Demonstration of a Watershed Approach To Wetland Restoration Planning Using GreenPlan-IT

Task 1.D Technical Memo
SFEI/ASC SWRCB STD Agreement Number: 15-021-250-1
Authors: Dr. Jing Wu, Pete Kahaunen, Sarah Lowe, Sarah Pearce, and Josh Collins
Date: December 2017

INTRODUCTION

This is the second part of a two-part demonstration of a watershed approach to wetland restoration or mitigation planning to reduce pollutant load reductions to downstream receiving waterbodies while improving the overall abundance, distribution, and diversity of wetlands in the watershed. The demonstration focuses on the Laguna de Santa Rosa (Laguna) and the lower portion of its watershed, the Santa Rosa Creek watershed, on the Santa Rosa Plain, near Santa Rosa, California (Figure 1-1). The focus area is termed the Project Evaluation Area (PEA) to be consistent with emerging California state procedures that planning and assessing compensatory mitigation in the watershed context.

The Laguna is much appreciated for its beauty and wildlife. Historical wetlands on the Santa Rosa Plain upstream of the Laguna helped protect the Laguna from excessive sedimentation by storing and filtering floodwaters. Groundwater maintained by infiltration of runoff in the wetlands fed springs along the Laguna and kept it cool enough to support salmon. More recently, the wetlands filtered nutrients and other pollutants from runoff generated by ranching, dairying, farming and early urbanization. The wholesale conversion of these wetlands to modern land uses has had multiple negative effects:

- Disruptions of stream flow (i.e., hydromodification) causing channel erosion;
- Discharges of excessive amounts of fine sediment and other pollutants into the Laguna;
- Ecological fragmentation of the Plain including isolation of remaining wetlands.

In consequence, the Laguna has been declared am impaired waterbody due to excessive inputs of nitrogen phosphorus, and fine sediment.

This demonstration project has two phases. Phase 1 applied the Hydrological Simulation Program-FORTRAN (HSPF) Model to evaluate flow and nutrient load reductions based on hypothetical increases in the acres of depressional wetlands in the PEA. Phase 2 of the project used GreenPlan-IT to prioritize wetland restoration opportunities to optimally reduce flow and nutrients loads from the PEA to the Laguna.

In Phase 1, the HSPF model was first calibrated to available flow and nutrient monitoring data, and then used to run three wetland restoration scenarios of increasing wetland area: minimum (existing), moderate, and maximum amounts of restoration. The existing amount of wetland was determined using California Aquatic Resources Inventory (CARI v0.2). The three wetland restoration scenarios were developed in a Geographic Information System (GIS) using aerial imagery and best professional judgement to identify potentially viable wetland creation and restoration sites within the PEA. Phase 1 demonstrated a) increasing the amount of depressional wetlands in the PEA can reduce stormwater runoff and nutrient loads to the Laguna and b) larger downstream wetlands appear more effective than smaller upstream wetlands (SFEI, July 2017).

In Phase 2, the GreenPlan-IT tools was used to optimize the relationship between wetland creation or restoration costs and nutrient load reduction for the maximum restoration scenario generated in Phase 1. This is a report of the Phase 2 demonstration project.

OVERVIEW OF GREENPLAN-IT

GreenPlan-IT is a planning level tool that was originally designed to support the cost-effective selection and placement of green infrastructure (GI) in urban watersheds through a combination

