APPENDIX D -DRAFT TECHNICAL MEMORANDUM

TO: CKB ENVIRONMENTAL CONSULTING

FROM: GEOSYNTEC CONSULTANTS

SUBJECT: **STORMWATER MANAGEMENT FOR HYDROMODIFICATION FLOW DURATION CONTROL CRITERIA AND SIZING METHODOLOGY**

TASK 3.2.6; TECHNICAL MEMORANDUM #6

DATE: MARCH 12, 2007

On-Site Control Alternative – Flow Duration Control Criteria

Stream erosion/deposition and sediment transport processes are functions of the long-term cumulative effects of geomorphically significant flows. Maintaining the long-term distribution of the geomorphically significant flows maintains the pre-project capacity to transport sediment and promotes long-term stability. Maintaining this distribution is referred to as “flow duration control”. Flow duration control was first discussed in the literature by Booth (1990), of the University of Washington. Flow duration control maintains the pre-project frequency distribution of hourly runoff as well as the total runoff volume within prescribed limits. Pre- and post-development scenarios and post-development with controls are compared and analyzed by comparing flow duration curves. On-site stormwater controls that match post-project flow duration curves to pre-project curves is effective at addressing the effects from hydromodification.

The flow duration method is essentially an analysis of distributions of all flows as opposed to using a design storm event. A distribution of hourly rainfall is transformed to a distribution of hourly runoff using the hydrologic model. The distribution of runoff is then analyzed for long-term cumulative flow duration. Flow duration control is a design methodology that maintains the existing distribution of in-stream flows above the critical flow for bed mobility and as a result maintains the existing capacity to transport sediment. Flow duration control is achieved by incorporating detention/retention basins with infiltration, or by incorporating other types of controls within the development that reduce urban runoff into the stream system.

In-Stream Control Alternative

In-stream controls are used to maintain a stable stream channel within an increased flow regime. The following describes the basis for defining and designing in-stream controls.

A stable channel is loosely defined as one that neither aggrades nor degrades, but instead maintains its average cross-section, planform, and profile features over time and within a range of normal variance. The hydraulic energy of stream flow imposes a shear force that mobilizes bed material and erodible bank soils. Over time, channels evolve to approximately stable equilibrium conditions that balance the imposed flow energy and sediment loads with the channel boundary material's ability to resist erosion. The processes of runoff and sediment transport interact with the boundary materials, establishing cross-sectional geometry, longitudinal slope, and planform.

In-stream controls are designed to create a future longitudinal profile and geometry that maintains the target sediment transport capacity given the new flow conditions. This future profile can be achieved through the use of grade control structures, as well as changes in channel planform.

Mixed Control Alternative

A mixed control alternative is defined as a combination of on-site and in-stream controls that together achieve long-term channel stability. Mixed solutions where both flow controls and in-stream modifications are applied are often the most effective and feasible solution. The choice of mix will depend on project specific conditions.

Development of Normalized Sizing Charts

This section discusses the development of normalized sizing charts for flow duration control basins designed according to flow duration criteria for the on-site flow and volume controls. The design charts are based on matching the flow duration curves from undeveloped land using local soil and geologic information including infiltration rates and stream channel resiliency (i.e., critical shear stress values). These design charts provide the volume and area requirements for flow duration control basins. On-site flow duration control basins, or other types of BMPs that are designed to match the pre-project flow duration curves meet the hydromodification control management objective.

Design of Flow Duration Control Facilities

A flow duration control basin is essentially a dry extended detention basin that is designed to provide hydromodification control. As shown in Figure D-1 below, the flow duration control facility is conceptualized as having two pools, a low flow pool (Zone A) and a high flow pool (Zone B). The low flow pool is designed to capture the difference in runoff volume between the pre- and post-development conditions. It will capture small storms that typically do not produce runoff from undeveloped land, the initial portions of larger storms, and dry weather flows. The increase in runoff volume must be released to the ground via infiltration, released to surface water at a fraction of the receiving stream's threshold for bed mobility, diverted to a safe discharge location, and/or stored for irrigation reuse. The high flow pool is designed to detain and release higher flows to maintain the pre-development flow regime. The flow duration control facility can also serve as a water quality treatment facility as well as a flood control facility by meeting the appropriate design criteria.

