APPENDIX B - DRAFT TECHNICAL MEMORANDUM

TO: CKB ENVIRONMENTAL CONSULTING

FROM: GARY PALHEGYI, GEOSYNTEC CONSULTANTS

SUBJECT: **MODEL DEVELOPMENT & HYDROLOGIC CHANGES OF UPPER LAGUNA CREEK WATERSHED**

TASK 3.2.4; TECHNICAL MEMORANDUM #4

DATE: APRIL 19, 2007

This appendix presents the development of the hydrologic modeling element required for the hydro-geomorphic model and its implementation on evaluating future conditions.

This appendix describes the methodology and evaluates the predicted changes in creek flows at select locations throughout the watershed. Runoff from sub-catchments is evaluated in certain circumstances.

The hydrologic model is a continuous hydrologic simulation model where measured hourly rainfall is used to mathematically predict hourly surface runoff and stream flows. The model is first calibrated to measured flows at Eagles Nest (gage ID 268) and at the intersection of Waterman & Bond (gage ID 1301). The calibration and verification period is from 10/1/1996 to 9/30/2000. The measured rainfall record extends from 9/1/1956 to 9/1/2005. At various locations throughout the upper watershed, the resulting 49-year record of runoff and stream flows are then analyzed for changes in peak flow, runoff volume, flow duration, and seasonality.

The model is set-up for three land use scenarios 1) pre-urban, 2) existing conditions, and 3) future land use conditions. A comparison between these three *land use* scenarios is presented in this appendix (as well as in Appendix C). The model and its use address the cumulative nature of urban development and its imperviousness as defined in this appendix.

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1 Background

1.1 Purpose and Organization

The purpose of this appendix is to present the details of the hydrologic models of the Upper Laguna Creek Watershed that Geosyntec developed to analyze the potential for hydromodification in the watershed. **Figure B-1** illustrates the study layout area.

The appendix is organized as follows.

- Section 1 summarizes hydromodification and its effects on the fluvial geomorphology of the receiving waters and presents the hydrologic modeling approach.
- Section 2 discusses the parameterization of the HEC-HMS hydrology model used to characterize the Upper Laguna Creek Watershed, along with the calibration methodology and the calibration results.
- Section 3 discusses the results of the hydrologic modeling.
- Section 4 presents the conclusions of the hydrologic analyses.

1.2 Modification of Hydrologic and Sediment Transport Processes

Hydrology plays a critical role in influencing the physical characteristics and ecological health of stream corridors. Stream flow magnitude, frequency, duration, and timing are major driving forces that control the physical and ecological conditions of a riparian corridor. As water flows downstream, it imposes forces on the boundary material due to its weight and velocity that scours, erodes and otherwise shapes the channel boundary. When there is a major change in runoff discharged to streams, or substantial changes in sediment supply, channels adjust until the planform, slope, and cross sectional dimensions have readjusted to the new hydrologic and sediment supply regime. When areas are converted from natural vegetated areas to impervious areas, the area over which infiltration occurs is reduced, surface storage and interception may be reduced, and overland flow increases due to impervious surfaces (Hollis, 1975). Urbanization changes the natural relative proportions of overland flow, interflow, and groundwater flow to stream channels (Booth et al. 1997). As a result, the natural storage of water in the watershed is reduced and more erosive energy is available to perform work on the streambed and banks. Hollis (1975) concluded that the effect of urbanization is most pronounced for flows with a frequency of 1 to 2-years and smaller, where flows increased as much as 20 times.

1.3 Modeling Approach

Recent research has shown that modeling approaches based on a design storm are not adequate to address long-term stream channel stability issues. A series of discrete events (2-year through 100-year) is often used to evaluate the effects of development. However, this approach neglects changes in flows less than the 2-year event and the influence of such flows, which can be significant in many stream systems. Andrews (1994) reported that 55% of the total bed load in Sagehen Creek, Tahoe, was carried by flows less than bankfull. Analysis conducted by Geosyntec (2003) indicated that for streams in the San Francisco Bay Area 50% or more of the sediment load was transported by flows less than the 2-year peak flow.

The key to the hydromodification methodology is the use of continuous hydrology and the analysis of all erosive flows as opposed to selecting discrete events. Continuous hydrology and analysis incorporates the full probability distribution of rainfall events and uses the resulting flow time series as a basis for long-term work and sediment load computations. This approach captures all the important geomorphically significant flows regardless of their magnitude and allows one to examine the distribution of sediment load transported and the most effective discharges.

Geomorphology, stream erosion, sediment transport, and work are all functions of the cumulative effects of all erosive flows. The analysis used herein is an analysis of the cumulative distribution of flow events as opposed to an analysis of single events. The distribution of rainfall is transformed into a distribution of runoff using a standard hydrologic model (e.g., HEC-HMS). The distribution of runoff is then analyzed in terms of flow duration, work and sediment load transported. All sediment transporting and erosive flows are accounted for and used to evaluate possible impacts and the effectiveness of proposed management strategies.

The project team modeled in-stream flows under existing and proposed future conditions. Flow duration and sediment transport characteristics are then compared between existing and proposed land use scenarios.

The hydrologic model incorporates information about the watershed characteristics (climate, topography, soils, vegetation, land use, imperviousness, etc.) to estimate how much rainfall is held in the watershed (including infiltration to the soil, interception on vegetation or shallow depressions, etc.), and how much precipitation results in surface runoff and interflow, eventually reaching stream channels.

2 Application to the Laguna Creek Watershed

2.1 HEC-HMS Model

The project team chose to model the Laguna Creek watershed using the U.S. Army Corps of Engineers' Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) rainfall-runoff model. The U.S. Army Corps of Engineers developed HEC-HMS to supersede the HEC-1 Flood Hydrograph Package. Unlike HEC-1, HEC-HMS allows continuous hydrograph simulation over long periods of time in addition to event-based analysis.

Geosyntec obtained the County of Sacramento hydrologic model for Laguna Creek from Public Works Agency. The version received was used for the Upper Laguna Creek Future Geomorphic Study conducted (William-Lettis & Associates, et al 2005). This model was originally developed with SacCalc, developed by David Ford Consulting Engineers in for a LOMR Submittal. December 2004. Geosyntec transferred the County model to HEC-HMS, converted it to a continuous hydrologic model, and updated the routing segments to the Muskingum-Cunge methodology.

Continuous modeling allows for continuous accounting of soil moisture and infiltration and other losses for an extended time period. Therefore, continuous modeling is preferable when trying to identify the hydromodification effects of development on small, frequent flows and to evaluate their impacts on stream stability. The following sections describe the methods and data sources used to generate input for the HEC-HMS models.

2.1.1 Drainage Area Delineation

The Upper Laguna Creek watershed was subdivided into smaller sub-watersheds or catchments to provide a detailed assessment. The sub-watersheds were based on the existing hydrologic delineation provided within the County's HEC-HMS model (WLA, 2005; aka DF 2004). This delineation was corroborated by analyzing topographic data in GIS. **Figure B-2** shows the drainage area delineation of the study watershed. **Table B-1** provides the catchment sizes.

2.1.2 Drainage Area Characteristics

Geosyntec identified land cover characteristics and soil types for the study watershed based on the project's GIS database. Geosyntec overlaid the drainage area delineations on those data to derive the hydrologic characteristics used in modeling each drainage area (**Figure B-2**). Existing hydrologic conditions were modeled using detailed soils GIS data from the NRCS (**Figure B-3**).

2.1.2.1 Pre-Urban Land Uses

The project team reviewed USGS topographic maps and historical aerial photos to characterize pre-urban land use conditions. These sources provided a representation of the pre-urban distribution of agricultural and woodland/grassland areas for each sub-watershed, which was then converted into model input parameters.

2.1.2.2 Existing Land Uses

The existing condition land use data was based on the existing County hydrology model for Upper Laguna Creek. The upper portion of the watershed is primarily agricultural with some large-parcel rural residential uses. Existing residential development exists in and around the Vineyard Spring Comprehensive Plan Area. The agricultural area is predominately dry pasture land suitable for cattle grazing, with some portions suitable for growing a variety of crops including row crops, orchards, vineyards and some irrigated pasture. There are some industrial land uses located just south of Mather Field and on properties owned by Aerojet immediately east of Rancho Cordova and south of Highway 50 (SCDPCD, 2007). The existing condition land use data was based on the existing County hydrology model for Upper Laguna Creek.

The lower portion of the watershed, especially within the City of Elk Grove, is primarily in residential and commercial use, as identified in the city's general plan. A vast majority of the urban residential land use designations in the City of Elk Grove are located in the western portion of the city while rural residential land use designations are dominant in the eastern half of the city. Areas identified for industrial uses are primarily located along the Highway 99 corridor in the southern portion of the city. Commercial land use designations are centrally located but are also dominant along Highway 99. Some infill in the form of residential and commercial land use is likely to occur within already established areas of the city; however a majority of new development will occur in green field areas in southern Elk Grove, within Laguna Creek Watershed.

2.1.2.3 Proposed Land Uses

For future conditions, the percentage of impervious land for each sub-watershed was based on assigning percent imperviousness to the land-use development plans included in the County of Sacramento General Plan, the City of Elk Grove General Plan, and the City of Rancho Cordova General Plan. **Figure B-4** illustrates the future land use condition applied in the hydrologic modeling. Most land use changes in Laguna Creek watershed will occur in the more undeveloped upper watershed area. For future conditions, the percentage of impervious land for each sub-watershed was based on assigning percent imperviousness to the land-use development plans included in the County of Sacramento General Plan, the City of Elk Grove General Plan, and the City of Rancho Cordova General Plan.

A number of new residential development projects are planned for the upper watershed, most of which will fall under the jurisdiction of the Natomas Community Plan. Large and new developments are proposed near Jackson Road; most of which will be residential and light commercial. Most land use changes in Laguna Creek watershed will occur in the more undeveloped upper watershed area. The future condition used in this study was generated from a number of sources; including the County General Plan, the general plans for the cities of Elk Grove and Rancho Cordova, and various tentative track maps for known projects within Laguna Creek watershed. Table B-1b below summarizes the combined land use break down as defined for this study. This table also lists the percent impervious values (%-imp) by land use type assigned for this study.

The Sun Creek Specific Plan land use GIS files were obtained from David Wade. The land use GIS layers for the South Eastern parcels of Rancho Cordova were provided by Christopher Jordan at the City of Rancho Cordova Planning Department. Roxy Anderson at Southgate Recreation and Park District provided the following developments: Garfoot Greens and Wildhawk South; Carmencita Ranch; Bradshaw Christian High School and Ogden. The North Natomas projected land use / impervious surface distribution information were provided by Sacramento County Planning Department.

