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Methodology for prioritizing areas of interest for surface water monitoring of pesticides in urban receiving waters of California

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1 Summary

The Surface Water Monitoring Prioritization (SWMP) model (http://cdpr.ca.gov/docs/emon/surfwtr/sw_models.htm) has been used by DPR and other agencies in monitoring project planning. Most of the model applications are to determine pesticides of interest (POI's) for surface water monitoring at predefined sites, i.e., site-specific prioritization. The model also includes a function for spatially continuous mapping (Luo and Deng, 2015), which calculates "priority mapping index" (PMI) of one pesticide (or each pesticide in a group) for watersheds at the spatial resolution of USGS 12-digit Hydrological Unit Code (HUC12). The results could be used for determining areas of interest (AOI's) for monitoring site selection. Based on the SWMP function of spatially continuous mapping, this report presents a methodology to prioritize HUC12's and recommend their streams (as mainstream and/or tributaries) for pesticide monitoring in urban receiving waters. This is developed for the proposed procedure "*1(a): Determine areas of interest for selecting monitoring sites*" for meeting monitoring objectives defined by the Urban Strategy Workgroup in DPR's Surface Water Protection Program.

The methodology is expected to generate a short list of HUC12's (out of the 4415 HUC12's in California) and associated streams to be considered in the site selection of an urban monitoring study. In addition, pesticide uses in agricultural and urban areas in the drainage area of the recommended HUC12's are compared to refine POI's. Below are example results for the Lower American River watershed (see Table 5 for the full results):

HUC12	HUC12 NAME	AOI's		POI's
		Stream type	Streams	
180201110105	Gibson Lake-Dry Creek	Mainstream and tributaries	Dry Creek and its tributaries	Table 1
180201110102	Miners Ravine	Mainstream	Dry Creek	Table 1
180201110303	Lower Steelhead Creek	Mainstream	Natomas East Main Drainage Canal (aka Steelhead Creek)	Table 1, except for 2,4-D
180201110302	Arcade Creek	Tributary	Arcade Creek	Table 1
180201110103	Antelope Creek	Tributary	Antelope Creek, Clover Valley Creek	Table 1

Notes: Table 1 lists the representative pesticides for urban monitoring based on statewide prioritization. In addition to the consideration of agricultural contributions, POI's at each monitoring site could be further refined by site-specific prioritization, which has been developed and demonstrated previously.

This report will summarize the theoretical considerations and technical details for the methodology. The proposed procedures are demonstrated with the available modeling capability of SWMP and manual calculations. Full computational implementation of the methodology will be developed soon and incorporated into the future version of SWMP.

2 Scope and limitations

- This methodology is designed for pesticide monitoring in urban receiving waters, not for stormdrain sampling. [1]
- The primary limitation of this methodology is related to urban PUR data with coarse spatial resolution (county-level data) and limited data coverage (professional applications only). If the principal investigators (PI's) of a monitoring project have refined data for local urban pesticide uses in the study area, they can bypass all or part of the procedures proposed here.
- Also related to the PUR resolution, SWMP provides the modeling option of user-delineated watershed for agricultural pesticide uses, but not for urban. User-defined drainage areas could be useful in some special cases, e.g., to represent water diversions by engineered water conveyance not reflected in the USGS-predefined HUC12's.
- Results of the proposed methodology recommend stream segments as candidate water bodies for urban monitoring, but not specify the geographic locations of sampling sites. Site development requires additional information (e.g., project objectives and budget, site accessibility, hydrological conditions, population distribution, and stormwater system), which is beyond the scope of this study.

3 Review of existing monitoring sites on urban receiving waters

Two sets of monitoring sites are reviewed for the implications of site selection for pesticide monitoring in urban receiving waters: current DPR urban sites and water bodies in the 303(d) list for pesticide runoff from urban sources.

DPR sites: currently there are 29 sites maintained by DPR for urban receiving waters, in 20 streams (Appendix 1). Site information is provided by the PI's of DPR urban monitoring studies. Please refer to the monitoring protocols for more details (http://cdpr.ca.gov/docs/emon/pubs/protocol.htm).

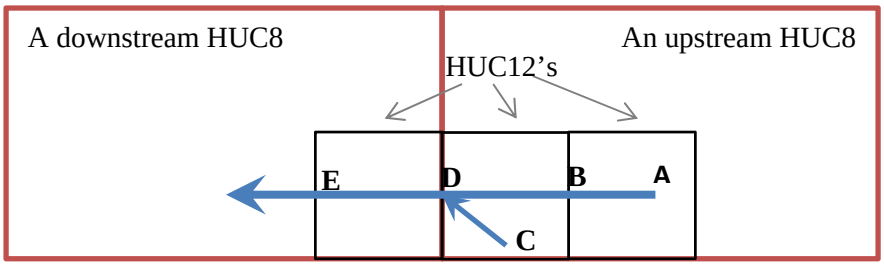
The 303(d) sites: impaired water bodies in the 2010 and 2012 303(d) lists (SWRCB, 2010, 2012) are first filtered by "pollutant category" for "pesticides" (legacy pesticides such as "DDT" and "DDE" are excluded), then by "source category" of "urban runoff". A significant number of

[1] The results may be also helpful to develop stormdrain sites, given the fact that most of the stormdrain sites maintained by DPR are located in the same or nearby HUC12's of receiving water sites. For the 29 stormdrain sites for fipronil data analysis (Budd et al., 2015), for example, 25 of them are paired with receiving water sites in the same HUC12's, and the remaining 4 are located in neighborhood HUC12's.

impaired water bodies which were originally listed with “urban runoff” sources in 2010, were revised to “unknown sources” in the 2012 list. Those include some well-known urban river segments such as the upper portion of Pleasant Grove Creek. For better coverage of potential urban monitoring, we use the combined results of the two 303(d) lists. In total 76 water bodies are identified with available geographic data (Appendix 1), mainly in the region 2 (San Francisco, 38 water bodies), region 3 (Central Coast, 16), and region 5 (Central Valley, mainly Sacramento and Stockton, 15).

Implications: the monitoring sites and monitored water bodies are georeferenced to USGS HUC system map, and summarized by their drainage areas and corresponding HUC levels. The historically and currently monitored urban receiving waters are located in 23 HUC8’s (out of the total 126 in California) (Appendix 1). In conclusion, all monitored water bodies are associated with drainage area within one watershed at the level of 8-digit HUC (or, HUC8 watersheds). Therefore, the associated monitoring site can be categorized as a “HUC8 tributary site”, since its drainage area is within one HUC8 watershed (no contributions of water and pesticides from any other HUC8’s). HUC8 mainstreams (e.g., Sacramento River, San Joaquin River) are associated with large drainage areas and mixed land use types, so are not appropriate for monitoring studies for urban pesticides.