A flow duration control basin is sized using an iterative process of adjusting basin storage as well as selecting and adjusting the outlet structure. A stage-storage-discharge relationship is defined for the design under consideration, and then the post-project runoff time series is routed through the facility and tested for meeting the flow duration criteria.

The time series of post-development runoff predicted by the model is routed through the facility and the stored volume and discharges are computed for each time step (i.e., In-Out = Δ Storage), according to the routing methodology defined in Hydraulics, A Guide to the EXTRAN, Transport and Storage Modules of the USEPA SWMM 4 (1988). Outflow can take the form of infiltration, evapotranspiration, flows less than Qcp, diversions, weir flow, and overflow. A wide range of outlet design styles are possible, such as weirs, orifices, sand filters, and risers.

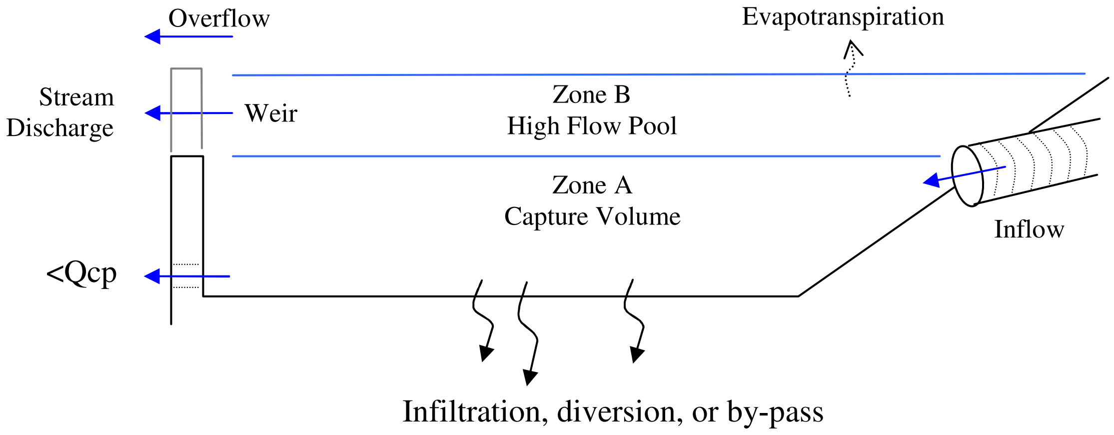


Figure D-1. Conceptualized Configuration of Flow Duration Basin

Selection of Low Flow Discharge Rate

The critical flow for bed mobility (Qc) is the threshold flow that creates an applied hydraulic shear stress equal to the critical shear stress for the channel boundary. The critical shear stress is based on either bed material or bank material, which ever is least resistant, and can be adjusted depending on the density of vegetation. When designing a flow duration control facility, the captured runoff volume is infiltrated to the extent practical given soil conditions. This volume can also be discharged at rates less than the critical flow for bed mobility, which is considered a non-erosive discharge rate. This low flow discharge rate is defined as Qcp. Qcp is the fraction of Qc that is apportioned to each project outfall.

Given the measured bed and bank material characteristics identified in the field, the estimated critical flow is 25% of the 2-Year peak flow. Both infiltration and Qcp are applied in the sizing charts presented herein. We have also provided sizing charts where the infiltration rates within the basin itself is zero.

Flow Duration Control Basin Configuration

Flow duration control basins as discussed herein are not designed to meet flood control requirements (i.e., design storm and peak flow criteria). However, a flow duration control basin, or series of basins, can be designed to meet flood control and hydromodification control criteria, as well as water quality treatment.

Due to the large number of possible basin configurations, some design features were held constant in the preparation of the sizing charts. Basin depths were limited to six feet to avoid triggering dam safety requirements. The outlet structure was limited in type and size, and held constant as much as possible.

