APPENDIX G

Survey of Modeling Approaches, Guidelines for the American River Basin Region

Attachment 3: Survey of Modeling Approaches

A variety of models, including simple spreadsheets through custom software packages, have been used to simulate drywell processes as part of current project planning and regulatory studies. Some software models used to date in simulating drywell processes are described below. This is not a comprehensive list, but rather a survey of the range of models in use.

Spreadsheet software: Oregon uses a one dimensional model based on the Advection Dispersion Equation (ADE)[4], which assumes transport under saturated conditions. Pollutant attenuation occurs by advection, dispersion, degradation, and retardation. Model input parameters include the following:

- Initial concentrations are 10x the EPA MCL. Contaminants without MCLs are not included in the list of priority pollutants that are modeled.
- Fraction Organic Carbon has been shown to be an influential factor in contaminant transport. The content of soil includes organic carbon from two sources: (1) naturally-occurring organic carbon in soil and (2) organic carbon in stormwater that filters out in soil surrounding the drywell.
    - Soil permeability is based on infiltration tests, and assumes a horizontal to vertical anisotropy of 1: 100 (if necessary, depending on the direction of permeability that was measured during the infiltration test).
    - Transport time is calculated based on the hours of runoff that flow into a drywell each year.
    - Biodegradation rate, total porosity, effective porosity, bulk density, and dispersivity values are drawn from the scientific literature. As appropriate, the input values reflect soil types (gravel, sand, etc.) and geochemical conditions of shallow soils (e.g., aerobic soils, appropriate pH). Dispersivity is conservatively estimated to be 5% of scale.
    - The model supports input of a single geologic type (e.g., silty clay, sand, etc.). The most permeable of the units in the profile is used in the modeling to arrive at a conservative estimate.

The value of this approach is its simplicity. One of the limitations is that it does not support an accurate representation of the vadose zone profile since it allows input of a single soil type (e.g., silty clay, sand, etc.). To manage this limitation, the most permeable geologic unit (e.g., sand or gravel) is often used in the analysis, therefore providing a more conservative result.

Hydrus: This is a software program that simulates water flow and solute transport in the vadose zone. It will accommodate data that reflects the complexity of the soil profile, so can provide a more realistic representation of local lithology. A public version of the software is available for modeling 1D processes, Hydrus-1D. A commercial version, Hydrus-2D, supports modeling of more complex situations involving two- and three-dimensional processes. In the Sacramento region, HYDRUS 1D was used to estimate drywell operations in a study in Elk Grove. 5 The travel time of selected contaminants moving vertically downward from the bottom of drywell to the top of the seasonal high water table was assessed for eight

[4] Most of the modeling in Oregon is performed by GSI Consulting. They have provided this summary of the key aspects of the proprietary spreadsheet that is used. Other states had adopted similar approaches.
[5] Assessing the Risks of Using Drywells for Stormwater Management and Groundwater Recharge: The Results of the Elk Grove Drywell Project." City of Elk Grove and the California Office of Environmental Health Hazard Assessment. https://www.elkgrovecity.org/UserFiles/Servers/Server_109585/File/Departments/Public%20Works/Drainage/Dry%20Wells/dry-well-doc-01.pdf

scenarios, thus providing an estimate of concentrations of contaminants at the water table over a range of parameter inputs.

GIFMod: The Green Infrastructure Flexible Model, or *GIFMod*, is EPA-funded, open source software developed for modeling hydrologic, hydraulic, and water quality processes at multiple geographic scales. [6] Like Hydrus, it models The software incorporates many common methods for estimating hydrologic processes, including evapotranspiration, infiltration, and saturated and unsaturated flow, along with water quality considerations for contaminant inflow concentrations and transport. The user interface was designed to be approachable. Users delineate separate infrastructure devices or physical features, such as a swale or a lake, and assign known physical parameters. Model results report simulated flows and contaminant concentrations for an identified time period. Notably, *GIFMod* offers capability to easily simulate a multi-step drywell installation that includes additional features for pre-treatment such as a vegetated swale or sedimentation chamber. It also can perform inverse modeling which could be used to estimate concentrations of contaminants allowable at the entry point into the drywell based on desired maximum allowable concentrations at the water table.

VS2DH 3.0: *VS2DH 3.0* is a software platform for simulating 2-dimensional, saturated-unsaturated flows based on a finite-difference modeling framework.[7] For drywells, this would simulate the radial flow in 2-dimensions, both vertically and laterally, within a soil column of potentially varying composition and areas of saturated and unsaturated movement. *VS2DH 3.0* was used to estimate calibrated steady-state infiltration rates from drywell installations in the state of Washington.[8] The modeling estimated how, over time, infiltration rates decreased as soils became more saturated for multiple types of drywell design and construction.

Custom Operations Research Models: Planning for on-site drywell installations can necessarily include investigating decisions on siting, construction depths, setbacks, and separation between wells. Operations research modeling with simulation and optimization is used in identifying optimal parameters that meet design criteria and constraints. Such methods are useful in planning drywells. For instance, as part of a research project at the Arizona State University, researchers developed non-linear, mixed-integer programming to inform drywell design parameters, including depth, size, and number of wells on a site.[9] The modeling used an objective function (goal) of minimizing total costs of construction, land acquisition, and “hydroseeding” (planting surface vegetation) to infiltrate runoff using the modified rational method. The model only considers water quantities and infiltration and does not simulate water quality processes.

[6] Massoudieh, A., M. Maghrebi, B. Kamrani, C. Nietch, M. Tryby, S. Aflaki, S. Panguluri (2017), A flexible modeling framework for hydraulic and water quality performance assessment of stormwater green infrastructure, *Environmental Modeling and Software*, 92, pp 57–73. http://gifmod.com/

[7] Healy, R.W., and Ronan, A.D., 1996, Documentation of computer program VS2DH for simulation of energy transport in variably saturated porous media -- Modification of the U.S. Geological Survey's computer program VS2DT, U.S. Geological Survey Water Resources Investigations Report 90-4025, 125 pages. https://wwwbrr.cr.usgs.gov/projects/GW_Unsat/vs2di/hlp/energy/vs2dh3p0.html

[8] Massmann (2004). “An Approach for Estimating Infiltrates Rates for Stormwater Infiltration Drywells. Washington State Department of Transportation, Research Office, Olympia, WA. https://trid.trb.org/view/859214

[9] Lacy, Mason. Optimization Model for the Design of Bioretention Basins with Drywells. (2016). Arizona State University. https://repository.asu.edu/attachments/170323/content/Lacy_asu_0010N_15741.pdf