Further data analysis indicated that about half of the monitored streams are tributaries or headwaters at HUC12 level, while the others are mainstreams at HUC12 level. A site is either a “HUC12 tributary site” (its drainage area is within only one HUC12, and not receives water from other HUC12’s) or a “HUC12 mainstream site” (contributed by multiple HUC12’s). Out of the 29 selected DPR sites, for example, 18 sites are classified as “HUC12 tributary sites” (e.g., “ARC_Nor”, “BAL”, “CHO2”…), and the other 11 sites are “HUC12 mainstream sites” (“LAR1, 2”, “SDR1, 2” …). See Figure 1 for more explanations on mainstream and tributary categorization at HUC8 and HUC12 levels.



At HUC8 level: the stream segment “D->E” is considered as a mainstream because it receives water from more than one HUC8’s (examples are lower Sacramento River, lower San Joaquin River…). All other stream segments are tributaries.

At HUC12 level: the segments “B->D” is a mainstream (e.g., Los Angeles River, and San Diego River), while “A->B” and “C->D” are tributaries.

Figure 1. Demonstration of streams and monitoring sites on the main stream and tributaries at various levels of watershed delineation, adapted from the Figure 2 in SWMP report #3 (Luo and Deng, 2015)

4 Methods and materials

4.1 Methodology overview

A four-stage procedure is proposed to determine POI's and AOI's for pesticide monitoring in urban receiving water (Figure 2):

1) Initial list of POI's: to generate representative POI's for urban monitoring.
2) HUC8-level analysis: to rank HUC8's in California, and provide a priority list from which the project PI's can select top HUC8's for the next analysis.
3) HUC12-level analysis: to rank HUC12's in each of the selected HUC8's, and recommend water bodies for urban monitoring, by HUC12 and stream types (mainstream and/or tributary).
4) Refinement of POI's: to finalize POI's for each AOI
    a. by site-specific prioritization. This has been developed and demonstrated previously (Luo and Deng, 2015)
    b. by identifying pesticides with significant contributions from agricultural uses in the same drainage area (mainstream only).

Remainder of page intentionally left blank; Figure 2 to follow.

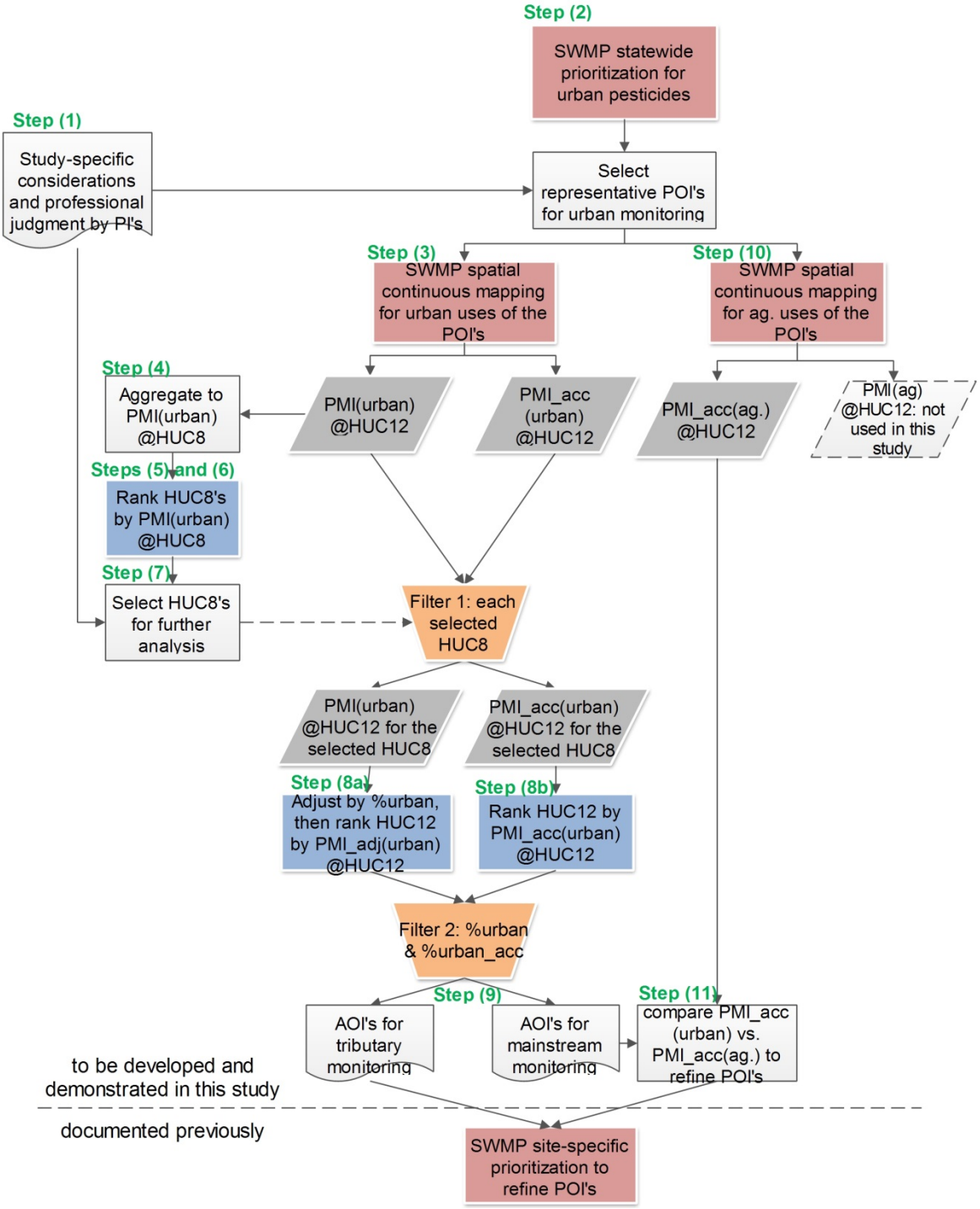


Figure 2. Methodology to determine areas of interest (AOI's) and pesticides of interest (POI's) for urban monitoring in receiving water bodies. See section 4.3 for the detailed data analyses in each step.

Notes: "SWMP"= Surface water monitoring prioritization model; "PMI(urban) @HUC8/12" = SWMP-generated priority mapping index for urban pesticide uses in tributary streams at the given resolution; "PMIacc(urban/ag.) @HUC12" = priority mapping index for urban/agricultural pesticide uses in mainstreams at HUC12 resolution; and "PMI_adj(urban) @HUC12" = "PMI(urban) @HUC12" normalized by the coverage fraction of urban land in the corresponding HUC12.

4.2 Data processing

4.2.1 Priority mapping index (PMI and PMIacc)

The primary input data for the AOI determination is priority mapping index (PMI), generated by SWMP's function of spatially continuous mapping. Each set of the index includes 4415*N*2 data values, where 4415 is the total number of HUC12's in the California hydrological region, N is the total number of pesticides of interest (POI's), and "2" for the paired results of the tributary and mainstream of each HUC12. Mainstream PMI is also called "PMIacc", where "acc" is taken from the hydrologic processing of "flow accumulation" for determining the total drainage area of a downstream site.