Figure D-2 presents a conceptual illustration of a flow duration basin. The basin has 2:1 side slopes and a depth of 6 feet for the purposes of this report; the basin length and width would vary by catchment size and percent imperviousness. Infiltration occurs everywhere the surface is inundated.

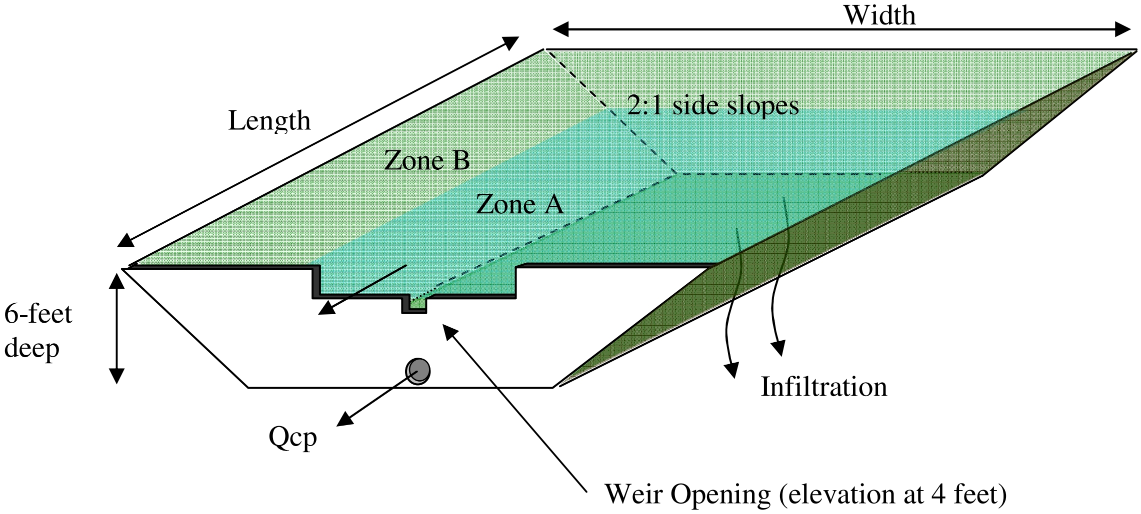


Figure D-2. Conceptual Illustration of a Flow Duration Basin

The low flow discharge (Qcp) can be controlled by an orifice hole in a headwall or by using a sand filter/buried perforated outlet pipe design. Any other design that controls the low flow discharge to below Qcp would also be acceptable.

The orifice is sized so that it discharges Qcp just at the overflow weir elevation. The weir outlet is designed so that its crest occurs at the top of Zone A, the capture volume, and is used to discharge the high flow pool (Zone B).

The Urban Drainage and Flood Control District, Denver, Colorado published the Urban Storm Drainage Criteria Manual, Best Management Practices that provides design guidance for outlet structures with orifice holes ranging from 0.5-inches to 2.0-inches. In this case, 2.0-inches is the *maximum* orifice size allowed. Screens and other steps are taken to prevent clogging and basin failure.

Normalized Sizing Charts

The normalized sizing charts presented here provide a simple mechanism to determine the volume and land area requirements for on-site control of post-development runoff that effective mitigates hydromodification. The charts are based on matching the post-development flow duration curve to the pre-development flow duration curve given a set of assumed conditions defined in this section. In practice, this volume and area requirement can be applied in one large unit at the end-of-pipe, or as several smaller units sub-divided and placed throughout the development.

Figures D-3 and D-4 present normalized sizing charts developed for the Laguna Creek Watershed. Figure D-3 provides the total volume (Zone A and B). Figure D-4 provides the surface area requirements assuming a 6-foot deep storage basin with 3:1 side slopes. Note that these charts are specific to the assumptions of 3:1 side slopes, a 6-foot depth, and a specified outlet design. Alternative sizing charts could be prepared for alternative design assumptions. The charts are based on the change in runoff between undeveloped and developed area with an assumed infiltration rate listed on each figure.