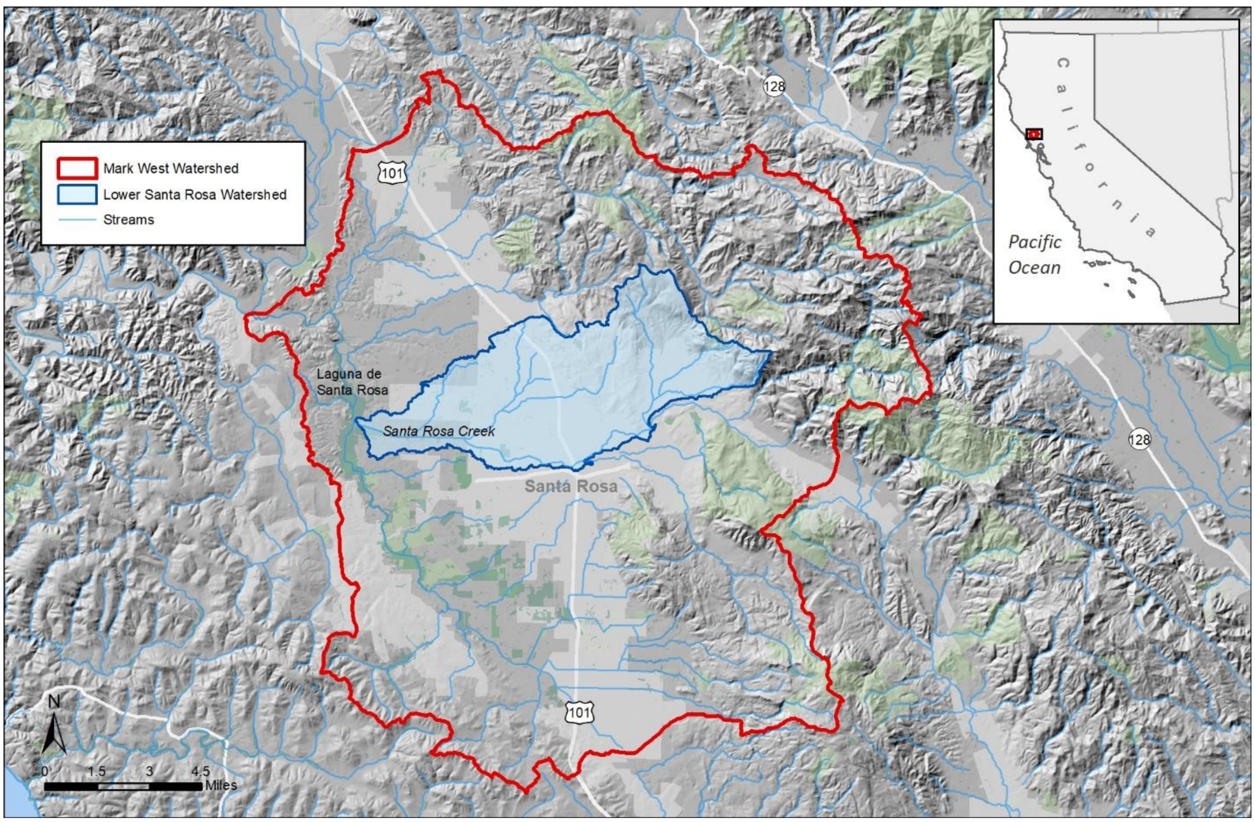

Figure 1-1. Map of the Lower Santa Rosa Creek Project Evaluation Area (PEA) in blue within the Mark West Creek watershed outlined in red.

of GIS analysis, watershed modeling, and optimization techniques. GreenPlan-IT is comprised of four standalone tools (Figure 2-1): (a) a GIS-based Site Locator Tool to identify and rank potential GI sites; (b) a Modeling Tool that quantifies anticipated watershed-scale runoff and pollutant load reduction from GI sites; (c) an Optimization Tool that uses a cost-benefit analysis to identify the best combinations of GI types and number of sites within a watershed for achieving flow and/or load reduction goals; and (d) a Tracker tool that records and displays information about GI implementation for individual sites, and assesses and reports their effectiveness in relation to regulatory compliance and other communication needs. This project utilized only the Site Locator Tool and the Optimization Tool, described in more detail below.

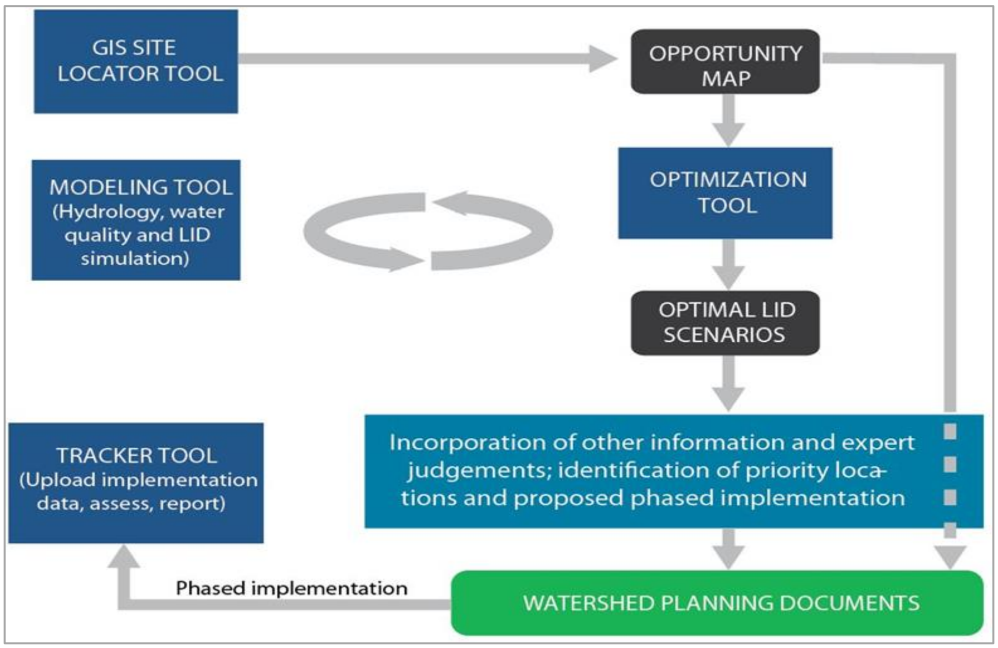

Figure 2-1. GreenPlan-IT Tool Structure

2.1 Site Locator Tool

The GIS-based Site Locator Tool is a screening tool that can be used to identify potential GI locations and rank them through GIS analysis. The Tool incorporates regional and publicly available GIS data layers and runs five intersecting analyses that require user input to produce maps of ranked possible GI locations.

