical concentrations and adjusting the ratios, if necessary. Flows under the point-of-reference scenario were simulated with the LAAMP model and were assumed to be similar to historical data for the calibration of these ratios. Historical data were compared to point-of-reference simulations at each output location to verify the accuracy of each ratio. Modeled and historical values for chlorides, arsenic, fluoride, and phosphate at the Lake Crowley reservoir outlet are presented in Figures K-10, K-11, and K-12. Lake Crowley reservoir values are compared because of the high concentrations of these constituents entering the lake. Modeled and historical values for these constituents at the LA Aqueduct filtration plant are presented in Figures K-13, K-14, and K-15.

LAAMP Simulation Data

The LA Aqueduct mass balance model will use data from the LAAMP aqueduct flow simulations developed for each Mono Basin EIR alternative. LAAMP flow simulation output data files correspond to each of the three locations in the model and use the same affected streams and water bodies. Model runs will be conducted using the simulated flows for each alternative.

The LAAMP model uses actual historical runoff data for each stream location. The major variable in the LAAMP model is the monthly volume of Mono Basin export in the East Portal outflow. Minor changes occur in storage at Grant Lake and Lake Crowley reservoirs with each flow regime. These changes are more pronounced if lower East Portal flows are simulated. The Owens Valley groundwater pumping component of the LAAMP model uses a higher volume of pumped groundwater from each of the five basins than are accounted for in historical values, but the monthly pattern of groundwater pumped is the same for each of the alternatives.

Once the LAAMP simulation data are imported into the mass balance model, a monthly conductivity estimate can be calculated at each output location for that alternative. The EC ratios are used in subsequent model runs to calculate the other constituent concentrations for a given flow regime. EC ratios for each constituent are inserted into the regression equations at the beginning of a model run. The model then recalculates monthly constituent concentrations at each location. All individual streams and water bodies are included in the recalculation. The resulting output from each model is an estimated constituent concentration at East Portal, Lake Crowley reservoir outlet, and LA Aqueduct filtration plant inflow for flow regime specified by the LAAMP model. Additional details of the LAAMP model are presented in Appendix B of the draft EIR.

Model Operational Requirements

The three modules were developed in spreadsheet format using Lotus 1-2-3 software. An IBM-compatible 386 or 486 computer with at least 2 megabytes of RAM is recommended to operate the model because of the large size of the spreadsheets.

Data Management and Analysis

Results from each alternative for all constituents of concern are combined in a single data file for evaluation and impact assessment. Data in the file will be used to evaluate the change in constituent concentrations between a given alternative and point-of-reference conditions. Tables and graphs containing data summaries and statistics will be generated as needed from each model run. A sample mass balance model output format is presented in Table K-2. Graphic examples of the model output format for Lake

Crowley reservoir outlet and LA Aqueduct filtration plant inflow conductivity and arsenic values are presented in Figures K-16, K-17, K-18, and K-19. These figures show a comparison of the model output for the No-Restriction and No-Diversion Alternatives, and the point-of-reference conditions for the two locations.