Detailed information for PMI calculation was documented previously (Luo and Deng, 2015). In summary, PMI's (lb[AI]/km^2/ppb) are calculated for each pesticide in tributary and mainstream of a HUC12:

$$\begin{aligned} \text{tributary mapping:} \quad & PMI(k) = USE(k)/AREA(k)/TOX \\ \text{mainstream mapping:} \quad & PMIacc(k) = USE(K)/AREA(K)/TOX \end{aligned} \tag{1}$$

where k (=1~4415) is a running index for HUC12's, and K is a collection of HUC12's for the total drainage area of k (including k and its upstream HUC12's). AREA(k) and AREA(K) (km^2) are the watershed area of k and the total drainage area of k (i.e., total areas of k and its upstream HUC12's), respectively. Similarly, USE(k) and USE(K) (lb[AI]) are pesticide uses within k and K. There are two options for calculating USE(K) in the SWMP: with or without the consideration of dissipation losses during the travel time from each upstream HUC12 to k. USE(K) adjusted by dissipation losses is used in this study. TOX (ppb) is toxicity value of a pesticide. There are options for different data source and format in the SWMP. For this study, we set TOX as the lowest value of acute and chronic benchmarks provided by USEPA.

The SWMP only reports PMI's at HUC12 level. In this study, we extended the PMI calculation for other HUC levels. For example, PMI at HUC8 level can be formulated in the same way as in Eq. (1):

$$\begin{aligned} \text{tributary mapping:} \quad & PMI(p) = USE(p)/AREA(p)/TOX \\ \text{mainstream mapping:} \quad & PMI\_acc(p) = USE(P)/AREA(P)/TOX \end{aligned} \tag{2}$$

where p (=1~126) is a running index for HUC8's in California, and P is a collection of p and all its upstream drainage areas. Similar to the definitions in Eq. (1), USE(p) is the total (unadjusted) use of the pesticide within p, while USE(P) could be adjusted by pesticide dissipation losses for a upstream location to the outlet of p. PMI(p) is used to rank HUC8's for pesticide sampling in their tributaries. PMIacc(p) is not used in this study since HUC8 mainstreams (e.g., Sacramento River, San Joaquin River) are associated with large drainage area and mixed land use types, so not appropriate for urban monitoring.

4.2.2 Percent urban land use (%urban)

The percent area coverage of urban land use in each HUC12, %urban(k) with k=1~4415 for each HUC12, is calculated with GIS data. In this study, National Land Cover Database (NLCD) version 2011 (USGS, 2011) is used. Specifically, the combined areas with codes of 21~24 in NLCD 2011 are considered as urban land use. For future development and updating, other land use maps with appropriate categories for urban areas can be incorporated by updating the values of %urban.

Urban land coverages are used for two purposes in this study: (1) to adjust PMI(k) for better representation of pesticide runoff from urban areas of a watershed; and (2) to select watersheds with urban land coverage higher than a certain critical value for urban monitoring. For PMI(k) adjustment: the SWMP-generated PMI's for HUC12 tributary are adjusted by %urban:

$$PMI\_adj(k) = PMI(k) / \%urban(k) \tag{3}$$

"PMI_adj" represents urban pesticide use intensity over the urban areas (rather than the total area) of a HUC12:

$$\begin{aligned} PMI(k) &= USE(k) / AREA(k) / TOX, \text{ so} \\ PMI\_adj(k) &= \{USE(k) / AREA(k) / TOX\} / \%urban(k) \\ &= USE(k) / \{AREA(k) \times \%urban(k)\} / TOX \\ &= USE(k) / AREAurban(k) / TOX \end{aligned} \tag{4}$$

where AREAurban(k) is the urban area of the HUC12 k. The adjustment process is to reflect the assumption that urban tributary sites are most likely located on streams which receive water from the urban portion of the watershed. The ratio [urban use]/[urban area] in the adjusted PMI's is a better predictor for the tributary monitoring, compared to [urban use]/[total area] (in the original PMI's).

Adjustment on PMIacc's (for HUC12 mainstream) by urban land coverages is not recommended, since the entire drainage area (urban and non-urban; the local HUC12 and all upstream HUC12's) should be considered to determine pesticide concentrations in a mainstream.

4.2.3 Flowline map in the National Hydrography Dataset (NHD)

The data analysis in the methodology will recommend AOI's by HUC12 and stream type (mainstream and/or tributary), but not specify stream names. For demonstration purpose, NHD "flowline" map (USGS, 2016) at medium resolution is used in this study as a post-processing to provide names of streams according to the modeling results. NHD documents all mainstreams (there is usually only one mainstream in a HUC12). For tributaries, however, some streams may not be reported by NHD, but could be considered for urban monitoring based on project objectives.

4.2.4 Population density

Population density is used in the SWMP (not specific to this study of AOI determination) to downscale urban PUR data from the spatial resolution of county to HUC12. Data from 2012 survey was incorporated in the previous version (Luo and Deng, 2015), and we keep updating it when new data is released by U.S. Census Bureau. In this study, 2014 survey data (USCB, 2016) was used.

4.3 Data analysis

4.3.1 Stage 1, representative POI's

Step (1): General description of the monitoring study. The project PI's will first define the monitoring study objectives, study regions, available resources, and other study-specific conditions. Those will be helpful in the later site selection processes by focusing on the desirable domain. If a study is to be developed for pesticide monitoring in Northern California, for example, all model-suggested HUC8's not in this region can be skipped. Similarly, if a study targets on freshwater sampling, the watersheds significantly affected by tides can be removed.

Step (2): Pesticides of interest (POI's) for urban monitoring. A list of representative pesticides can be defined with statewide prioritization for urban pesticides by SWMP with the following settings:

- Use pattern: structural pest control and landscape maintenance (in the model interface, check the option for "urban" use patterns, but not check that for "right-of-way" applications)
- Toxicity data: both acute and chronic benchmarks
- Default settings for other options (all counties, all months, the most recent 3 years PUR data, etc.)

Based on the SWMP results, pesticides to be monitored can be determined based on priority scores and professional judgement (e.g., historical monitoring data, availability of analytical methods). For demonstration purpose in this study, we select 20 pesticides (Table 1) as representative POI's for urban monitoring, by considering top pesticides recommended by SWMP with 2012-2014 PUR data and removing some of them (pyriproxyfen, sulfometuron-methyl, spinosad, and oxadiazon) due to lack of DPR analytical methods.

Statewide prioritization is demonstrated here for representative urban pesticides for California. Please note that the SWMP also supports regional prioritization. PI's may generate representative POI's by selected counties or by HUC at various levels. "Northern" and "Southern" California designation by HUC4's is discussed as an example in the next section.