User-defined site location priorities are identified, weighted and used to rank GI locations. Site ranking priorities can be broadly or narrowly defined, and can include all kinds of considerations, such as ecological, physical, regulatory, or social factors. The Site Locator Tool allows the user to add data layers to further identify and rank GI locations, which produces outputs with different levels of refinement or permits analyses with varying levels of available data. Although the Site Locator Tool is a stand-alone tool, some outputs are required inputs to the Optimization Tool.

2.2 Optimization Tool

The GreenPlan-IT Optimization Tool uses an optimization technique adopted from evolutionary biology (Nondominated Sorting Genetic Algorithm II , Deb, et al 2002) to evaluate the benefits (runoff and pollutant load reductions) and costs associated with various GI implementation scenarios (type, location, number) and identify the most cost-effective options that satisfy user-defined management goals. The Optimization Tool requires both site information generated from the GIS Site Locator tool (to form its search space), and time-series results of flow and pollutant loads from a hydrologic modeling tool (as the baseline conditions) to evaluate the GI performance. Therefore, using the Optimization Tool will require the running of both the Site Locator Tool and a hydrologic model.

3.0 SITE LOCATOR TOOL - RANKING POTENTIAL WETLAND RESTORATION PROJECT AREAS

The maximum wetland restoration scenario from Phase 1 identifies all potential depressional wetland restoration project areas within the PEA (Figure 3-1). It includes existing wetlands that could be enhanced or restored, as well as other areas where wetlands could be created. The areas for wetland creation include open space areas, undeveloped land, pastures, and agricultural fields (including orchards and vineyards). The GIS data layer was hand-digitized using aerial imagery at a scale of 1:3,000 or greater, and served as the basemap for the Site Locator Tool priority ranking analysis.

The GreenPlan-IT Site Locator Tool ranking analysis employed the following user-defined factors: 1) ecological and physical factors that evaluated the potential for a wetland location to support depressional wetland functions, and 2) land-use and ownership factors that might influence the ability to purchase the land for restoration.

3.1 Wetland Restoration Priorities Used to Rank Potential Wetland Project Sites

Four main wetland restoration priorities (or Factors) were identified for prioritizing potential depressional wetland project areas identified in the Extreme Wetland Placement Scenario basemap. These factors helped to develop and group specific site suitability ranking questions and designate their relative importance (relative influence on the final ranks).

- **Feasibility –** Wetland projects should be located where they will naturally thrive. Wetlands should have an appropriate water source to support their hydrology, should be placed in an appropriate location on the landscape, and have minimal constraints due to adjacent land uses.

- **Condition –** Specific physical and hydrologic settings support wetland functions and conditions (e.g. site is near streams, channels or ditches, or other wetlands). Wetlands adjacent to other aquatic areas, or larger, more complex wetlands will provide greater habitat value and function.
- **Incentives -** Different land ownership (working with one landowner is easier than many owners in a land sale) will make wetland creation or enhancement easier. For example wetland projects may be easier (less costly) to develop in areas that are publically owned or subject to conservation easements, especially if private lands or easements must be purchased. Also, priority conservation areas may have incentives for restoration.
- **Setting** – Certain adjacent land uses will provide better buffer function to support wetland hydrology and provide wildlife corridors and filtration functions.

Three to five restoration site suitability questions were identified for each priority factor and their relative influence (weight) on the final rank determined by consulting with local and regional wetland specialists (Table 3-1). The custom restoration site suitability ranking was determined by a nested weighted overlay of GIS layers representing the prioritized questions for the four factors identified as important to local priorities. The following publicly available GIS-datasets were utilized to geospatially analyze and rank the wetland restoration planning areas[1] based on the ranking questions.

- California Aquatic Resource Inventory (CARI v0.2).
- Slope from National Elevation Dataset (NED 10m DEM).
- California Protected Areas Database (CPAD 2016).
- California Conservation Easement Database (CCED 2016).
- Sonoma County Public Lands.
- National Land Cover Database (NLCD 2011).