Table B-1b. Land Use Summary of Future Conditions for the Upper Laguna Creek Watershed

Land-Use	%-imp	acres
Agricultural-Residential	6%	5,921.57
Blodgett Reservoir	100%	68.94
Canal	100%	8.9
Cemetery, Public, Quasi-Public	26%	204.19
Commercial	71%	103.45
Community Retail	80%	30.8
Detention Basin	100%	19.13
General Agriculture	4%	4,682.14
Heavy Industrial	91%	0.21
High Density Residential	60%	75.28
Jackson Corridor Planning Area	70%	1,447.94
Light Industrial	84%	0.13
Low Density Residential	40%	1,267.80
Medium Density Residential	55%	1,472.20
Mixed Use	82%	7.55
Open Space	2%	1,348.05
Park	10%	133.33
Preserve	2%	263.5
Resource Conservation Area	2%	1,855.97
Road	95%	998.33
School	82%	266.98
Very-Low Density Residential	26%	85.56
Village Center	82%	3.06
Water-Quality Basin	100%	1.51
Grand Total		**20,266.51**

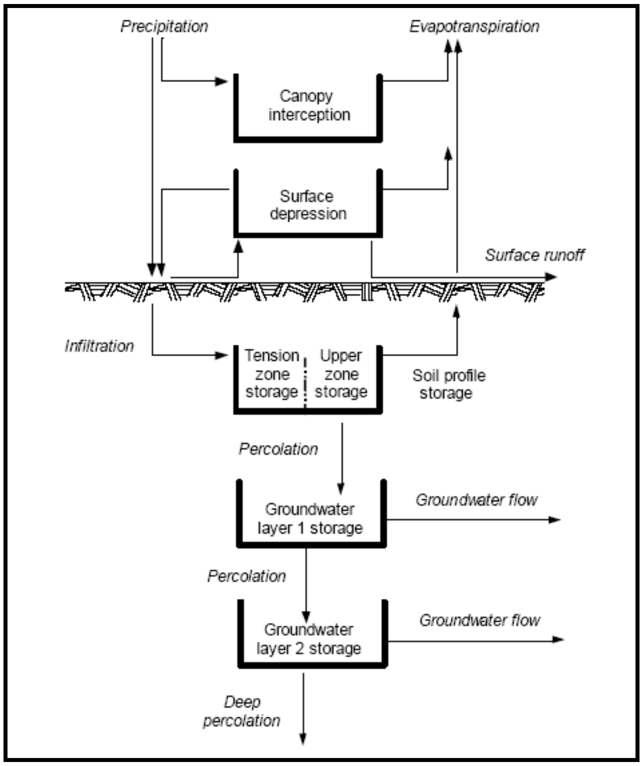
2.1.3 Excess Rainfall

HEC-HMS uses soil infiltration rate estimates and other losses described below to calculate excess precipitation that contributes to stormwater runoff. The continuous simulation routine uses the Soil Moisture Accounting (SMA) method (unique to HEC-HMS).

The SMA method provides a more complex method for evaluating rainfall runoff processes in a watershed. In this approach, actual measured rainfall over an extended time period is used as input. Losses are computed on a continuous basis, and include evapotranspiration, surface depression storage, and infiltration. The continuous model is designed to model the dynamic effect of soil infiltration and other losses on storm runoff over the course of a long-term rainfall record. Parameters to compute these losses include climatic data, land use conditions, vegetation cover, and soils data. The simplified conceptual schematic of **Figure B-5** illustrates the SMA model:

For each computational time step in the model, HEC-HMS calculates storage in each of the loss categories shown in the schematic, which allows for a continuous accounting of losses and runoff over a long time series. For infiltration, when soils are dry, the model assumes that water enters the soil at the maximum infiltration rate and when soils are fully saturated the model assumes that water percolates out of the soil at the maximum percolation rate. SMA parameter estimation is described in section 2.2.

Figure B-5. Conceptual Schematic of SMA Algorithm (USACE, 2000)



2.1.4 Hydrograph Generation

Initially, the model determines how much incident rainfall is held in the watershed (losses), and how much will appear as runoff. That which appears as runoff is referred to as "excess precipitation." The model then determines the time distribution of this watershed-wide excess precipitation, as it flows across the land surface or in shallow "interflow," eventually reaching culverts or small drainage channels, and finally the main stream channel at the various flow computation points of interest. The resulting time distribution of runoff at a given location is referred to as "hydrograph."

HEC-HMS offers a variety of methods for transforming excess precipitation from any given storm into a runoff hydrograph for each model drainage area. The hydrology model of Laguna Creek provided to Geosyntec by the Sacramento County Department of Water Resources included specific unit-hydrographs for each of the model subbasins. These unit-hydrographs were converted to the Clark's synthetic unit hydrograph method to assist in the calibration process. Clark's method requires two inputs: time of concentration (T_c) and a storage coefficient (R). T_c values were calculated for each of the subbasins based on the time to peak (T_p) of the provided unit-hydrographs in the County model (T_p=0.67*T_c). The Clark's storage coefficient for each subbasin was determined through comparison with the County and during the model calibration process. The unit hydrograph parameters used in the modeling are listed in **Table B-1**.

2.1.5 Reach Routing

HEC-HMS provides a variety of reach routing methods to translate the hydrograph from one drainage area downstream to a point where it can be combined with another drainage-area hydrograph. The hydrology model of Laguna Creek provided to Geosyntec by the Sacramento County Department of Water Resources did not include any routing elements, and instead utilized storage-discharge relationships to simulate routing. Geosyntec chose to replace these storage-units with routing based on the Muskingum-Cunge method, which uses basic channel (or culvert) dimensions and characteristics to estimate hydrograph translation and attenuation over the routing reach. For existing and future conditions, surveyed cross-section data was used to characterize channel dimensions and characteristics for reach routing. Reach routing parameters are summarized in **Table B-2**.

The diversion of flow from Laguna Creek to Gerber Creek during high flow events at the Central California Traction Railroad (CCTRR) was included in the existing condition model immediately upstream of junction LCC9A, which represents the CCTRR crossing. The inflow-diversion function was utilized in HEC-HMS, with the rating curve derived from the interbasin transfer reach (David Ford, 2005). The interbasin transfer was not included in the future condition HMS model based on the County's plans to remove the diversion.

2.1.6 Precipitation

The HEC-HMS continuous simulation was run using continuous, hourly rainfall data. Data from two Sacramento County DWR gage stations within the Laguna Creek watershed were investigated to generate records to be used in the hydro-geomorphic model: sensor ID-269, “Laguna Creek at Eagles Nest Road”, and sensor ID-270, “Elk Grove Fish Hatchery”. A 49-year period of rainfall record, from September 1956 through August 2005 was used within the model. However, the available rainfall records from stations ID-269 and ID-270 were from 1994 to 2005 and had to be appended to achieve the 49-year period of record using an additional gage with a longer available record.

Table B-2a. Summary of Precipitation Gage Data used in Model Development

ID	Station	Period of Record	Annual Average (inches)
47630	Executive Airport	1948 - 1994, 1998 - 2004	16.6
47633	Post Office	1936 - 2004	18.7
269	Eagle's Nest	1986 - 2003	18.3
270	Fish Hatchery	1994 - 2005	
	Adjusted Data	1956 to 2004	15.7

Precipitation data was available from 1936 through 2004 at NCDC Station 47633, “Sacramento 5 ESE”, located roughly 10-miles northeast of the project study area. The precipitation data of gage ID-269 and gage ID-270 was compared to NCDC-47633 for a period from November 1994 to December 2004. The monthly precipitation totals over this 10-year period were plotted versus the NCDC monthly totals to calculate a linear scaling factor for each County gage. The results for gage ID-269 plotted versus the NCDC gage was a scaling factor of 1.099 with a R^2 value of 0.91. The results for gage ID-270 plotted versus the NCDC gage was a scaling factor of 1.177 with a R^2 value of 0.94. The County gage precipitation records were extended by applying the respective scaling factors to the NCDC data from 1956 to 1994 and appending this data to the available County gage records. **Figure B-2** highlighted the locations of the two County precipitation gages as well as NCDC Station 47633. **Figures B-6** and **B-7** below illustrate NCDC gage correlation analysis for gages ID-269 and ID-270, respectively.

The NCDC gage, although located outside the study area, has recorded a significantly longer period of precipitation than have other gages in the area. It is recognized that measured rainfall at Sacramento 5 ESE is only an estimate of rainfall distributed across the study watershed. Actual rainfall rates vary spatially, and intense rainfall rates (resulting from individual convective cells within a rainstorm) often occur over one area, but may miss another area nearby. Thus, while measured rainfall at the Sacramento gage represents a valuable estimate of rainfall for the project watershed, variations during any individual storm are possible.

Figure B-6. Analysis of Scaling Factor between Gage ID-269 and NDCD Station 47633

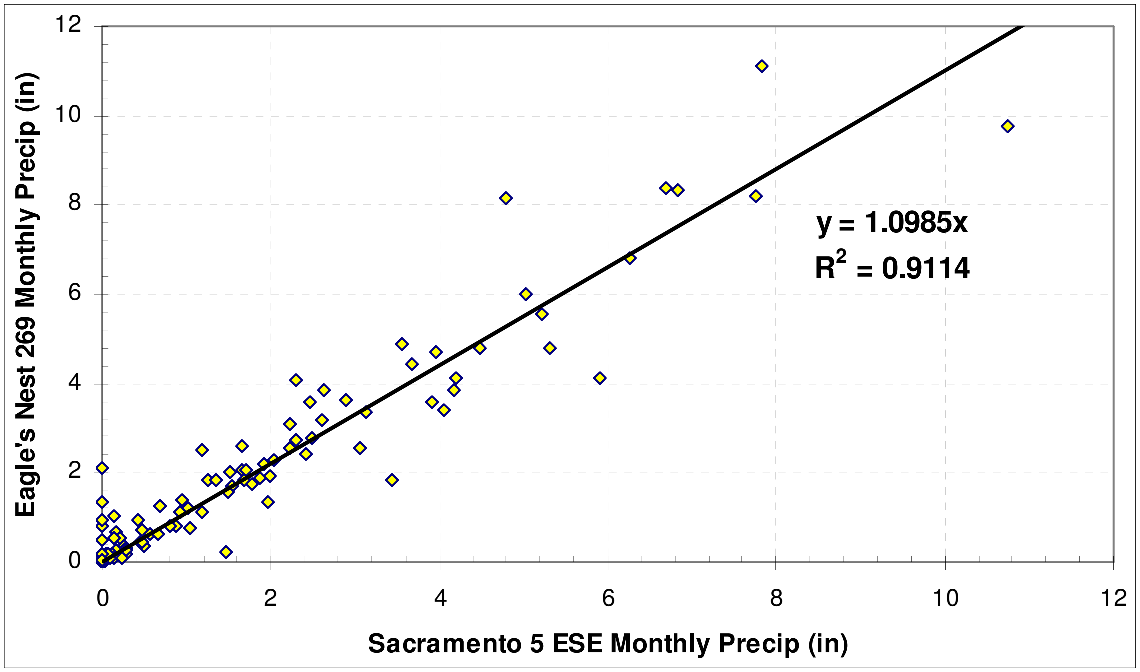
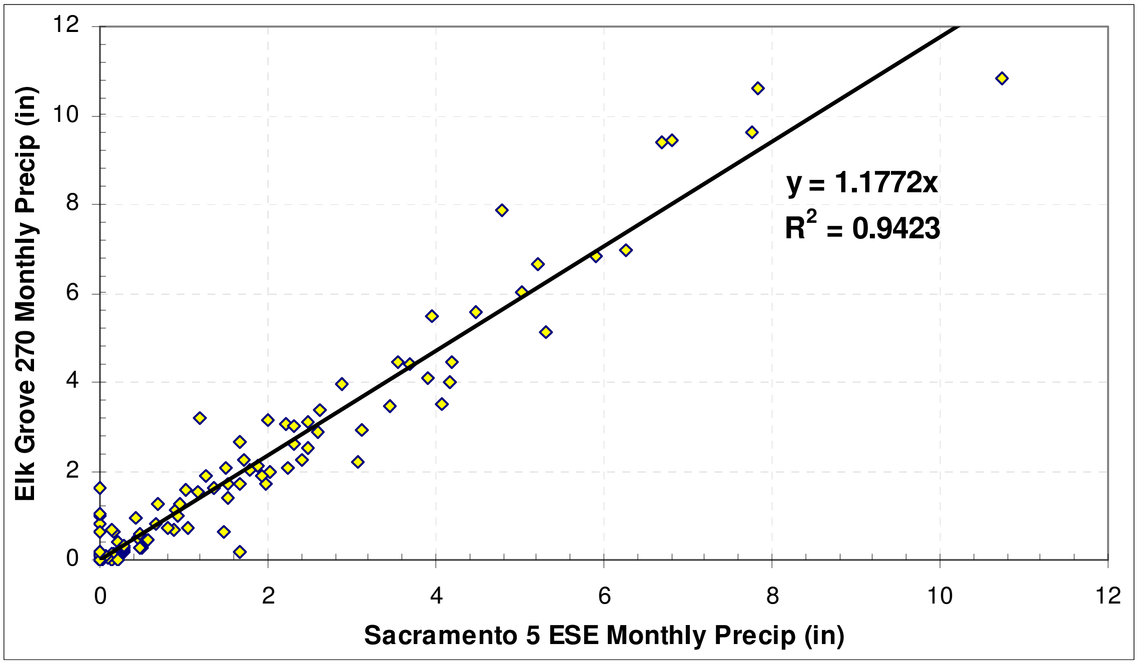