Table 1. The 20 urban pesticides for surface water monitoring recommended by the Urban Strategy Workgroup with 2012-2014 PUR data, reported in SWMP model output format. They are selected based on the top-24 SWMP-recommended pesticides by removing 4 of them without DPR analytical methods

chem_code	CHEMNAME	use	usescore	benchmark	toxscore	finalscore
2008	PERMETHRIN	175,809	5	0.0014	7	35
2300	BIFENTHRIN	118,154	5	0.0013	7	35
2223	CYFLUTHRIN	61,876	5	0.0074	7	35
3995	FIPRONIL	67,915	5	0.011	6	30
3010	DELTAMETHRIN	17,551	4	0.0041	7	28
2297	LAMBDA-CYHALOTHRIN	14,349	4	0.002	7	28
2171	CYPERMETHRIN	39,965	4	0.069	6	24
187	DDVP	2,093	3	0.0058	7	21
3849	IMIDACLOPRID	61,514	5	1.05	4	20
231	DIURON	45,935	5	2.4	4	20
367	MALATHION	4,983	3	0.035	6	18
2236	PRODIAMINE	37,514	4	1.5	4	16
83	BROMACIL	25,018	4	6.8	4	16
1929	PENDIMETHALIN	24,388	4	5.2	4	16
3938	CHLORFENAPYR	21,608	4	2.915	4	16
105	CARBARYL	3,277	3	0.5	5	15
1973	OXYFLUORFEN	2,384	3	0.29	5	15
1868	ORYZALIN	25,935	4	15.4	3	12
2170	TRICLOPYR, BUTOXYETHYL ESTER	23,271	4	19	3	12
636	2,4-D	21,858	4	13.1	3	12

4.3.2 Stage 2, HUC8-level analysis

Step (3): PMI's at HUC12 level. With the representative POI's, the PMI's can be calculated by running the SWMP model with the following settings:

- Use pattern: same as step (2)
- Toxicity data: same as step (2)
- Simulation mode: spatial continuous mapping (in the model interface, enable "watershed-based prioritization", then check the option "spatially continuous mapping", and input the representative POI's from the previous step, delimited by comma; also check the option for "pesticide use adjustment by travel time")
- Default settings for other options

As introduced in section 4.2.1, the model run will generate PMI (for tributary) and PMIacc (for mainstream) values for each POI in each HUC12. PMI values will be used in the next step (4), while PMIacc values will be used later in the HUC12-level analysis.

Step (4): PMI's for HUC8 tributaries. This variable can be calculated by Eq. (2) with resultant PMI's at HUC12 level from the previous step.

Step (5): HUC8 ranking for each POI. For each POI, HUC8's are ranked by the PMI values calculated in (4): the HUC8 with the largest PMI is assigned with the rank value of 1, the HUC8 with the second largest PMI is with rank 2, …, and the HUC8's with zero PMI's is assigned with a fixed value of 126 (there are 126 HUC8's in California hydrological region). Finally we have a matrix of ranks with size of 126*N, where N is the total number of POI's selected in (2).

Step (6): HUC8 ranking for all POI's. The "total rank" for each HUC8 is calculated by summing up its individual ranks for all POI's. HUC8's are ranked by their "total rank" values, and reported by ascending order (i.e., smaller value of the "total rank" indicates higher priority).

Table 2. Example of top-20 HUC8's for urban monitoring, order by the ranking process in Step (6). Notes are manually added.

HUC8		**Notes**	
Code	**Name**	**Monitored by DPR?**	**With 303(d)-listed water bodies for pesticides from urban runoff?**
18070201	Seal Beach		
18020111	Lower American	4 sites	4 listed water bodies
18070105	Los Angeles	2	
18070203	Santa Ana		
18070204	Newport Bay		
18070106	San Gabriel	1	
18070104	Santa Monica Bay	1	
18050001	Suisun Bay	3	5
18050003	Coyote	2	9
18050004	San Francisco Bay	1	9
18070202	San Jacinto		
18050002	San Pablo Bay		15
18040003	San Joaquin Delta		4
18020163	Lower Sacramento		3
18020161	Upper Coon-Upper Auburn	7	4
18070304	San Diego	4	
18070301	Aliso-San Onofre	3	1
18070302	Santa Margarita		4
18060015	Monterey Bay		5
18100201	Whitewater River		

Demonstrated in Table 2 are the top-20 HUC8's identified based on the SWMP results for the selected POI's in Table 1 and other model settings in the step (3). The identified HUC8's are compared to the monitoring sites and water bodies complied in Appendix 1. In summary, the top-20 HUC'8 cover 28 of the 29 DPR urban monitoring sites, and 63 of the 76 303(d)-listed water bodies for pesticide pollution from urban sources. The DPR site "BOQ" (Bouquet Creek) is not covered by the top-20 HUC8's due to the relatively low urban land use and urban pesticide use density in its HUC8 (18070102, "Santa Clara", ranked #39 in the demonstration, so not shown in Table 2). Some impaired water bodies in the 303(d) list are not included by the top-20

HUC8's, such as Orcutt Creek, lower Salinas River, San Luis Obispo Creek, and Santa Maria River. Some of these streams are currently covered by DPR agricultural monitoring projects (http://cdpr.ca.gov/docs/emon/pubs/protocol.htm).

Step (7): Candidate HUC8's for the stage-2 analysis at HUC12 level. We generally suggest the top-20 HUC8's generated from the step (6) for statewide monitoring. Project-specific considerations from Step (1) (e.g., study objectives, region of interest, budget) may be incorporated here to reduce the number of candidate HUC8's. For example, DPR considers two regions for urban sampling: Northern and Southern California (Table 3).

Table 3. California HUC4 by urban sampling sub-project for Northern (NorCal) and Southern (SoCal) California

Region	HUC4	HUC4 name	Major cities
SoCal	1503	Lower Colorado	Needles, Blythe
NorCal	1605	Central Lahontan	Truckee, South Lake Tahoe
NorCal	1801	Klamath-Northern CA	Santa Rosa, Arcata
NorCal	1802	Sacramento	Sacramento, Redding
NorCal	1803	Tulare-Buena Vista Lakes	Bakersfield, Fresno
NorCal	1804	San Joaquin	Modesto, Stockton
NorCal	1805	San Francisco Bay	San Francisco, San Jose
NorCal	1806	Central CA Coast	Santa Barbara, Monterey
SoCal	1807	Southern CA Costal	Los Angeles, Riverside, San Diego
NorCal	1808	North Lahontan	Susanville
NorCal	1809	Northern Mojave-Mono Lake	Lancaster, Palmdale, Victorville, Mammoth Lakes
SoCal	1810	Southern Mojave-Salton Sea	Palm Springs, Imperial

Notes: SWMP was mainly development for California Hydrological Region (i.e., HUC4=18**), and thus does not automatically generate results for watersheds in other regions, such as HUC4's of 1503 (in Lower Colorado Region) and 1605 (in Great Basin Region) in the table. For agriculture uses of pesticides, an option was provided to cover those areas with user-defined watershed by sections (Luo and Deng, 2015). Modeling for urban pesticide uses in those HUC4's requires additional map layers, and will be incorporated in the next version.