Unit total storage volume (inches/acre) can be determined from Figures D-3 based on the imperviousness of the flow duration basin's tributary catchment area. For example, a developing area with an infiltration rate of 0.20 in/hr and 50 percent imperviousness requires 1.6 inches/acre of total stormwater storage. The result of 1.6 inches/acre is then multiplied by the total area draining to the proposed basin to derive the total storage.

Figure D-4 presents the flow duration control basin surface area requirements. A deeper basin will result in smaller surface area requirements, given the assumed 6-foot basin depth. Surface area can be adjusted according to depth between 3 and 8 feet as long as the total volume remains as specified in the sizing charts. The use of the sizing chart beyond these limits would require further verification that the basin design is achieving the desired hydromodification control objectives. Using the developing area's estimated percent imperviousness, the *Unit Area* requirement from Figure D-4 is multiplied by the total drainage area to derive the total required land area to meet the flow duration criteria. For example, a developing area with 0.20 in/hr soils and 50% imperviousness requires the equivalent of 2.3% of the area for a flow duration control basin that is six feet deep with 3:1 side slopes.

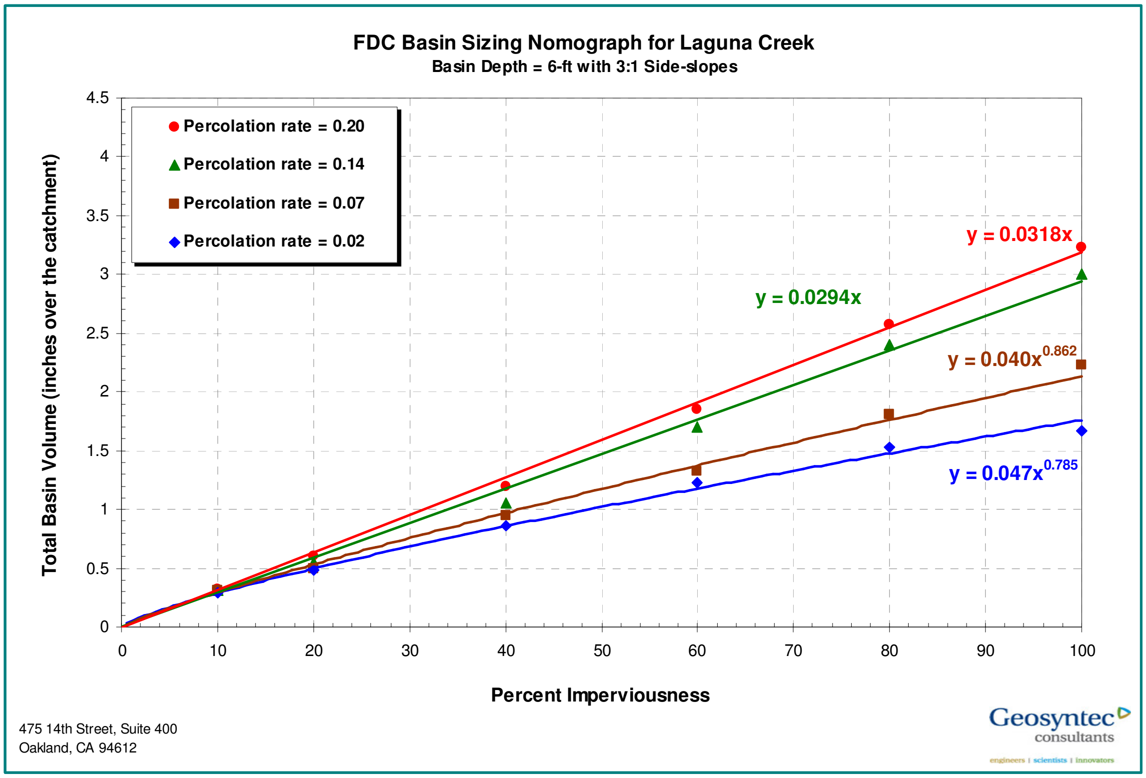


Figure D-3. Total Storage Volume Requirements

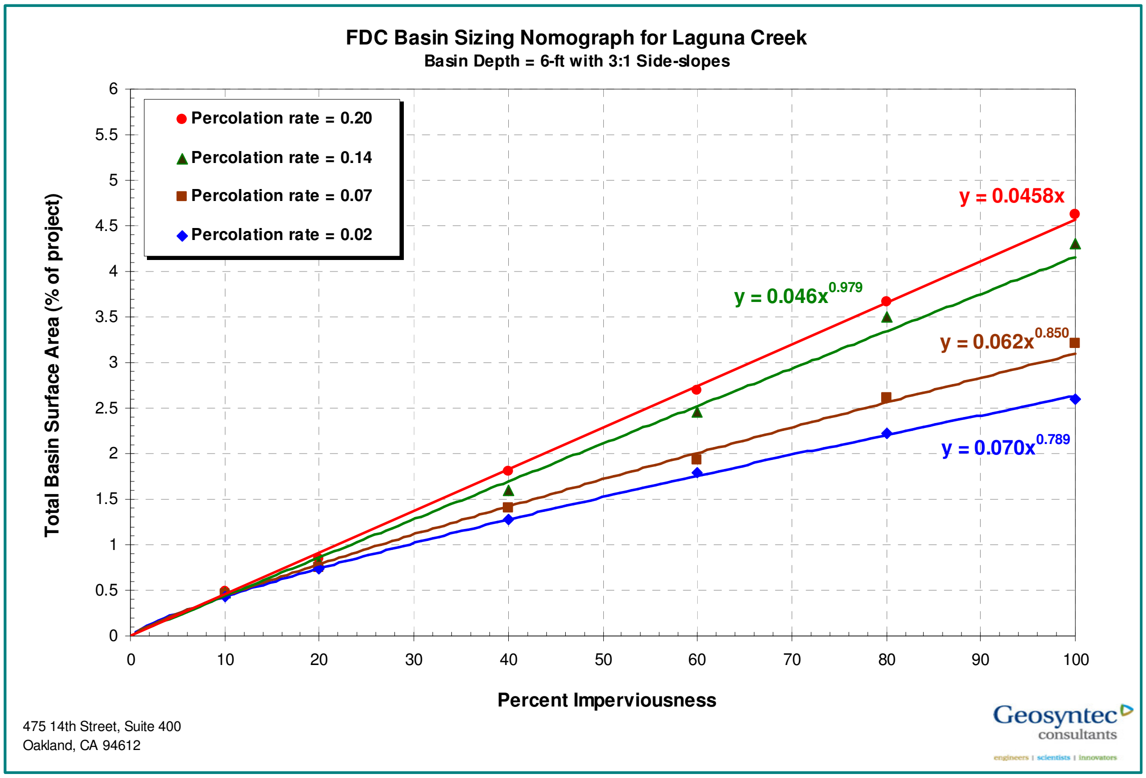


Figure D-4. Land Area Requirements

Figures D-5 and D-6 presents results assuming ZERO infiltration within the flow duration control facility itself. The difference between pre- and post-project runoff is detained and released only at the allowable low flow discharge (Qcp). The infiltration rate shown in the figures is the loss rate of the catchment area discharging to the basin.

There are two primary methods for releasing the increase in runoff volume: infiltration to deep soils and through the Qcp orifice. The influence of these two mechanisms on basin size is relative. The higher the allowable Qcp the less influential infiltration is on the results; and visa-versa. A comparison to Figures D-3 and D-4 reveal that the curves with the lowest infiltration rate (0.07 and 0.02 in/hr) has little influence on the basin size – given the high allowable Qcp (i.e., 25% of the 2-year peak flow). Thus, these two curves are nearly the same between sizes with and without basin infiltration.

These sizing charts should be used when the basin infiltration rate is unknown, restricted by impermeable sub-layers, have high groundwater elevations or have clay soils that *swell* and cut-off infiltration rates.