Figure B-7. Analysis of Scaling Factor between Gage ID-270 and NDCD Station 47633



2.1.7 Evapotranspiration

Evapotranspiration data was obtained from the California Irrigation Management Information System (CIMIS) for Fair Oaks, California, June 2006. The total evapotranspiration at this gage is 57-in/yr. This value is a reference value based on turf grass and a coefficient is required to adjust these values to rangeland that is present in Laguna Creek watershed. Geosyntec used a coefficient of 0.5 to convert turf Eto to rangeland grasses Eto which results in a yearly Eto of 28.5 in/yr. Table B-2c below summarizes the data input into the hydrologic model.

Table B-2c. Modeled Evapotranspiration Data

Month	Eto	Pan Coefficient
Jan	1.59	0.5
Feb	2.20	0.5
Mar	3.66	0.5
Apr	5.08	0.5
May	6.83	0.5
Jun	7.80	0.5
Jul	8.67	0.5
Aug	7.81	0.5
Sep	5.67	0.5
Oct	4.03	0.5
Nov	2.13	0.5
Dec	1.59	0.5
Annual		57.06
Rangeland		28.5

2.1.8 Interflow

Interflow is shallow sub-surface flow that migrates to stream channels slower than surface runoff, but faster than baseflows. Interflow tends to extend the runoff period between storms and into spring and early summer (over a few months). On the other hand, baseflows maintain the perennial nature streams throughout the year. Geosyntec attempted to capture the low relief, hummocky landscape with multiple drainage swales, seasonal wetlands and Vernal pools; overlain on less permeable hardpan. Vernal pools are small depressional wetlands that pond during the wet season, then drain and dry through the spring (Rains et al., 2005). According to Rains research suggests that vernal pools are supported by seasonal interflow layers, where shallow sub-surface water hydrologically connects upland, vernal pools, and streams at the catchment scale. Vernal pools are typically perched above regional water tables due to a restricting sub-layer and tend to be clustered at the landscape scale (Dites & Guardino Consulting, 2006).

Interflow was incorporated in the continuous simulation using the HEC-HMS linear reservoir function. Interflow was applied in the first sub-surface layer. The linear reservoir function requires an initial condition, a lag coefficient and recession constant. Every subbasin in the Upper Laguna Creek watershed was assigned an initial condition of zero, with a lag coefficient of 8670 hours, which corresponds to a linear recession constant of roughly 0.99. The linear recession lag coefficient was used as a calibration parameter in the calibration analysis. **Table B-4** shows the interflow values entered in the HEC-HMS model.

Table B-1. Drainage Area Parameterization

Subbasin	Subbasin Area (acres)	Tc (hr)	Clark R (hr)	Existing % Impervious	Future % Impervious
LC01	780	3.98	12	2.0	15.6
LC02	559	2.64	7.95	2.0	5.2
LC04	849	2.99	9	2.0	27.5
LC10	854	3.06	9.23	2.0	32.3
LC12	1,020	3.46	10.43	2.0	47.3
LC14	1,075	3.03	9.15	9.1	35.9
LC18	277	1.84	5.55	2.0	46.1
LC18B	73	1.05	3.15	2.0	70.0
LC19	926	3.09	9.3	8.0	12.4
LC21	372	2.61	7.88	2.0	65.9
LC22	178	1.52	4.58	2.0	4.9
LC23	649	1.34	4.05	9.4	9.5
LC24	630	2.34	7.05	2.0	5.8
LC26	271	1.97	5.93	2.0	5.6
LC30	1,089	4.9	14.78	2.0	49.4
LC31	627	3.71	11.18	2.0	4.1
LC35	1,218	3.68	11.11	3.2	3.7
LC40	523	2.79	8.4	6.2	27.4
LC41	843	1.74	5.25	23.4	28.5
LC42A	831	1.47	4.42	22.7	40.5
LC42B	611	1.57	4.73	7.8	7.8
LC45	272	1.12	3.37	7.3	9.9
LC50	299	1.59	4.8	10.9	10.9
LC51	146	1.09	3.3	9.9	9.9
LC51A	127	0.72	2.17	25.0	25.0
LC52	793	2.34	7.05	8.5	9.6
LC54	333	0.7	2.1	23.3	23.3
LC55	648	1.05	3.15	14.5	17.4
LC56	279	0.9	2.7	13.2	13.9
LC57	663	1.87	5.63	8.5	8.7
LC58	179	1.29	3.9	9.4	12.1
LC60	780	2.09	6.3	6.7	9.2
LC61	1,499	2.64	7.95	16.0	18.2

Table B-2. Reach Parameters for Muskingum-Cunge Routing

Reach ID	Connection	Flow Length (ft)	Slope (ft/ft)	Manning's n	Bottom Width (ft)	Side Slope (xH:1V)
LCR0	LCC0 to LCC0A	8,700	0.005	0.07	6	1
LCR2	LCC0A to LCC1A	8,100	0.005	0.07	15	2.5
LCR2A	LC12 to LCC1A	9,000	0.001	0.07	15	2.5
LCR3	LCC2 to LCC2A	4,200	0.002	0.07	15	2.5
LCR3A	LCC2A to LCC3	1,050	0.0005	0.07	15	2.5
LCR4	LCC3 to LCC3A	3,600	0.001	0.07	15	2.5
LCR4A	LCC3A to LCC3C	2,550	0.0018	0.07	15	2.5
LCR23	LC23 to LCC3C	1,800	0.0011	0.07	5	2
LCR4C	LCC3C to LCC4	4,500	0.0018	0.07	15	2.5
LCR5	LCC4 to LCC5	5,650	0.0011	0.07	15	2.5
LCR6	LCC5 to LCC6	4,330	0.0011	0.07	15	2.5
LCR7	LCC6 to LCC7	6,950	0.0011	0.07	4	1.5
LCR8	LCC7 to LCC8	1,900	0.0022	0.07	20	3
LCR9	LCC8 to LCC9	5,100	0.0022	0.07	8	3.5
LCR9A	LCC9 to LCC9A	5,180	0.0012	0.07	15	1.5
LCR10	LCC9A to LCC10	3,485	0.0009	0.07	16	1.3
LCR10A	LCC10 to LCC10A	4,330	0.0006	0.07	8	1.5
LCR11	LCC10A to LCC11	5,260	0.0006	0.07	8	3.5
LCR12	LCC51A to LCC12	2,615	0.0001	0.07	9	1.3
LCR13	LCC12 to LCC13	4,025	0.0001	0.07	9	1.3
LCR14	LCC13 to LCC14	9,200	0.0001	0.07	9	1.3
LCR15	LCC14 to LCC16	5,000	0.0001	0.07	9	1.3
LCR16	LCC11 to LCC16	5,230	0.0004	0.07	20	1.5
LCR17	LCC16 to LCC17	3,050	0.0004	0.07	20	4
LCR18	LCC17 to LCC18	1,660	0.0004	0.07	20	4
LCR18B	LC18B to LCC2A	1,300	0.003	0.07	5	2
LCR51	LC51 to LCC51A	4,350	0.0001	0.07	9	1.3

Table B-3. SMA Parameterization for Laguna Creek Watershed

Sub-Basin	Canopy Storage Capacity (in)	Surface Storage Capacity (in)	Soil Infil. Max Rate (in/hr)	Soil Storage Capacity (in)	Field Capacity (in)	Soil Perc. Max Rate (in/hr)	GW1 Storage Capacity (in)	GW1 Perc. Max Rate (in/hr)	GW1 Storage Coeff. (hr)
LC01	0.08	0.30	0.26	6.0	4.8	0.26	50	0.26	200
LC02	0.08	0.30	0.09	6.0	4.8	0.09	50	0.09	200
LC04	0.08	0.30	0.08	6.0	4.8	0.08	50	0.08	200
LC10	0.08	0.30	0.09	6.0	4.8	0.09	50	0.09	200
LC12	0.08	0.30	0.08	6.0	4.8	0.08	50	0.08	200
LC14	0.08	0.30	0.09	6.0	4.8	0.09	50	0.09	200
LC18	0.08	0.30	0.09	6.0	4.8	0.09	50	0.09	200
LC18B	0.08	0.30	0.07	6.0	4.8	0.07	50	0.07	200
LC19	0.08	0.30	0.08	6.0	4.8	0.08	50	0.08	200
LC21	0.08	0.30	0.07	6.0	4.8	0.07	50	0.07	200
LC22	0.08	0.30	0.02	6.0	4.8	0.02	50	0.02	200
LC23	0.08	0.30	0.04	6.0	4.8	0.04	50	0.04	200
LC24	0.08	0.30	0.03	6.0	4.8	0.03	50	0.03	200
LC26	0.08	0.30	0.07	6.0	4.8	0.07	50	0.07	200
LC30	0.08	0.30	0.09	6.0	4.8	0.09	50	0.09	200
LC31	0.08	0.30	0.10	6.0	4.8	0.10	50	0.10	200
LC35	0.08	0.30	0.07	6.0	4.8	0.07	50	0.07	200
LC40	0.08	0.30	0.08	6.0	4.8	0.08	50	0.08	200
LC41	0.08	0.30	0.06	6.0	4.8	0.06	50	0.06	200
LC42A	0.08	0.30	0.04	6.0	4.8	0.04	50	0.04	200
LC42B	0.08	0.30	0.04	6.0	4.8	0.04	50	0.04	200
LC45	0.08	0.30	0.06	6.0	4.8	0.06	50	0.06	200
LC50	0.08	0.30	0.07	6.0	4.8	0.07	50	0.07	200
LC51	0.08	0.30	0.07	6.0	4.8	0.07	50	0.07	200
LC51A	0.08	0.30	0.07	6.0	4.8	0.07	50	0.07	200
LC52	0.08	0.30	0.03	6.0	4.8	0.03	50	0.03	200
LC54	0.08	0.30	0.04	6.0	4.8	0.04	50	0.04	200
LC55	0.08	0.30	0.02	6.0	4.8	0.02	50	0.02	200
LC56	0.08	0.30	0.02	6.0	4.8	0.02	50	0.02	200
LC57	0.08	0.30	0.02	6.0	4.8	0.02	50	0.02	200
LC58	0.08	0.30	0.03	6.0	4.8	0.03	50	0.03	200
LC60	0.08	0.30	0.03	6.0	4.8	0.03	50	0.03	200
LC61	0.08	0.30	0.02	6.0	4.8	0.02	50	0.02	200

Table B-4. Linear Reservoir Interflow Parameterization for Laguna Creek Watershed

Subbasin	Initial Type	GW1 Initial (cfs/mi2)	GW1 Coefficient (hr)	Routing Steps
All	Discharge Per Area	0.000	1450	1

2.2 Methodology for Hydrologic Calibration

To simulate the watershed response to a rainfall event, a variety of parameters must be estimated in the hydrologic model. These estimated parameters affect the size and shape of the storm hydrograph predicted by the model compared to what may result from any individual actual storm. Whenever possible, modelers compare model results to recorded concurrent rainfall and flow data to calibrate the model by adjusting various parameters to reproduce the actual flow resulting from measured rainfall. Geosyntec calibrated the model by adjusting the SMA parameters and the Clark unit hydrograph R values.