4.3.3 Stage 3, HUC12-level analysis (for selected HUC8's from the previous steps)

HUC12-level analysis can be conducted (next section) for each selected HUC8. Based on the available data and monitoring experiences, however, the PI's may skip the HUC12-level analysis for some HUC8's (e.g., those mainly covered by urban land use, thus less spatial variability within the watershed).

Step (8): HUC12 ranking. HUC12's are ranked for both tributaries (without upstream drainage areas) and mainstreams (with upstream drainage area).

- HUC12 ranking for tributaries. Adjusted PMI's for HUC12 tributary can be calculated with Eq. (4), and used for HUC12 ranking, by following the same data analysis in the steps (5) and (6).
- HUC12 ranking for mainstreams. The SWMP-generated PMI's for HUC12 mainstreams are used for HUC ranking, by following the same data analysis in the steps (5) and (6).

Step (9): Filtering by urban land coverage. To focus on urban areas, a HUC12 will be excluded for monitoring if it's %urban is less than a user-defined cutoff value. A default cutoff value is set as 20% for statewide analysis. Higher values can be used for monitoring programs in highly urbanized regions. This cutoff value is related to the total number of AOI's suggested by the model (less potential HUC12's will be generated with higher cutoff value), but does not significantly change the ranking of suggested HUC12's.

4.3.4 Stage-4, POI refinement

It's essentially an iterative process for the determination of POI's and AOI's: we start with a statewide prioritization to generate a list of representative POI's for urban monitoring, and use them to determine potential candidate AOI's at HUC12 level. For each individual AOI, however, it may not be appropriate to sample all representative POI's. There are two reasons to exclude some pesticides from monitoring at a given sampling site:

- Consideration of use amounts: POI's with relatively small amounts of urban uses in the corresponding drainage area. Those pesticides can be identified by one more SWMP run for the given HUC12 (i.e., site-specific prioritization). This approach (shown as a post-processing in the flowchart, Figure 2) has been used in our previous monitoring studies, so not demonstrated here.
- Consideration of relative contributions from agricultural uses of the same pesticides. Co-existence of agricultural and urban areas and pesticide uses within a watershed is not a problem for urban monitoring on tributary sites, which are usually located in the urban portion of the watershed. For mainstream sites, however, upstream agricultural uses of the same set of POI's to be monitored should be evaluated by comparing to urban uses.

This section is to develop the methodology for identifying pesticides with significant contributions from agricultural uses in a mainstream AOI. The identified pesticides are not recommended for urban monitoring in the given AOI, although they are suggested by statewide or site-specific prioritization for urban pesticides uses.

Step (10): Priority mapping index for agricultural uses in mainstreams, PMIacc(ag). With the same set of POI's (e.g., demonstrated in Table 1), PMIacc(ag) can be calculated with similar SWMP settings as in step (3):

- Use pattern: agriculture
- Other settings: same as step (3)

Step (11): Relative contribution of urban uses. The relative contribution of urban uses (R) is calculated as,

$$R = \frac{\text{PMIacc(urban)}}{\text{PMIacc(urban)} + \text{PMIacc(ag)}} \qquad \text{for each pesticide in the drainage area of each HUC12} \qquad (5)$$

If the resultant *R* for a pesticide in a HUC12 is less than a certain value, the pesticide is not recommended for urban monitoring in the mainstream of the HUC12. A cutoff value of 75% is used for demonstration purpose, and it can be altered by a user.

4.3.5 AOI determinations in unprioritized HUC8's

In summary, the proposed methodology first prioritizes HUC8's, then HUC12's. We notice that, in the HUC8's which are not prioritized in the top 20 results, there may be also highly populated areas, and thus potential streams and sites for urban monitoring. For example, high detections are observed in the DPR site BOQ (HUC12=180701020202, Bouquet Creek near Santa Clarita) although the enclosing HUC8 (18070102, "Santa Clara") has lower urban land coverage and pesticide uses compared to the top-20 HUC8's (Table 2).

This section is to develop the methodology to determine additional AOI's for "unprioritized" HUC8's. This is expected for use in [1] statewide search of AOI's (without preferred region of monitoring), and [2] predefined region of monitoring by HUC8's (regardless of the HUC8-level analysis results). The methodology is generally consistent with that proposed for prioritized HUC8's, with the following procedures:

- In step (7), specify HUC8's by a user for further data analysis, regardless of the HUC8 ranking results. The user- specified HUC8's could be considered as part of the "study-specific considerations and professional judgment", and thus incorporated in the methodology as shown in Figure 2. The user's input could be one HUC8, multiple HUC8's, or all HUC8's in California. In this report, HUC8's ranked 21-40 are used for demonstration purpose.
- Conduct HUC12-level analysis for the user- specified HUC8's. The same procedures in Section 4.3.3 are applied here.

5 Results and Discussion

5.1 Settings for model demonstrations

The proposed methodology is associated with multiple options and parameters which can be set as default values or specified by a user. For demonstration purpose, the following settings are applied:

- SWMP settings: as documented in the in the previous sections.
- POI's: 20 pesticides in Table 1.
- HUC8's
    - (Section 5.2) Model-suggested top-20 HUC8's with DPR sites or with 303(d)-listed water bodies (Table 2).
    - (Section 5.3) User-specified HUC8's. HUC8's ranked #21-40 (Table 4) are used to demonstrate the modeling capability for statewide search of AOI's for urban monitoring.
- Cutoff value for %urban: 20%
- Cutoff value for *R* (relative contribution of urban uses over total uses of a pesticide): 75%.

Table 4. HUC8's for the demonstration of the methodology with user-specified HUC8's, selected as the HUC8's ranked #21~40 in Step (6). Notes are manually added.