Figure D-7 and D-8 provides sizing curves for a bioretention facility. The bioretention facility is 10-feet wide overall and has 4:1 side slopes. Excluding the underlying filter outlet for Qcp discharges, the bioretention facility is 3-feet deep, with part of this depth filled with soil and vegetation.

The total storage available in the soil is defined by the porosity, which ranges from 38% to 55% depending of soil type. However, 10% to 40% of water is held in the pores of the soil matrix by capillary forces (the so-called sponge effect) and does not drain by gravity. The sponge is referred to as the field capacity and can only be dried by evapotranspiration. Winter time evapotranspiration rates range from 1 to 2 inches per month and is several orders of magnitude less than the infiltration rates. The only portion of the soil column emptied between storms is the free draining portion (porosity – field capacity). So, only 28% to 15% of the soil matrix is free draining (plus a small amount from ET) and available for storage when next storm arrives. As a consequence, ET from the soil matrix has little influence on the sizing of a bioretention facility. Not including ET in the sizing provides a small level factor of safety.

The bioretention facility always requires more land area than the flow duration or infiltration basin in order to achieve the same stormwater volume reduction.

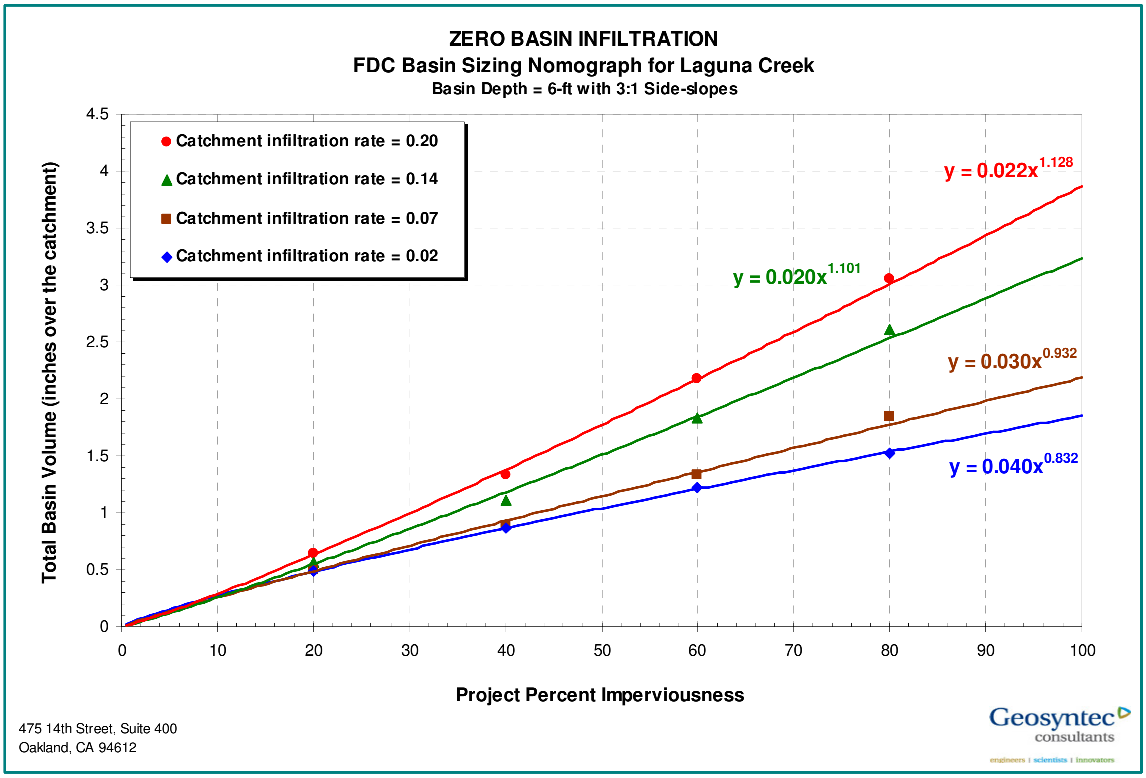


Figure D-5. Total Storage Volume Requirements

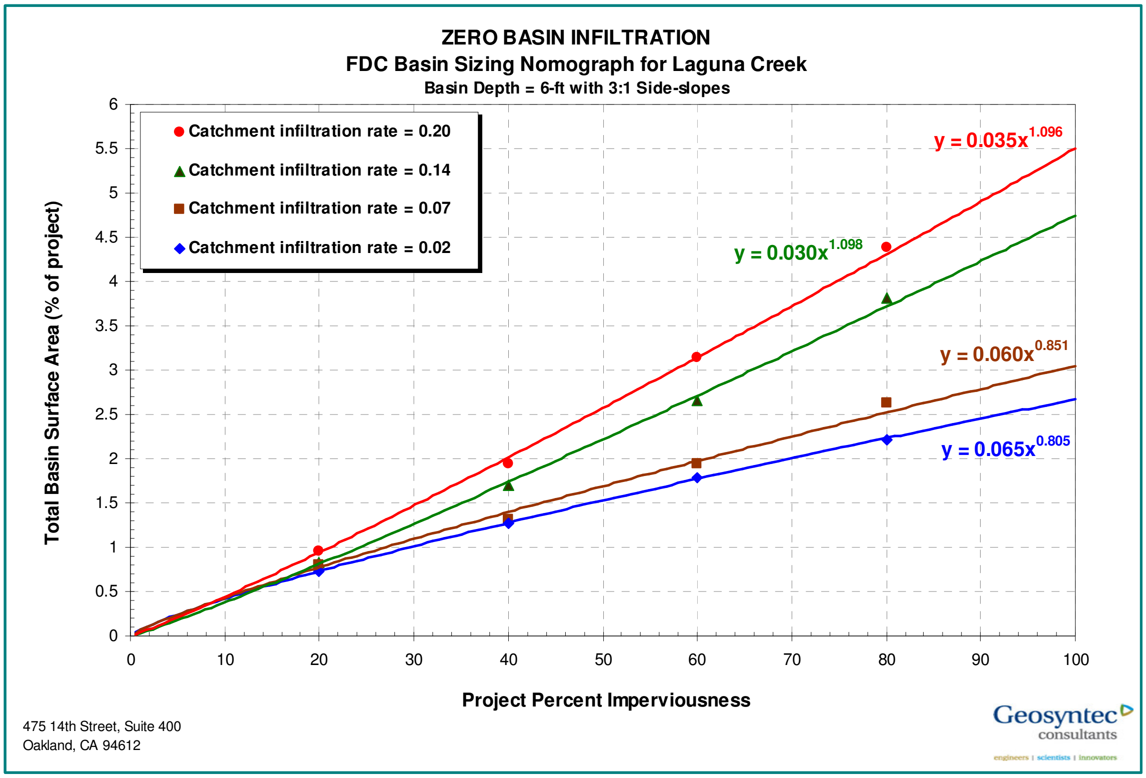
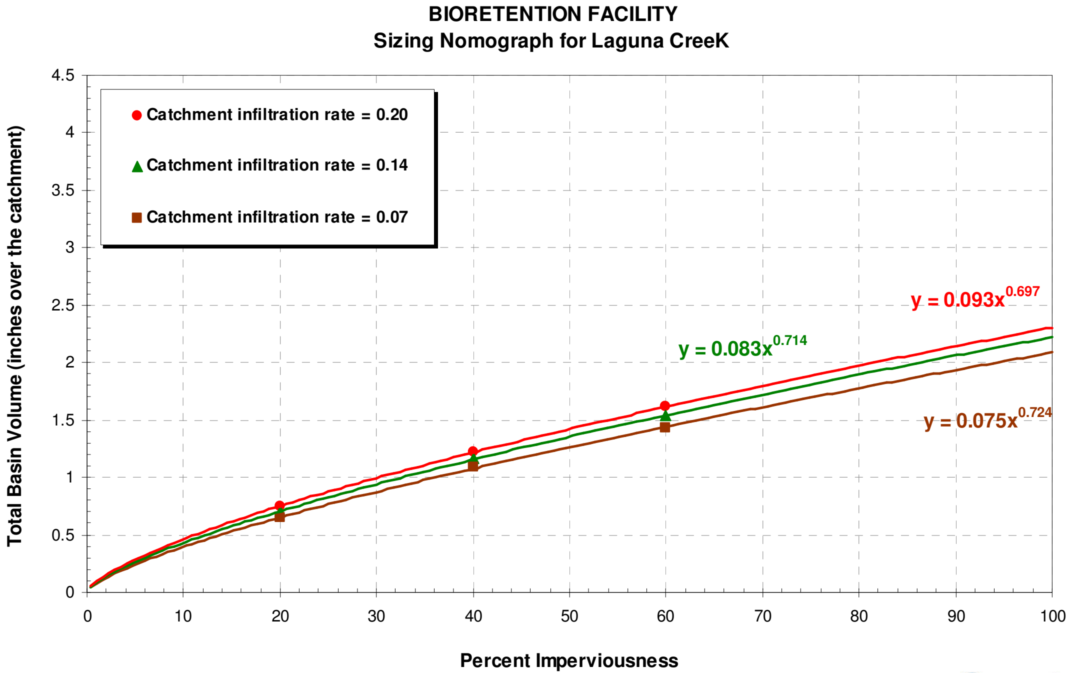