Initial estimations of SMA parameters were developed in accord with the methodology outlined in the HEC-HMS Technical Reference Manual (USACE, 2000). Model calibration was then utilized to refine the initial SMA parameters within acceptable parameter ranges. A calibration was performed for the Laguna Creek watershed, using rainfall and stream flow measurements collected from within the project area, from October 1996 through September 1998. The calibrated parameters were then verified using rainfall and stream flow measurements from October 1998 through September 2000. The calibrated SMA parameters are presented in **Table B-3**.

2.2.1 Rating Curves for Stream Flow Gages

Two stream gages are available on Laguna Creek: one at Eagles Nest Road and one at the intersection of Waterman & Bond. The County of Sacramento operates the gage at Eagles Nest as part of their Alert System, and the USGS operates the gage at Waterman & Bond for the City of Elk Grove (11336585 LAGUNA C NR ELK GROVE CA). Flow data (cfs) from October 1995 to September 2004 is available by download from http://waterdata.usgs.gov/nwis/. The Eagles Nest gage measures stage but not flows, therefore, a rating curve had to be developed to convert the stage data to flow data in order to compare measured flows to model predicted flows. Stage data available and used in this study range from February 1987 to August 2005.

Greg Suba and Nancy Meyers, of Environmental Education Services (EES) collected stream flow measurements for five storm events between February and April of 2006.

Cross sectional flow profiles were measured from the Eagles Nest bridge. At one foot interval, water depth was measured using a collapsible stadia rod. Within each one foot interval, water velocity was measured in (ft/s) using a Global Water FP-101 Global Flow Probe. Each velocity measurements represent the average of 30 readings taken at either the middle of each stream subsection, or at a depth of 10" below the surface of each subsection for deeper subsections. Velocity readings less than 0.01 m/s (0.03 ft/s) were beyond the detectable range of the meter and were recorded as 0.0 m/s (ft/s).

The measured data covered a range of flows from 1 cfs to 316 cfs. A short distance downstream form the gage is an old stream crossing with multiple culverts (agriculture diversion). This culvert crossing was measured by Geosyntec and used to develop a rating curve for flows greater than 316 cfs and up to the maximum predicted by the hydrologic model. This part of the rating curve incorporates the effects of multiple culverts and overflows as broad crested weir flows.

2.2.2 Peak-weighted RMS Error

The degree of correlation between the observed and simulated flows was measured using the peak-weighted root mean square (RMS) error objective function. This function is identical to the calibration objective function included in computer program HEC-1 (USACE, 1998). It compares all ordinates, squaring differences, and it weights the squared differences. The weight assigned to each ordinate is proportional to the magnitude of the ordinate. Ordinates greater than the mean of the observed hydrograph are assigned a weight greater than 1.00, and those smaller, a weight less than 1.00. The peak observed ordinate is assigned the maximum weight. The sum of the weighted, squared differences is divided by the number of computed hydrograph ordinates; thus, yielding the mean squared error. Taking the square root yields the root mean squared error.

Therefore, this function is an implicit measure of comparison of the magnitudes of the peaks, volumes, and times of peak of the two hydrographs. The function is defined as follows:

$$Z = \sqrt{\frac{\sum_{t=1}^{n} (Q_0(t) - Q_S(t))^2 \frac{Q_0(t) + Q_A}{2Q_A}}{n}}$$

$$Q_A = \frac{1}{n}\sum_{t=1}^{n} Q_0$$

Where Z is the objective function, $Q_0(t)$ is the observed flow at time t, $Q_S(t)$ is the computed flow at time t, and Q_A is the average observed flow. The objective function is evaluated for all times t in the objective function time window.

2.2.3 Sum of Squared Residuals

The sum of squared residuals (Diskin and Simon, 1977) is a commonly-used objective function for model calibration. It compares each ordinate of the computed hydrograph with the observed, using the squared differences as the measure of fit. Thus a difference of 10 cfs "scores" 100 times worse than a difference of 1 cfs. Squaring the differences also treats overestimates and underestimates as undesirable. This function is implicitly a measure of the comparison of the magnitudes of the peaks, volumes, and times of peak of the two hydrographs.

$$Z = \sqrt{\frac{\sum_{t=1}^{n} (Q_0(t) - Q_S(t))^2}{n}}$$

Where Z is the objective function, $Q_0(t)$ is the observed flow at time t and $Q_S(t)$ is the computed flow at time t. The objective function is evaluated for all times t in the objective function time window.

2.3 Calibration Results

The existing condition model for Laguna Creek was calibrated against the observed data for two flow gages within the Laguna Creek watershed. Gage ID-268 is located on Laguna Creek at the Eagle's Nest Road crossing; Gage ID-1301 is located on Laguna Creek just below the intersection of Waterman Road and Bond Road. Gages 268 and 1301 correspond to HEC-HMS model nodes LCC4 and LCC18, respectively (**Figure B-2**). Due to the large quantity of data generated in the Laguna Creek model (49 years of flow estimates at one-hour intervals for multiple locations), this section will limit the results discussion to the results from junctions LCC4, LCC18, and junction LCC10A, which represents the Laguna Creek crossing at Calvine Road.

In the upper portion of the watershed, the flow record for Gage 268, Laguna Creek at Eagle's Nest Road, was used to calibrate the model at junction LCC4. Flow data was utilized from October 1996 to September 2000 for Gage 268 for the existing condition calibration and verification of the model at LCC4. The hydrograph results for the existing condition calibration at LCC4 are shown in **Figures B-8a and B-8b**.

The flow record for Laguna Creek Gage 1301 at the Waterman-Bond intersection was used to calibrate the lower portion of the Laguna Creek watershed model at junction LCC18. Flow data was utilized for this gage from October 1996 to September 2000 for the existing condition calibration and verification of the model at LCC18. The hydrograph results for the existing condition calibration at LCC18 are shown in **Figures B-9a and B-9b**.

Tables B-5 through **B-8** lists the numerical results for each of the calibration and verification periods discussed above. The total volume for the flow gage record and the simulation are shown. The percent error from observed volume is also presented in these tables, and due to the variability of hydrologic modeling, a deviation of 20 percent is considered a strong correlation. The average discharge for each condition was included for comparison. The RMS error function value and the Sum-of-Squared Residuals value for the model results when compared to the gage data are presented in the tables.

Table B-5: Gage 268 Calibration - Period from 10/1/1996 – 9/30/1998

	Volume (ac-ft)	Average Q (cfs)	Model Results' Peak-weighted RMS Error	Model Results' Sum-of-Squared Residuals	Percent Error in Volume
Gage 268	38,226	26.4	-	-	-
Model Results @ LCC4	39,811	27.5	44	23.1	-4.1%

Table B-6: Gage 268 Verification - Period from 10/1/1998 – 9/30/2000

	Volume (ac-ft)	Average Q (cfs)	Model Results' Peak-weighted RMS Error	Model Results' Sum-of-Squared Residuals	Percent Error in Volume
Gage 268	20,953	15.3	-	-	-
Model Results @ LCC4	22,138	14.5	133.8	30.9	5.4%

Table B-7: Gage 1301 Calibration - Period from 10/1/1996 – 9/30/1998

	Volume (ac-ft)	Average Q (cfs)	Model Results' Peak-weighted RMS Error	Model Results' Sum-of-Squared Residuals	Percent Error in Volume
Gage 1301	50,620	35.0	-	-	-
Model Results @ LCC18	48,227	33.3	206.2	64.9	4.7%

Table B-8: Gage 1301 Verification - Period from 10/1/1998 – 9/30/2000

	Volume (ac-ft)	Average Q (cfs)	Model Results' Peak-weighted RMS Error	Model Results' Sum-of-Squared Residuals	Percent Error in Volume
Gage 1301	27,321	18.8	-	-	-
Model Results @ LCC18	29,447	20.3	170.7	55.2	-7.8%