HUC8		**Notes**	
Code	**Name**	**Monitored by DPR?**	**With 303(d)-listed water bodies for pesticides from urban runoff?**
18070303	San Luis Rey-Escondido		
18030009	Upper Dry		
18040010	Upper Stanislaus		
18070103	Calleguas		1 listed water body
18020159	Honcut Headwaters-Lower Feather		
18040012	Upper Mokelumne		
18040002	Lower San Joaquin River		
18050006	San Francisco Coastal South		
18020154	Clear Creek-Sacramento River		
18060013	Santa Barbara Coastal		4 listed water bodies
18010110	Russian		
18040013	Upper Cosumnes		
18040051	Rock Creek-French Camp Slough		
18040009	Upper Tuolumne		
18020158	Butte Creek		
18060002	Pajaro		1 listed water body
18020157	Big Chico Creek-Sacramento River		
18030003	Middle Kern-Upper Tehachapi-Grapevine		
18070102	Santa Clara	BOQ	
18030012	Tulare Lake Bed		

5.2 Results for model-suggested HUC8's

Table 5 shows the top-3 HUC12's by tributary ranking and the top-3 HUC12's by mainstream ranking for each HUC8 with DPR sites (Table 2). Some HUC8's may have total number of HUC12's less than 3 for the stream type of "tributary" or "mainstream". In this case, all identified HUC12's will be reported. Results for other HUC8's without DPR monitoring are provided in the Appendix 2. Please note that "top 3" here is only used for demonstration purpose, while the number of candidate AOI's may vary by monitoring programs.

Table 5. Top-3 results of HUC12-level analysis for HUC8's with DPR monitoring (Table 2) (i.e., top-4 tributary sites and top-4 mainstream sites in each user-selected HUC8's. Results are first ordered by HUC8, then by the ranking of suggested HUC12's and stream types)

Notes: [Type] = stream type of "trib" for tributary and "main" for mainstream. [Streams and notes] = manually added mainly based on NHD, water bodies in the 303(d) or monitored by other programs are labelled.

(a) Northern California

HUC12	HUC12 NAME	Type	Site(s)	Streams and notes
HUC8=18020111, Lower American:				
180201110105	Gibson Lake-Dry Creek	main	DRY100	Dry Creek
180201110102	Miners Ravine	main	DCC7_A	Dry Creek
180201110303	Lower Steelhead Creek	main		Natomas East Main Drainage Canal (aka Steelhead Creek) (303d)
180201110302	Arcade Creek	trib	ARC_Nor	Arcade Creek (303d)
180201110103	Antelope Creek	trib		Antelope Creek, Clover Valley Creek
180201110105	Gibson Lake-Dry Creek	trib		Multiple tributaries to Dry Creek
HUC8=18020161, Upper Coon-Upper Auburn:				
180201610302	Pleasant Grove Creek	trib	PGC's, KBC's, SBP100	Pleasant Grove Creek (303d),Pleasant Grove Creek, South Branch(303d),Kaseberg Creek(303d)
180201610101	Orchard Creek	trib		Orchard Creek
180201610402	Natomas Main Drainage Canal-Sacramento River	trib		Unnamed NHD streams
HUC8=18050001, Suisun Bay:				
180500010204	Walnut Creek-Frontal Suisun Bay Estuaries	main	Wal_Marsh	Walnut Creek (303d)
180500010203	Pine Creek	trib		Pine Creek (303d)
180500010204	Walnut Creek-Frontal Suisun Bay Estuaries	trib	GRY030	Grayson Creek
180500010301	Kirker Creek-Frontal Suisun Bay Estuaries	trib	KIR_Cr	Kirker Creek (303d)
HUC8=18050003, Coyote:				
180500030304	Guadalupe River	main	GUA_TRM	Guadalupe River (303d)
180500030201	Silver Creek	trib		Silver Creek, Thompson Creek
180500030302	Canoas Creek	trib		Canoas Creek
180500030304	Guadalupe River	trib		Ross Creek
180500030202	Metcalfe Canyon-Coyote Creek	main		Coyote Creek (303d)
HUC8=18050004, San Francisco Bay:				
180500040502	South San Ramon Creek	main		South San Ramon Creek
180500040802	San Lorenzo Creek	main		San Lorenzo Creek (303d)
180500040805	Sausal Creek-Frontal San Francisco Bay Estuaries	trib		Sausal Creek, Peralta Creek
180500040501	Alamo Creek	trib		Alamo Creek
180500040502	South San Ramon Creek	trib	MCC040	Dublin Creek,Laurel Creek, South San Ramon Creek
180500040203	Lower Arroyo Las Positas	main		Arroyo Las Positas (303d)

(b) Southern California

HUC12	HUC12 NAME	Type	Site(s)	Streams and notes
HUC8=18070104, Santa Monica Bay:				
180701040300	Ballona Creek	trib	BAL	Ballona Creek
180701040403	Santa Monica Beach-Frontal Santa Monica Bay	trib		unnamed NHD streams
180701040500	Manhattan Beach-Frontal Santa Monica Bay	trib		unnamed NHD streams
HUC8=18070105, Los Angeles:				
180701050303	Alhambra Wash-Rio Hondo	main		Rio Hondo
180701050206	Lower Pacoima Wash	main		Pacoima Wash
180701050402	Compton Creek-Los Angeles River	trib		Compton Creek
180701050206	Lower Pacoima Wash	trib		East Canyon Channel (Canal/Ditch)
180701050303	Alhambra Wash-Rio Hondo	trib		Rubio Wash, Alhambra Wash
180701050208	Tujunga Wash-Los Angeles River	main	LAR2	Los Angeles River
HUC8=18070106, San Gabriel:				
180701060102	Lower Dominguez Channel	main		Dominguez Channel
180701060402	Big Dalton Wash	main		Big Dalton Wash
180701060502	Lower San Jose Creek	main		San Jose Creek
180701060703	San Pedro Bay	trib		San Pedro Bay
180701060101	Upper Dominguez Channel	trib		Dominguez Channel
180701060604	Fullerton Creek	trib		Fullerton Creek
HUC8=18070301, Aliso-San Onofre:				
180703010301	Aliso Creek	trib	WC's	Aliso Creek
180703010104	Lower San Juan Creek	main		San Juan Creek
180703010302	Salt Creek-Frontal Gulf of Santa Catalina	trib	SC's *	Salt Creek
180703010103	Arroyo Trabuco	trib		Arroyo Trabuco Creek (303d)
HUC8=18070304, San Diego:				
180703040403	Carmel Valley	main		Poway Creek
180703041201	Chollas Creek	trib	CHO2	Chollas Creek
180703041202	San Diego Bay	trib		Seventh Street Channel
180703041004	Poggi Canyon-Otay River	trib		unnamed NHD streams
180703041004	Poggi Canyon-Otay River	main		Otay River
180703040703	Los Coches Creek-San Diego River	main		San Diego River

* SC’s are historical DPR sites on Salt Creek, not in the list of the 29 current sites (Appendix 1)

(c) POI's not recommended for mainstream monitoring due to significantly contributions by agricultural uses in the same drainage areas