Figure D-6. Land Area Requirements



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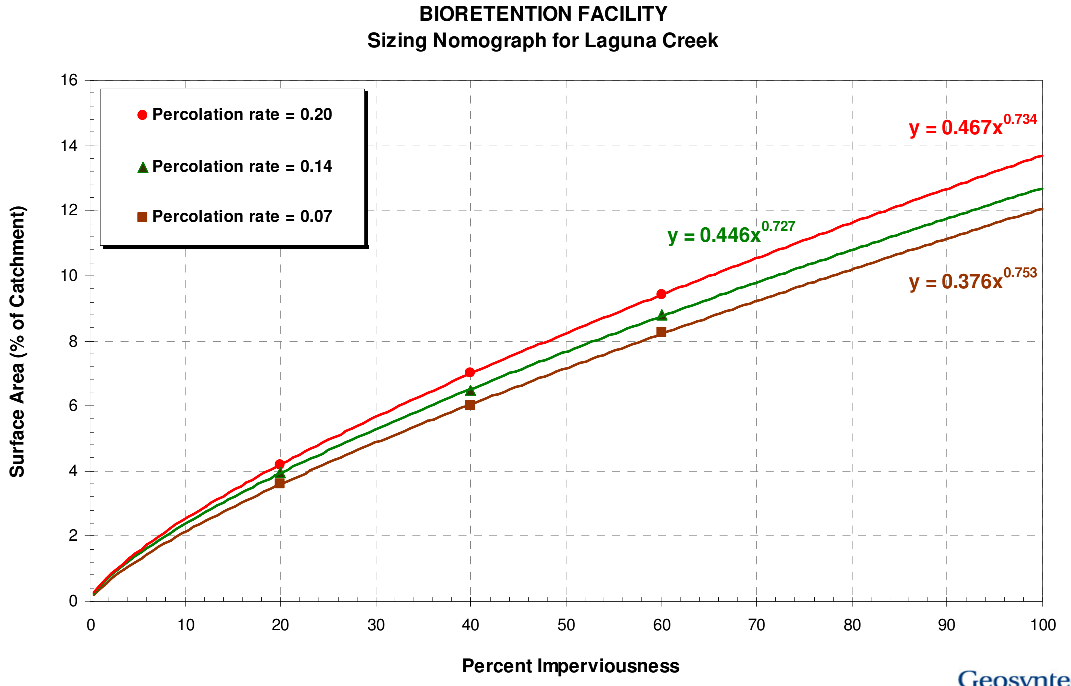

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