Figure B-8a. Calibration for Gage 268, Runoff Hydrographs for Nov96 - Mar97

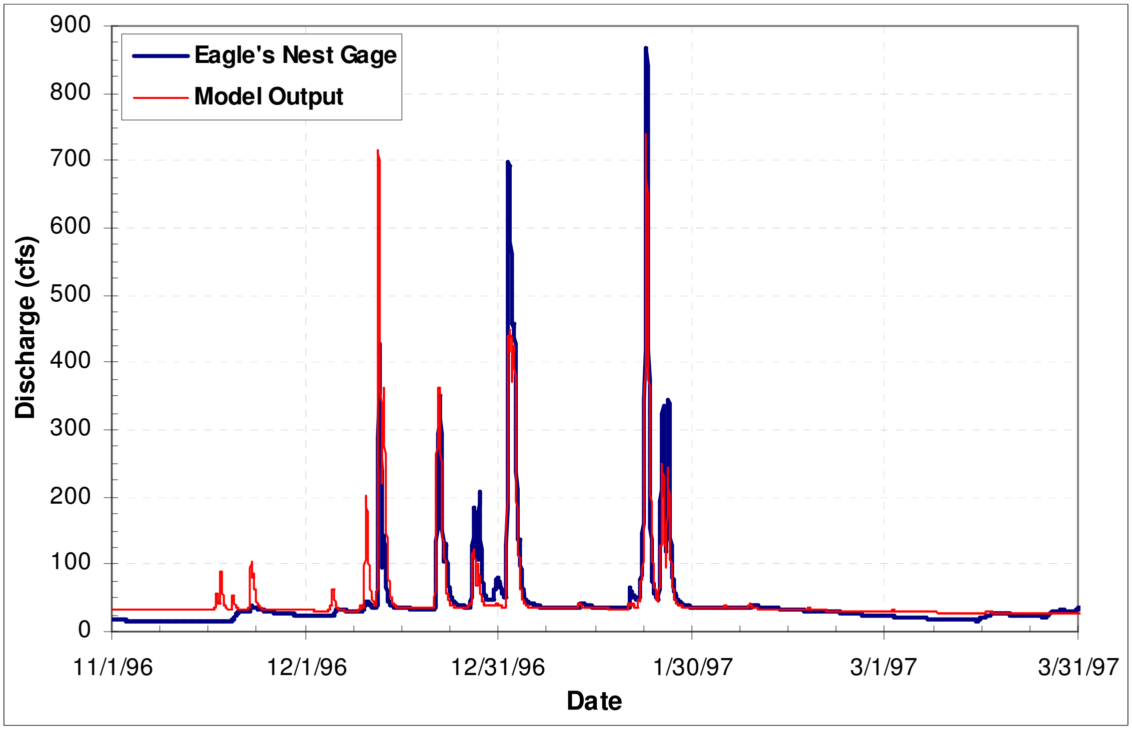


Figure B-8b. Calibration for Gage 268, Runoff Hydrographs for Nov97 - Mar98

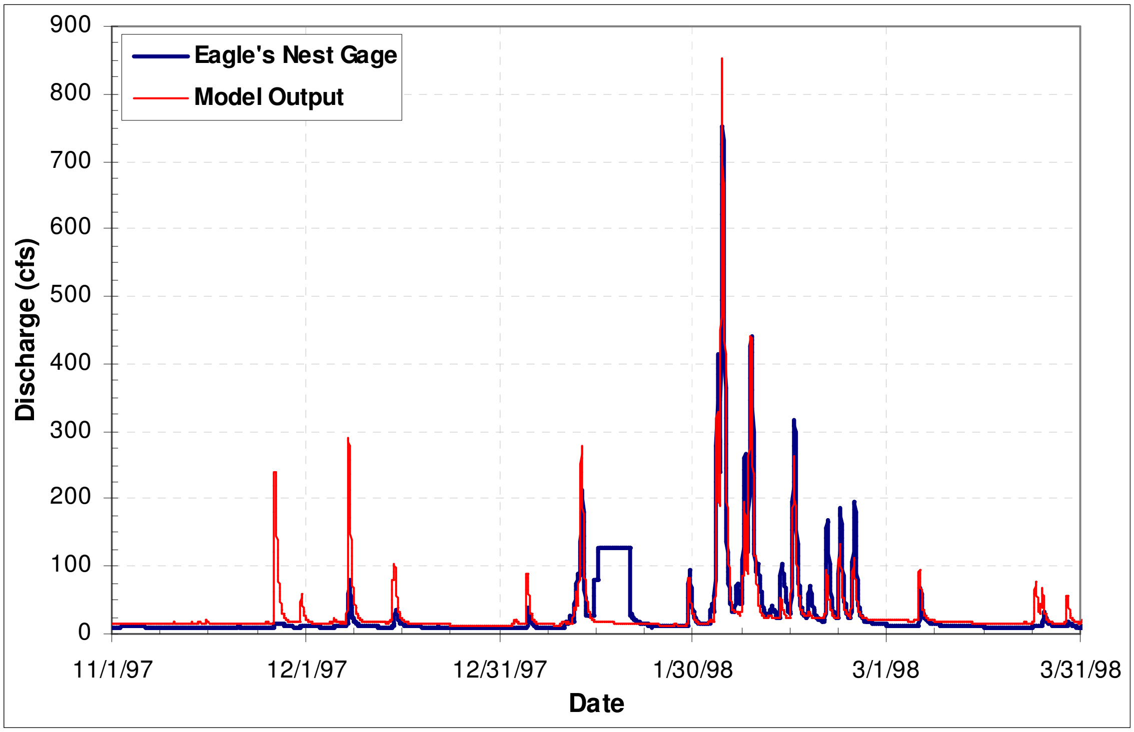


Figure B-9a. Calibration for Gage 1301, Runoff Hydrographs for Nov96 - Mar97

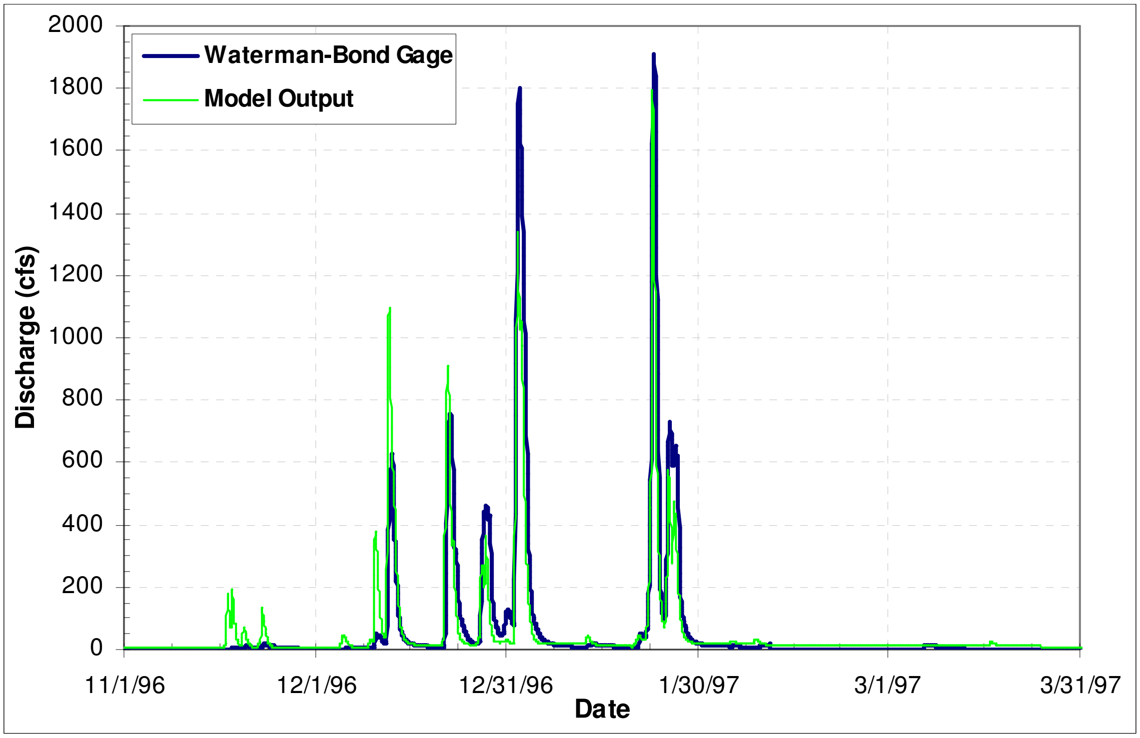


Figure B-9b. Calibration for Gage 1301, Runoff Hydrographs for Nov97 - Mar98

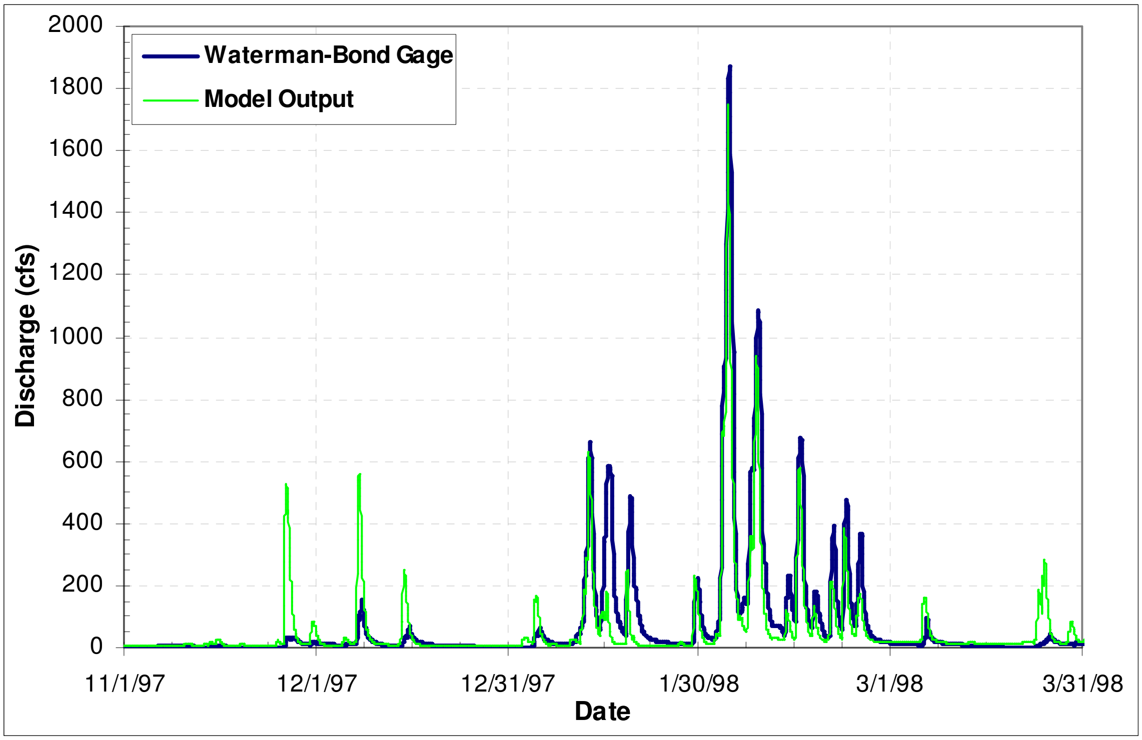


Figure B-10. Calibration & Verification for Gage 268, Cumulative Runoff Volume

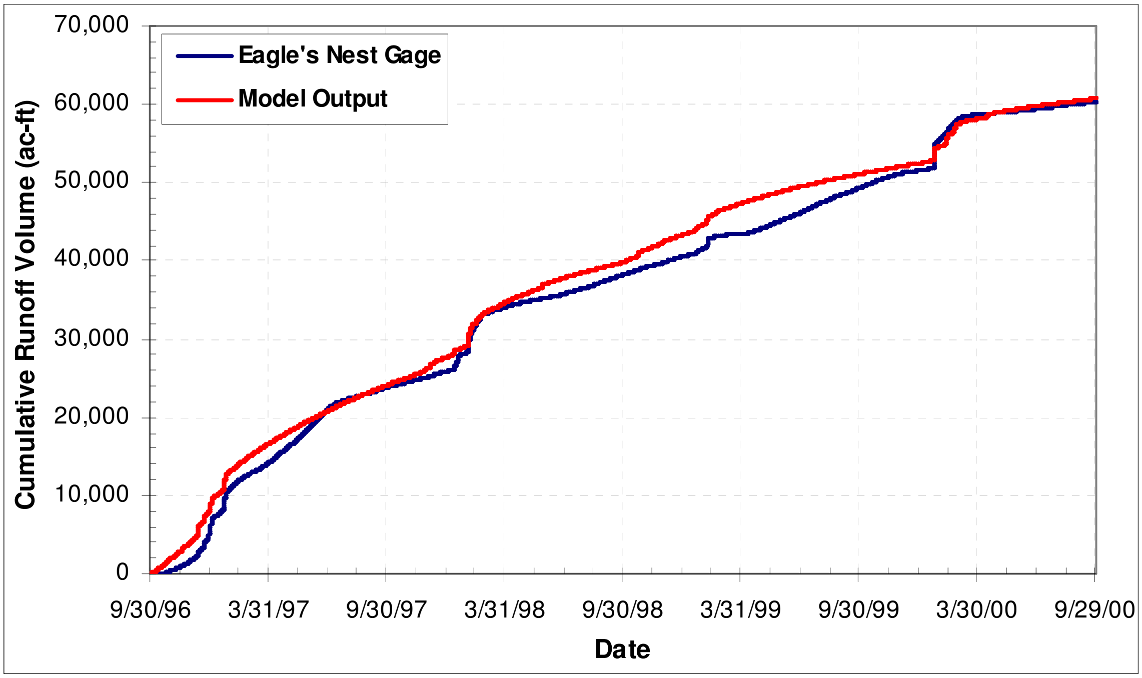


Figure B-11. Calibration & Verification for Gage 1301, Cumulative Runoff Volume

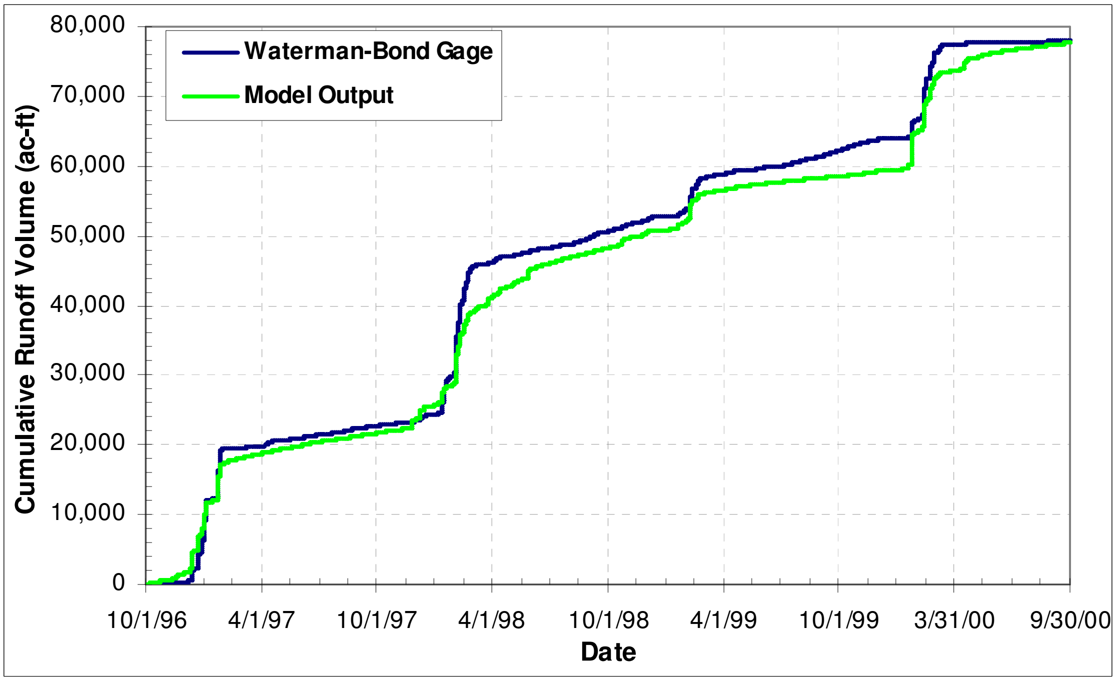


Figure B-12. Calibration & Verification for Gage 268, Flow Duration Curves

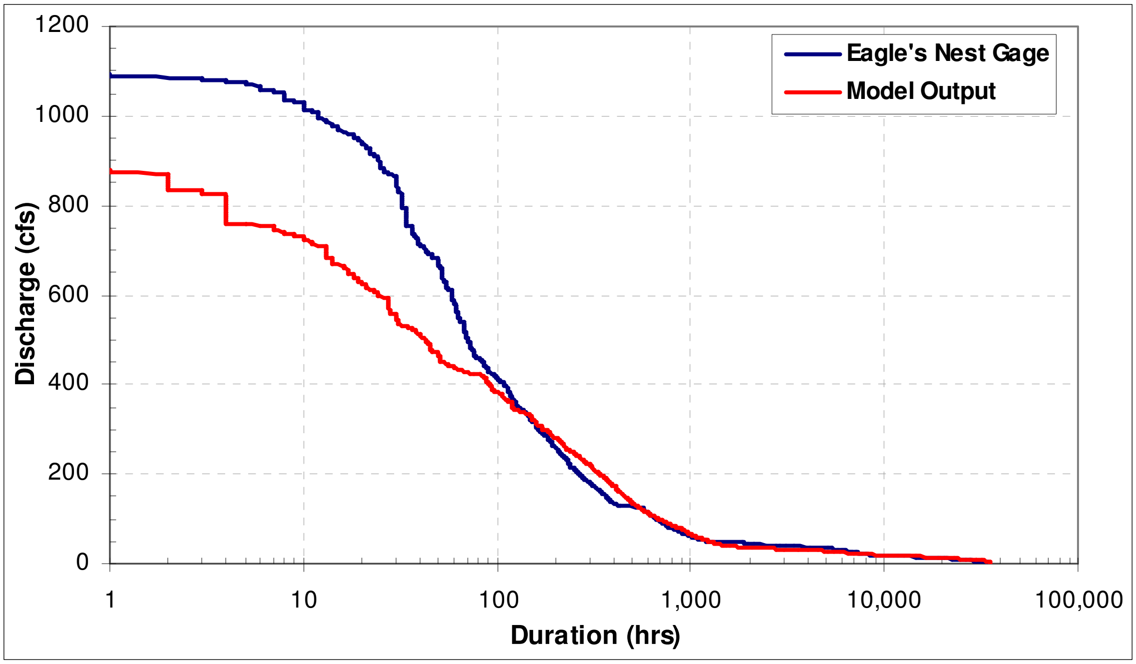
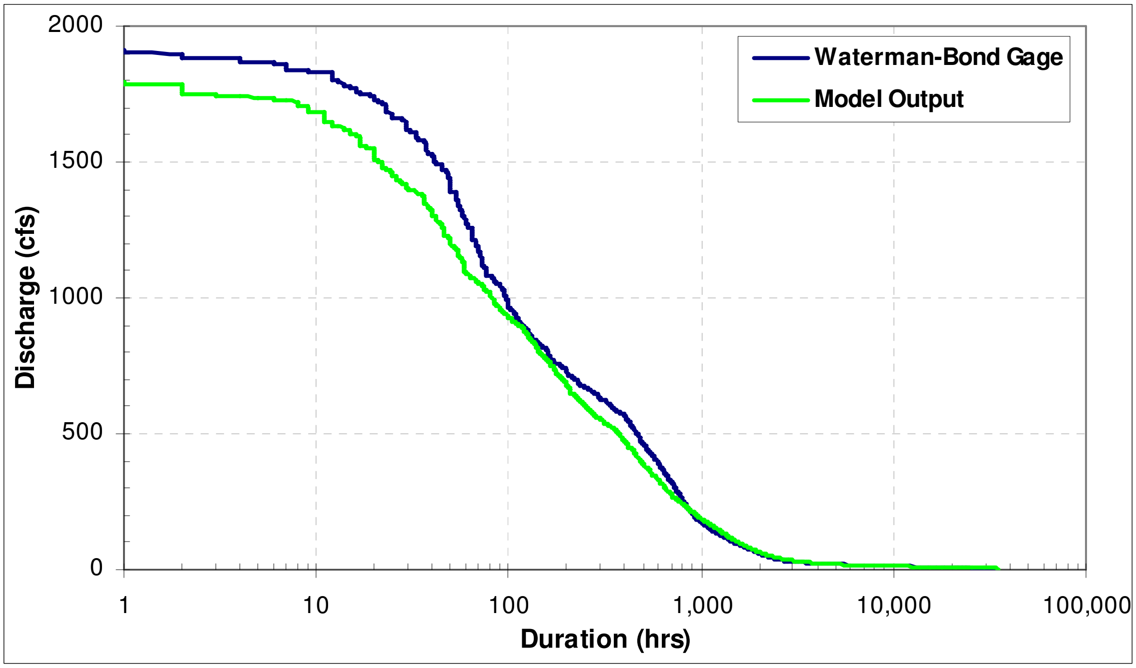


Figure B-13. Calibration & Verification for Gage 1301, Flow Duration Curves



2.4 Comparison to the David Ford Study

In December of 2005, David Ford Consulting Engineers conducted a hydrologic and hydraulic study of the Laguna Creek watershed. The extent of the hydrologic model is the portion of the Laguna Creek watershed within and upstream of the City of Elk Grove. David Ford developed models to evaluate four future condition scenarios. This study was conducted to address following questions for four land use scenarios, 1) what are the approximate 10-year and 100-year flows in Laguna Creek within the Elk Grove city limits for the current conditions; and 2) what are the approximate 10-year and 100-year flows in Laguna Creek.

Tables B-8a and B-8b present the comparison between models and methods for two equivalent locations: at Calvine Road and Waterman Road. Under existing conditions, for the 10-year storm the models are predicting peak flows at Calvine Road within 10%. For the 100-year storm, the models are within 5% of each other at Calvine Road. The peak flows predicted by HMS at Waterman Road is twice the magnitude as that predicted by David Ford. At the time of this writing, we had not investigated these differences.