HUC12	HUC12 NAME	Type	Pesticides (by Chem_code) not recommended
180201110303	Lower Steelhead Creek	main	636
180500030202	Metcalfe Canyon-Coyote Creek	main	105, 367, 1868, 1973, 2170, 2297, 2300, 3849
180500040802	San Lorenzo Creek	main	1973
180500040203	Lower Arroyo Las Positas	main	231, 1868, 1929, 1973, 3849
180701050303	Alhambra Wash-Rio Hondo	main	105, 1973
180701050208	Tujunga Wash-Los Angeles River	main	1973, 2170
180701060102	Lower Dominguez Channel	main	105, 367
180701060402	Big Dalton Wash	main	367, 1973
180701060502	Lower San Jose Creek	main	1973
180703010104	Lower San Juan Creek	main	83, 105, 231, 367, 1868, 1929, 1973, 2236
180703040703	Los Coches Creek-San Diego River	main	105, 367
Other mainstream AOI's in the panels (a) and (b)			none

Two of the current DPR sites are not included in the modeling results

- BOQ (Bouquet Creek, HUC12=180701020202) is not identified. The HUC8 of 18070102 is ranked out of top-20 (Table 2), thus not included in this HUC12-level analysis. This site is captured by the modeling results with user-specific HUC8's, see section 5.3.
- Coyote Creek (Santa Clara County) is suggested by the model for monitoring. The model selects a more upstream site (HUC12=180500030202, "Metcalfe Canyon-Coyote Creek") than the current DPR site COY060 (at 180500030203, "Upper Penitencia Creek-Coyote Creek"). The upstream site is associated with higher %urban (44.4%) relative to COY060 (17.6%).

All other DPR sites are identified by the proposed procedures. Some sites are not among top-3 results, so not displayed in the short list of Table 5, *i.e.*, FOL100 (rank #7), LAR1 (#7), SDR's (#4), SGR (#4), and TCC (#4) in their corresponding HUC8.

5.3 Results for user-specified HUC8's

In this demonstration, model suggested HUC8's for urban monitoring are replaced by user-specified HUC8's in Table 4. Only the AOI's with the highest rank in each HUC8, for tributary or mainstream, are reported here (Table 6).

Table 6. The top-ranked monitoring sites in each of the user-specified HUC8's (Table 4). Results are first ordered by HUC8, then by the ranking of suggested HUC12's and stream types)

Notes: [Type] = stream type of "trib" for tributary and "main" for mainstream. [Streams and notes] = manually added mainly based on NHD, water bodies in the 303(d) or monitored by other programs are labelled.

HUC12	HUC12 NAME	Type	Streams and notes
180101100703	Lower Santa Rosa Creek	main	Santa Rose Creek (SWAMP sites)
180101100703	Lower Santa Rosa Creek	trib	tributaries to Santa Rosa Creek
180201540303	Olney Creek-Sacramento River	trib	Olney Creek
180201570604	Kusal Slough-Mud Creek	trib	Channel Slough, east to Chico
180201590202	Oregon Gulch-Feather River	trib	unnamed streams near Oroville
180300031201	Kern Island Canal-Frontal Kern Lake Bed	trib	unnamed streams near Bakersfield
180300031201	Kern Island Canal-Frontal Kern Lake Bed	main	unnamed streams near Bakersfield
180300090503	Mill Ditch	main	unnamed streams south to Fresno and Clovis
180300090403	Lower Dry Creek	trib	unnamed streams near Clovis
180300120802	Goose Lake Slough	main	Goose Lake Slough
180300120801	West Shore Gulch	trib	unnamed streams north to Bakersfield
180400091403	Town of Riverdale Park-Tuolumne River	trib	Lateral 5 (ag sites)
180400091403	Town of Riverdale Park-Tuolumne River	main	Tuolumne River (USGS sites)
180400100705	Riley Slough	main	Lateral 3 (SURF site_code: 50_103)
180400100705	Riley Slough	trib	unnamed streams in Modesto
180400121002	South Stone Lake-Snodgrass Slough	main	multiple streams near Elk Grove
180400510403	Walker Slough-French Camp Slough	trib	Duck Creeks (ag sites)
180400510403	Walker Slough-French Camp Slough	main	French Camp Slough (ag sites)
180500060204	San Pedro Creek-Frontal Pacific Ocean	trib	multiple streams near Pacifica (EPA sites for sediment monitoring)
180500060205	Denniston Creek-Frontal Pacific Ocean	main	multiple streams (SFEI sites)
180600020303	Lower Llagas Creek	main	multiple streams in Gilroy
180600020303	Lower Llagas Creek	trib	Llagas Creek
180600130202	San Pedro Creek	main	multiple streams near Isla Vista
180600130203	Mission Creek-Frontal Santa Barbara Channel	trib	multiple streams near Santa Barbara
180701020202	Lower Bouquet Canyon	main	Bouquet Canyon (DPR site BOQ)
180701020202	Lower Bouquet Canyon	trib	unnamed streams
180701030105	Lower Conejo Arroyo	main	Conejo Arroyo
180701030202	McGrath Lake-Frontal Pacific Ocean	trib	unnamed streams near Oxnard (multiple existing sites in the urban area)
180703030402	Lower Escondido Creek	main	multiple streams near Escondido
180703030401	Upper Escondido Creek	trib	Escondido Creek (SWAMP urban sites)

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Appendices
A1. Summary of pesticide monitoring studies

Table 7. Historically and currently monitored urban receiving waters for pesticides (based on DPR urban monitoring studies and 303(d) listed water bodies impaired by urban runoff of pesticides), organized by USGS 8-digit Hydrological Unit Codes (HUC8)

HUC8	HUC8 NAME	Monitored water body name ("303d" for the 303(d) listed water bodies impaired by urban pesticide runoff)	Current DPR sites
18020111	Lower American	Arcade Creek (303d)	ARC_Nor
		Chicken Ranch Slough (303d)	
		Dry Creek	DRY100, DCC7_A
		Natomas East Main Drainage Canal (aka Steelhead Creek, downstream of confluence with Arcade Creek) (303d)	
		Strong Ranch Slough (303d)	
		unnamed tributary to Alder Creek	FOL100
18020161	Upper Coon-Upper Auburn	Curry Creek (Placer and Sutter Counties) (303d)	
		Kaseberg Creek (tributary to Pleasant Grove Creek, Placer County) (303d)	KBC090, KBC100
		Pleasant Grove Creek (303d)	PGC001, PGC040, PGC050, PGC058
		Pleasant Grove Creek, South Branch (303d)	SBP100
18020163	Lower Sacramento	Elder Creek (303d)	
		Elk Grove Creek (303d)	
		Morrison Creek (303d)	
18040003	San Joaquin Delta	Five Mile Slough (Alexandria Place to Fourteen Mile Slough; in Delta Waterways, eastern portion) (303d)	
		Marsh Creek (Marsh Creek Reservoir to San Joaquin River; partly in Delta Waterways, western portion) (303d)	
		Mosher Slough (downstream of I-5; in Delta Waterways, eastern portion) (303d)	
		Smith Canal (in Delta Waterways, eastern portion) (303d)	
18050001	Suisun Bay	Grayson Creek	GRY030
		Kirker Creek (303d)	KIR_Cr
		Ledgewood Creek (303d)	
		Mt. Diablo Creek (303d)	
		Pine Creek (Contra Costa Co) (303d)	
		Walnut Creek (303d)	Wal_Marsh
18050002	San Pablo Bay	Arroyo Corte Madera Del Presidio (303d)	
		Calabazas Creek (303d)	
		Corte Madera Creek (303d)	
		Coyote Creek (Marin County) (303d)	
		Gallinas Creek (303d)	
		Miller Creek (303d)	
		Novato Creek (303d)	
		Petaluma River (303d)	
		Petaluma River (tidal portion) (303d)	

HUC8	HUC8 NAME	Monitored water body name ("303d" for the 303(d) listed water bodies impaired by urban pesticide runoff)	Current DPR sites
		Pinole Creek (303d)	
		Rodeo Creek (Contra Costa County) (303d)	
		San Antonio Creek (Marin/Sonoma Co) (303d)	
		San Pablo Creek (303d)	
		San Rafael Creek (303d)	
		Wildcat Creek (303d)	
18050003	Coyote	Coyote Creek (Santa Clara Co.) (303d)	COY060
		Guadalupe River (303d)	GUA_TRM
		Los Gatos Creek (R2) (303d)	
		Matadero Creek (303d)	
		Permanente Creek (303d)	
		San Felipe Creek (303d)	
		San Francisquito Creek (303d)	
		Saratoga Creek (303d)	
		Stevens Creek (303d)	
18050004	San Francisco Bay	Alameda Creek (303d)	
		Arroyo De La Laguna (303d)	
		Arroyo Del Valle (303d)	
		Arroyo Las Positas (303d)	
		Arroyo Mocho (303d)	
		Laurel Creek (Solano Co) (303d)	
		San Leandro Creek, Lower (303d)	
		San Lorenzo Creek (303d)	
		San Mateo Creek (303d)	
		South San Ramon Creek	MCC040
18060002	Pajaro	Pajaro River (303d)	
18060005	Salinas	Chualar Creek (303d)	
		Salinas River (lower, estuary to near Gonzales Rd crossing, watersheds 30910 and 30920) (303d)	
18060006	Central Coastal	San Luis Obispo Creek (below Osos Street) (303d)	
18060008	Santa Maria	Bradley Channel (303d)	
		Main Street Canal (303d)	
		Orcutt Creek (303d)	
		Santa Maria River (303d)	
18060013	Santa Barbara Coastal	Arroyo Paredon (303d)	
		Carpinteria Creek (303d)	
		Franklin Creek (Santa Barbara County) (303d)	
18060015	Monterey Bay	Arana Gulch (303d)	
		Espinosa Slough (303d)	
		Old Salinas River (303d)	
		Salinas Reclamation Canal (303d)	
		Tembladero Slough (303d)	
18070102	Santa Clara	Bouquet Creek	BOQ
18070103	Calleguas	Calleguas Creek Reach 4 (was Revolon Slough Main Branch: Mugu Lagoon to Central Avenue on 1998 303d list) (303d)	
18070104	Santa Monica Bay	Ballona Creek	BAL

HUC8	HUC8 NAME	Monitored water body name ("303d" for the 303(d) listed water bodies impaired by urban pesticide runoff)	Current DPR sites
18070105	Los Angeles	Los Angeles River	LAR1, LAR2
18070106	San Gabriel	San Gabriel River	SGR
18070301	Aliso-San Onofre	Arroyo Trabuco Creek (303d)	
		Salt Creek	SC5, SC6, SC7
18070302	Santa Margarita	Murrieta Creek (303d)	
		Redhawk Channel (303d)	
		Santa Gertrudis Creek (303d)	
		Warm Springs Creek (Riverside County) (303d)	
18070304	San Diego	Chollas Creek	CHO2
		San Diego River	SDR1, SDR2
		Tecolote Canyon Creek	TCC
18070305	Cottonwood-Tijuana	Tijuana River (303d)	

A2. Additional modeling results

Table 8. Top-3 results of HUC12-level analysis for HUC8's with 303(d)-listed water bodies but not currently monitored by DPR (Table 2) (i.e., top-3 tributary sites and top-3 mainstream sites in each user-selected HUC8's. Results are first ordered by HUC8, then by the ranking of suggested HUC12's and stream types)

Notes: [Type] = stream type of "trib" for tributary and "main" for mainstream. [Streams and notes] = manually added mainly based on NHD, water bodies in the 303(d) or monitored by other programs are labelled.

HUC12	HUC12 NAME	Type	Streams and notes
180201630404	Lower Morrison Creek	main	Morrison Creek (303d)
180201630404	Lower Morrison Creek	trib	Beacon Creek, Strawberry Creek
180201630401	Elder Creek	trib	Elder Creek (303d)
180201630403	Laguna Creek	trib	Laguna Creek (303d)
180400030702	Lower Marsh Creek	main	Marsh Creek (303d)
180400030702	Lower Marsh Creek	trib	Dry Creek
180400030803	Dutch Slough-Big Break	trib	unamed NHD stream
180400030303	McLeod Lake-Mormon Slough	main	Mormon Slough
180400030504	Fivemile Creek-San Joaquin River	trib	Five Mile Slough (303d)
180400030803	Dutch Slough-Big Break	main	Marsh Creek (303d)
180500021001	Angel Island-San Francisco Bay Estuaries	main	San Rafael Creek (303d), Corte Madera Creek(303d)
180500020702	Pinole Creek-Frontal San Pablo Bay Estuaries	trib	Wildcat Creek (303d), Pinole Creek(303d), Rodeo Creek (303d)
180500020904	Cerrito Creek-Frontal San Francisco Bay Estuaries	trib	Cerrito Creek, Codornices Creek
180500020701	San Pablo Creek	trib	San Pablo Creek (303d)
180500020303	Lower Sonoma Creek	main	Sonoma Creek
180500020205	Lower Napa River	main	Napa River
180600150102	Nativdad Creek-Gabilan Creek	main	Salinas Reclamation Canal (303d)
180600150102	Nativdad Creek-Gabilan Creek	trib	Nativdad Creek
180600150103	Alisal Slough-Tembladero Slough	main	Salinas Reclamation Canal (303d)
180600150304	Canyon Del Rey	trib	unnamed NHD streams
180600150305	Monterey Bay	trib	Arana Gulch (303d)
180703020401	Warm Springs Creek	trib	Warm Springs Creek (303d)
180703020402	Cole Canyon-Murrieta Creek	trib	Murrieta Creek
180703020302	Pechanga Creek-Temecula Creek	trib	Pechanga Creek
180703020405	Lower Tucalota Creek	main	Tucalota Creek
180703020407	Long Canyon-Murrieta Creek	main	Murrieta Creek (303d)
180703020406	Santa Gertudis Creek	main	Santa Gertrudis Creek (303d)