For the unmitigated future conditions, the models are predicting peak flows at Calvine Road and Waterman Road within 22% of each other; and are within 13% when HMS is compared to the Most Likely Future by David Ford. Geosyntec's future includes removing the interbasin transfer, but does not include the Triangle Rock detention basin.

Predicting peak flows within 22% using different hydrologic models, using different algorithms, for different purposes would be considered very good.

Table B-8a. Peak flows at selected locations, p=0.10 event (10-year)

	David Ford				HMS	
Location	Current (cfs)	Most-likely future[1] (cfs)	Unmitigated future (cfs)	Unmitigated ultimate (cfs)	HMS Existing w/Diversion	HMS Unmitigated Future
Calvine Road	**892**	1,527	1,664	2,521	**966**	1,319
Waterman Road	956	1,527	1,664	2,521	1,740	1,968

Table B-8b. Peak flows at selected locations, p=0.01 event (100-year)

	David Ford				HMS	
Location	Current (cfs)	Most-likely future[1] (cfs)	Unmitigated future (cfs)	Unmitigated ultimate (cfs)	Existing w/Diversion	Unmitigated Future
Calvine Road	**1,237**	2,521	2,837	4,240	**1,197**	2,190
Waterman Road	1,453	2,522	2,839	4,241	2,946	3,486

3 Results and Discussion

This section summarizes the predicted changes in flow duration characteristics, magnitude of recurrence interval events and the cumulative runoff volumes over the 49 year continuous hydrologic simulation.

3.1.1 Flow Duration

Flow duration curves are presented for three locations within the Upper Laguna Creek watershed. The future condition at Eagle's Nest Road captures the majority of the new development within the Jackson Corridor Planning Area and the City of Rancho Cordova. Figure B-14 illustrates the change in flow-duration due to this development. The future condition at Calvine Road reflects all of the development within the upper portion of the watershed along with the new developments at Carmencita Ranch, Ogden, Garfoot Greens and the Bradshaw Christian High School. Figure B-15 illustrates the change in flow-duration due to this development. The future condition at the Waterman-Bond intersection reflects the cumulative effects of all the new development considered in this study of the Upper Laguna Creek watershed. Figure B-16 illustrates the change in flow-duration due to this development.

Figure B-14. Flow-Duration Results for Laguna Creek at Eagles Nest Rd.

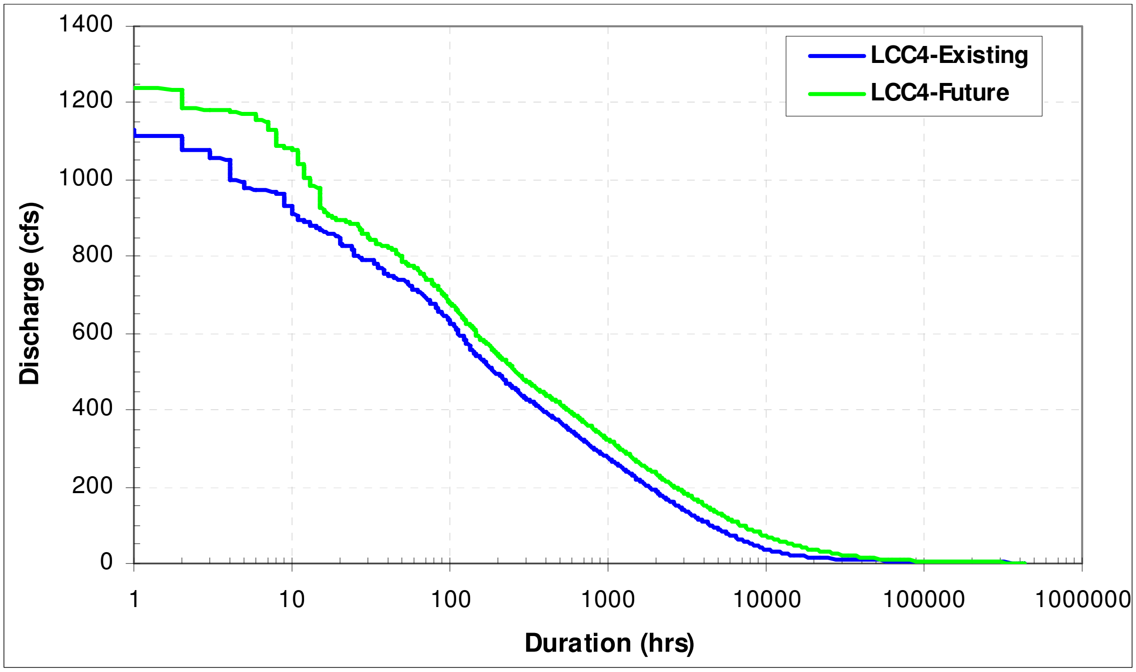


Figure B-15. Flow-Duration Results for Laguna Creek at Calvine Rd.

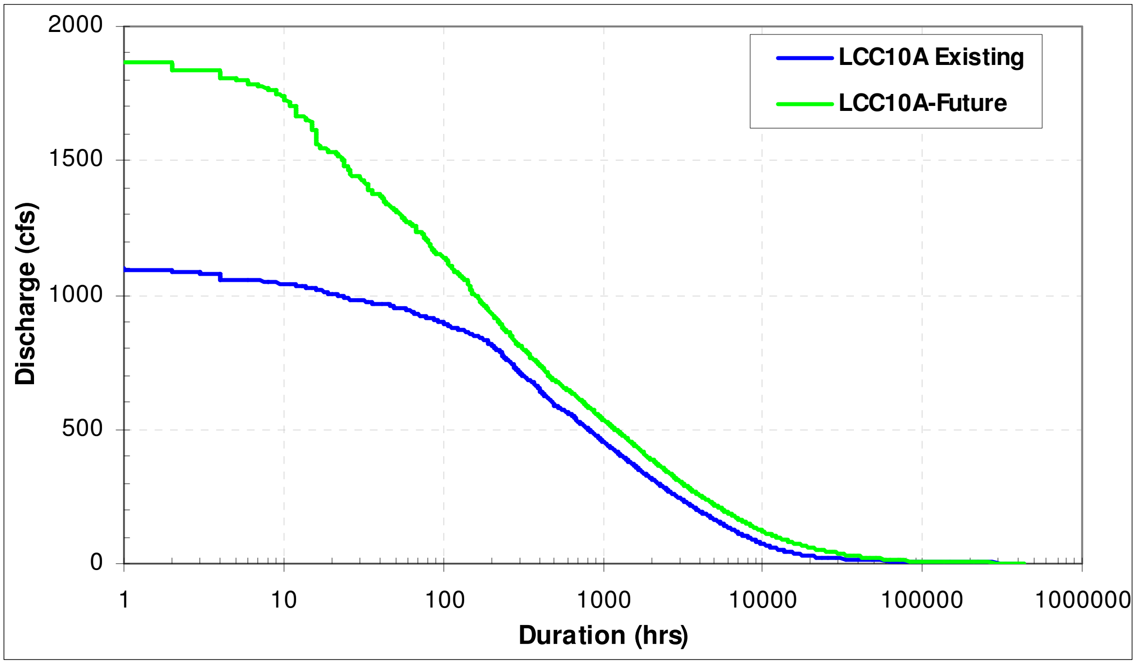
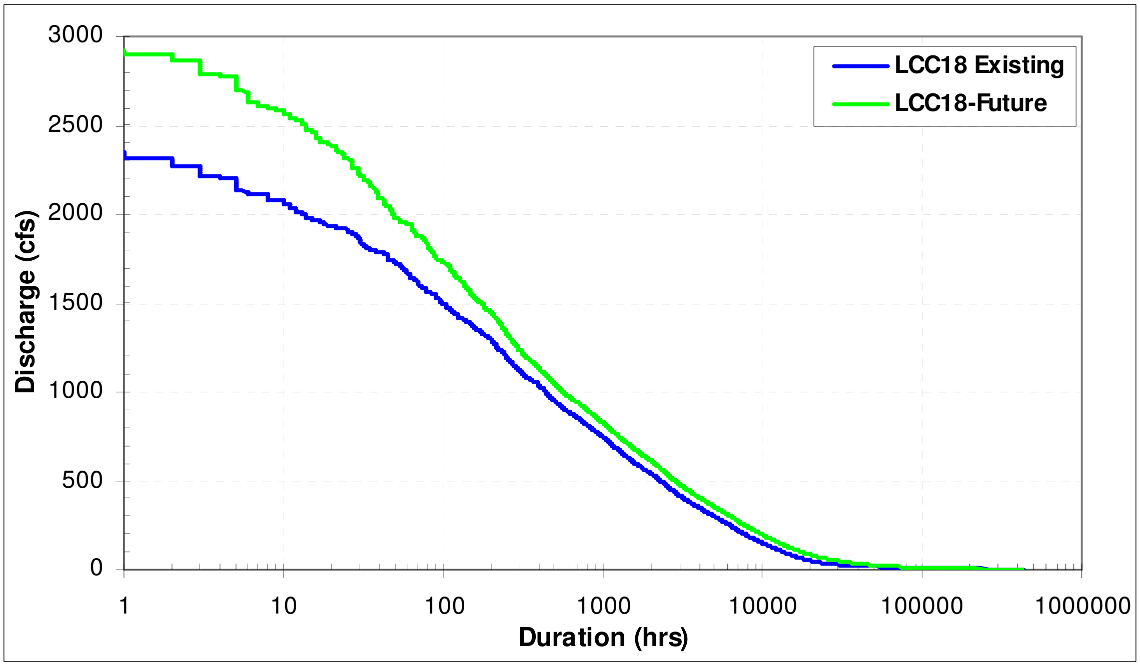


Figure B-16. Flow-Duration Results for Laguna Creek at Waterman-Bond



3.1.2 Flood Frequency

Flood frequencies were calculated for all the model junctions using both a partial-duration series analysis and the Log-Pearson Type III distribution. This section presents the flood frequency results for three locations within the study area. The existing condition results at Calvine Road and at the Waterman-Bond intersection include the effects of the interbasin diversion of high flows from Laguna Creek to Gerber Creek. This diversion was not included in the future condition model.

Figure B-17. Recurrence Interval Results for Laguna Creek at Eagle's Nest Rd.

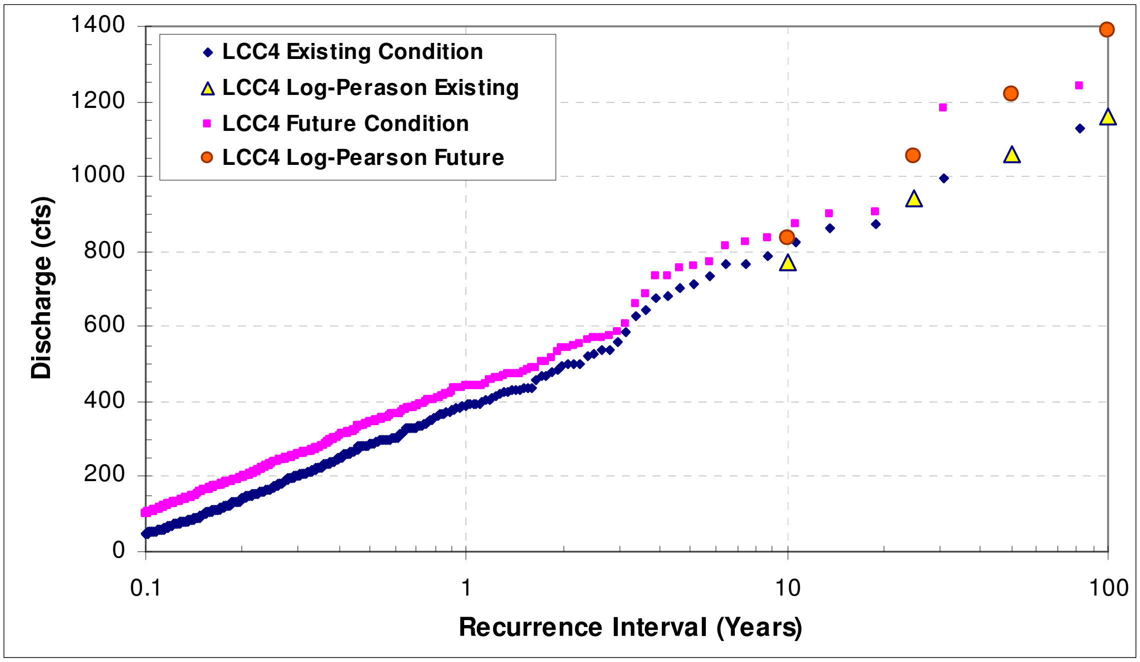


Figure B-18. Recurrence Interval Results for Laguna Creek at Calvine Rd.

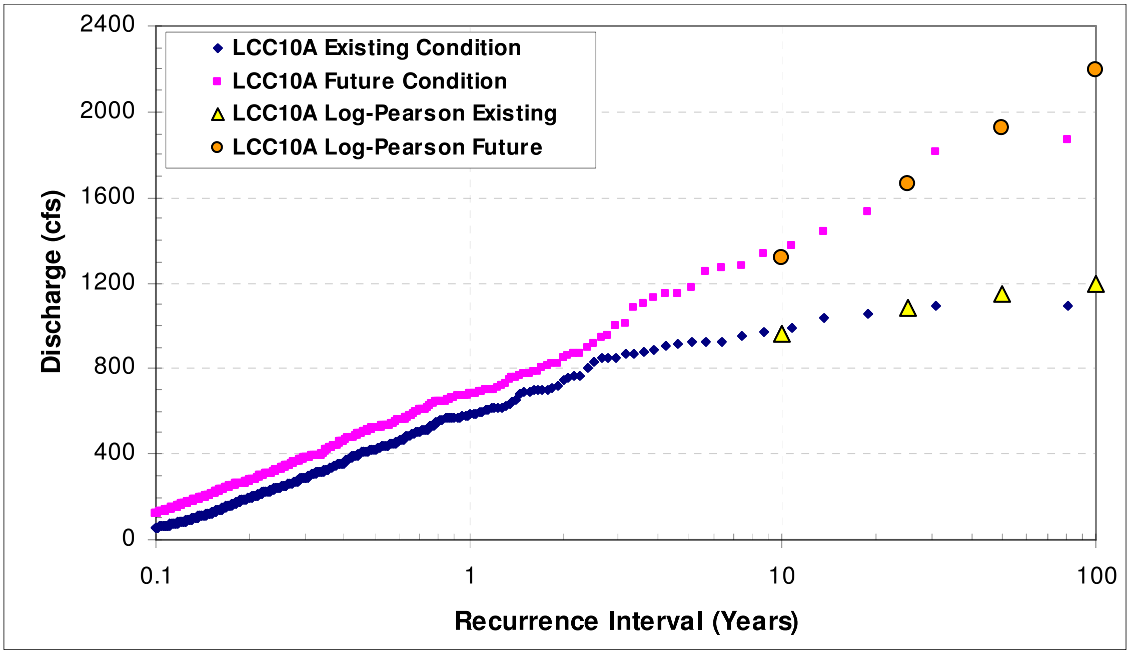
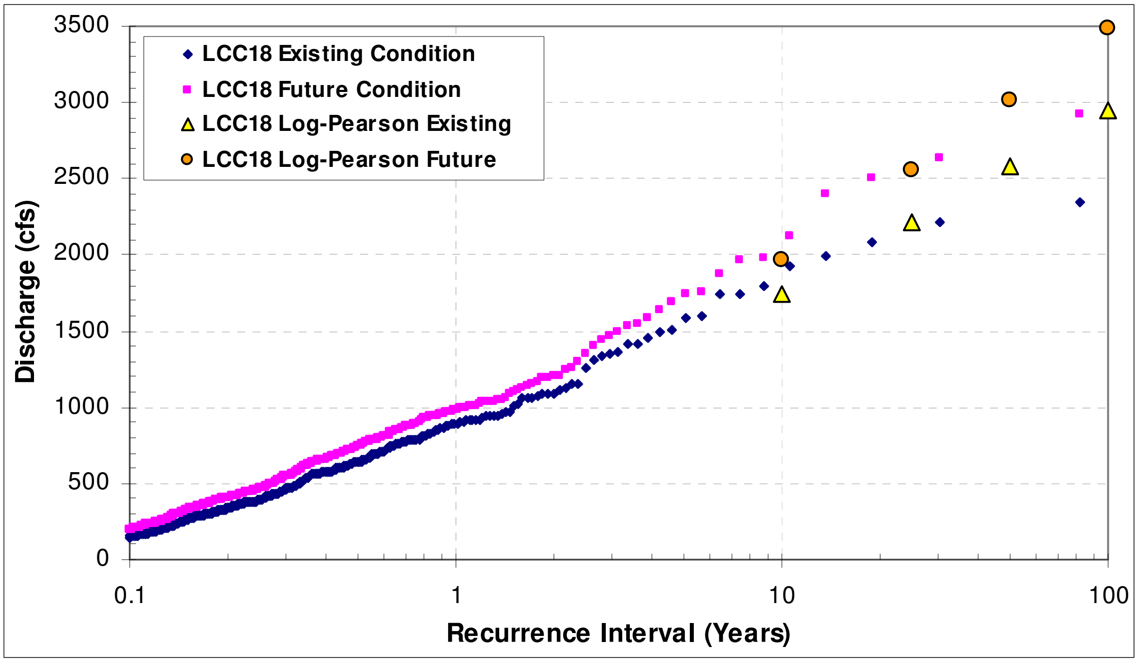


Figure B-19. Recurrence Interval Results for Laguna Creek at Waterman-Bond



3.1.3 Water Balance

Cumulative runoff volumes at every model node for the entire 49-year continuous hydrologic simulation are presented below in Tables B-9 to B-11 for both the existing and future condition, as well as the percent change in volume from existing to future condition.

Table B-9. Runoff Volumes for Existing Condition

Model Node	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)
Subbasin LC01	48	50	24	16	0.9	0.0	0.0	0.0	0.0	3	12	13	166
Subbasin LC02	61	63	46	23	2	0.0	0.0	0.0	0.7	5	12	25	238
Subbasin LC12	119	120	89	42	6	0.0	0.0	0.0	1.5	11	23	47	460
Subbasin LC30	122	125	92	47	5	0.0	0.0	0.0	1.3	11	23	49	474
Junction LCC0	102	100	82	42	8	1.1	0.0	0.0	1.3	10	19	39	405
Junction LCC3C	859	810	615	389	134	70	9	8	19	101	200	370	3,584
Junction LCC4	967	897	678	428	148	74	10	8	21	114	228	404	3,978
Junction LCC5	1,116	1,038	782	500	168	86	12	10	24	129	261	458	4,583
Junction LCC6	1,178	1,097	825	530	178	91	12	10	25	135	273	481	4,836
Junction LCC8	1,389	1,293	981	621	208	98	15	11	30	159	323	566	5,693
Junction LCC9A	1,464	1,376	1,063	655	224	126	16	15	35	168	372	649	6,162
Junction LCC10A	1,649	1,517	1,174	706	251	139	19	17	43	192	432	716	6,856
Junction LCC11	1,758	1,609	1,250	748	257	145	18	18	46	206	469	762	7,286
Junction LCC14	509	449	340	174	59	25	3	4	15	77	176	254	2,085
Junction LCC16	2,333	2,104	1,645	948	318	177	23	23	63	291	662	1,042	9,628
Junction LCC18	2,782	2,502	1,935	1,072	386	194	27	26	78	363	832	1,281	11,479

Table B-10. Runoff Volumes for Future Condition

Model Node	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)
Subbasin LC01	70	63	51	31	11	4	0.0	1.0	3	12	26	36	309
Subbasin LC02	63	63	47	27	6	1.2	0.0	0.0	1.2	7	15	26	256
Subbasin LC12	207	180	143	75	28	10	2	3	13	42	96	126	925
Subbasin LC30	228	197	157	82	31	10	2	4	14	47	107	139	1,018
Junction LCC0	133	122	94	59	21	9	1.4	2	5	19	41	62	566
Junction LCC3C	1,254	1,112	895	486	189	75	12	19	60	224	499	716	5,540
Junction LCC4	1,354	1,201	966	521	201	80	13	20	62	239	530	766	5,953
Junction LCC5	1,629	1,424	1,152	616	238	94	15	24	76	289	644	907	7,108
Junction LCC6	1,694	1,484	1,197	647	249	100	16	25	77	296	658	933	7,375
Junction LCC8	1,926	1,697	1,363	738	285	118	19	27	85	327	727	1,038	8,348
Junction LCC9A	2,052	1,839	1,455	792	306	126	20	29	91	352	788	1,137	8,989
Junction LCC10A	2,272	2,007	1,581	854	328	139	22	32	101	387	873	1,217	9,811
Junction LCC11	2,379	2,100	1,651	891	341	145	23	33	104	402	908	1,263	10,240
Junction LCC14	513	452	343	175	60	25	3	4	15	79	180	258	2,108
Junction LCC16	2,950	2,609	2,045	1,082	412	175	28	37	121	488	1,111	1,553	12,612
Junction LCC18	3,425	3,008	2,347	1,226	461	194	32	41	138	562	1,279	1,793	14,504

Table B-11. Increase in Runoff Volume from Existing to Future Condition

Model Node	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Subbasin LC01	46%	27%	111%	98%						269%	126%	177%	86%
Subbasin LC02	3%	1%	3%	18%	165%					27%	25%	4%	8%
Subbasin LC12	74%	49%	61%	77%	371%					275%	310%	170%	101%
Subbasin LC30	88%	57%	71%	76%	555%					334%	366%	184%	115%
Junction LCC0	30%	22%	14%	40%	149%					97%	120%	60%	40%
Junction LCC3C	46%	37%	45%	25%	41%	6%	32%	145%	214%	123%	150%	93%	55%
Junction LCC4	40%	34%	42%	22%	35%	9%	30%	134%	196%	110%	132%	90%	50%
Junction LCC5	46%	37%	47%	23%	42%	10%	32%	149%	221%	124%	146%	98%	55%
Junction LCC6	44%	35%	45%	22%	40%	10%	31%	143%	211%	119%	141%	94%	52%
Junction LCC8	39%	31%	39%	19%	37%	20%	24%	141%	187%	106%	125%	83%	47%
Junction LCC9A	40%	34%	37%	21%	37%	0%	27%	95%	161%	110%	112%	75%	46%
Junction LCC10A	38%	32%	35%	21%	31%	0%	14%	83%	132%	102%	102%	70%	43%
Junction LCC11	35%	30%	32%	19%	33%	0%	25%	78%	126%	95%	94%	66%	41%
Junction LCC14	1%	1%	1%	1%	1%	0%	1%	3%	3%	2%	2%	2%	1%
Junction LCC16	26%	24%	24%	14%	30%	-1%	22%	62%	94%	68%	68%	49%	31%
Junction LCC18	23%	20%	21%	14%	19%	0%	20%	57%	77%	55%	54%	40%	26%

These results indicate that future development is predicted to increase the total runoff to the main stem of Laguna Creek by **26% to 55%** (shaded rows in table). These increases are not as high as other projects Geosyntec has evaluated, which can have had increases up to 5 times the pre-developed conditions in sandy soil watersheds.

The largest increases in stream flows occur during the late summer and fall where early season storms now produce runoff due to impervious surfaces, where before development these storms would have been retained by watershed storage mechanisms (through soils and vegetation).

4 Conclusions

The development included in the future condition hydrology model increased the duration and magnitude of flows along with the total runoff volume over the 49-year period of simulation when compared to the existing condition. The decrease in runoff volumes during the summer months due to the future development reflects the effects of imperviousness on reducing the amount of baseflow that is slowly metered out of the soil column in the existing condition. Peak events calculated using the Log-Pearson method were increased in the future condition by roughly 14% at Eagle’s Nest, by 60% at Calvine Road, and by 16% at the Waterman-Bond intersection. The increase in peak flows at Calvine Road is amplified due to the loss of peak flows in the exiting condition at the CCTR diversion. However, the future condition hydrology model did not include any of the anticipated water-management structures that also in planning for the Upper Laguna Creek watershed. These structures will be analyzed in a future analysis by Geosyntec Consultants to assess the mitigation of hydromodification in the study area.

References

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