Each of the four Factors was assigned an equal weight, and each data layer within them (each site suitability question) was assigned a proportional weight that summed up to 25% (Table 3-1). The data layers that present a favorable situation for wetland restoration or creation (gentle slope, close to stream, suitable land uses, publicly owned land, etc) were assigned a positive one (1), while the data layers that represent a restriction or unfavorable situation (adjacent to urban area,

[1] http://www.sfei.org/data/california-aquatic-resource-inventory-cari-version-02-gis-data
https://nationalmap.gov/elevation.html
http://www.calands.org/data
http://www.calands.org/cced
http://sonomacounty.ca.gov/ISD/Information-Management/GIS/Data-Downloads/
https://www.mrlc.gov/nlcd2011.php

steep slope, etc) were assigned a negative one (-1). Higher proportional weights were given to the data layers that were deemed more important within each Factor. Each Factor contributes (assumed equally in this run) to the valuation of wetland restoration goals. These weights are customizable and can be easily adjusted to reflect local priorities and evolving management goals. These ‘opportunities and constraints’ are translated into geospatial queries that the Site Locator Tool analyses in order to rank wetland restoration areas across the study area.

The Site Locator Tool output is a GIS shape file of ranked wetland areas within the Lower Santa Rosa Creek watershed.

Table 3-1. Restoration project site suitability priority questions employed by the Site Locator Tool for the Lower Santa Rosa Creek watershed

Ranking Question	Rationale	Positive or Negative Rank Impact	Percent Influence on Final Rank
Feasibility			
Is the potential wetland area within 50 meters of a stream?	Locations adjacent to streams/ditches have a water source that can be routed into the wetland, and support its hydrology.	1	8%
Is the landscape relatively flat (≤2% slope)?	Topographic basins or gentle slopes are more feasible for depressional wetlands	1	8%
Is the site within 50 meters of an existing wetland?	Expanding the area of an existing wetland will likely create a successful wetland, because it already has the hydrology to support it.	1	5%
Is the adjacent area within 50 meters of urban or industrial land use?	Wetlands constructed in urban or industrial areas may have greater ecological feasibility concerns and permitting restrictions because they could contribute to flood risk or unforeseen building structural issues.	-1	5%
Condition			
Which areas are within 500 meters of a stream?	Wetlands adjacent to streams benefit ecologically from the stream including access to surface water (flooding), ground water, nutrients, seeds, critters.	1	6%
Is the pixel within 500m of an existing wetland?	Wetlands near other wetlands have greater ability to interact (surface water, ground water, nutrients, seeds, critters)	1	6%

Is this a large wetland? Let's define large as 10 acres or larger.	Larger wetlands are more structurally complex, and have greater capacity for higher condition	1	6%
Is this a medium or larger wetland? Let's define medium as 5 acres or larger.	Larger wetlands are more structurally complex, and have greater capacity for higher condition	1	4%
Attribute using "type" in "extreme wetland" polygons. Is this a wetland enhancement?	Existing wetlands that are enhanced will likely have greater condition than wetlands that are created.	1	3%
Incentives			
Is the polygon in a conservation area shown in CPAD?	Wetlands in conservation areas will be easier to build and likely higher condition	1	9%
Is the polygon in a conservation area shown in CPAD?	Wetlands in easement areas will be easier to build and likely higher condition	1	9%
Is the polygon on a publicly owned parcel? Do we have an ownership layer?	Wetlands in public lands will be easier to build	1	6%
Setting			
Is the pixel within 250m of high density urban land use?	Wetlands with adjacent high density urban land use will have poor buffer and high stress	-1	6%
Is the pixel within 250m of an agricultural land use?	Wetlands with adjacent agriculture will have poor buffer and moderately high stress	-1	4%
Is the pixel within 250m of low density urban land use?	Wetlands with adjacent low density urban will have moderate buffer and low stress	-1	2%
Is the pixel within 250m of designated open-space?	Wetlands with adjacent open space will have good buffer and no/low stress	1	13%

3.2 GIS Analysis Results

Running the Site Locator Tool is typically an iterative and interactive process. Through the process, GIS data layers can be added and removed, rankings and data layer weights can be changed, and the Tool can be rerun by including or excluding any of the layers associated with the ranking questions. This iterative process normally proceeds with stakeholder review and input as questions and goals change or more accurate local data become available.

Figure 3-1 presents the final ranked output from the Site Locator Tool. It provides a starting point for prioritizing wetland restoration in a watershed context. This output becomes the initial wetland placement constraints for the Optimization Tool as described in next section. Furthermore, this output can be used in conjunction with outputs from the Optimization Tool for a more refined analysis and decision making process. For example, the ranked wetland area and the Optimization output (type and size per sub-basin) can be used in the field to identify the best potential locations for implementing the optimal restoration scenario.

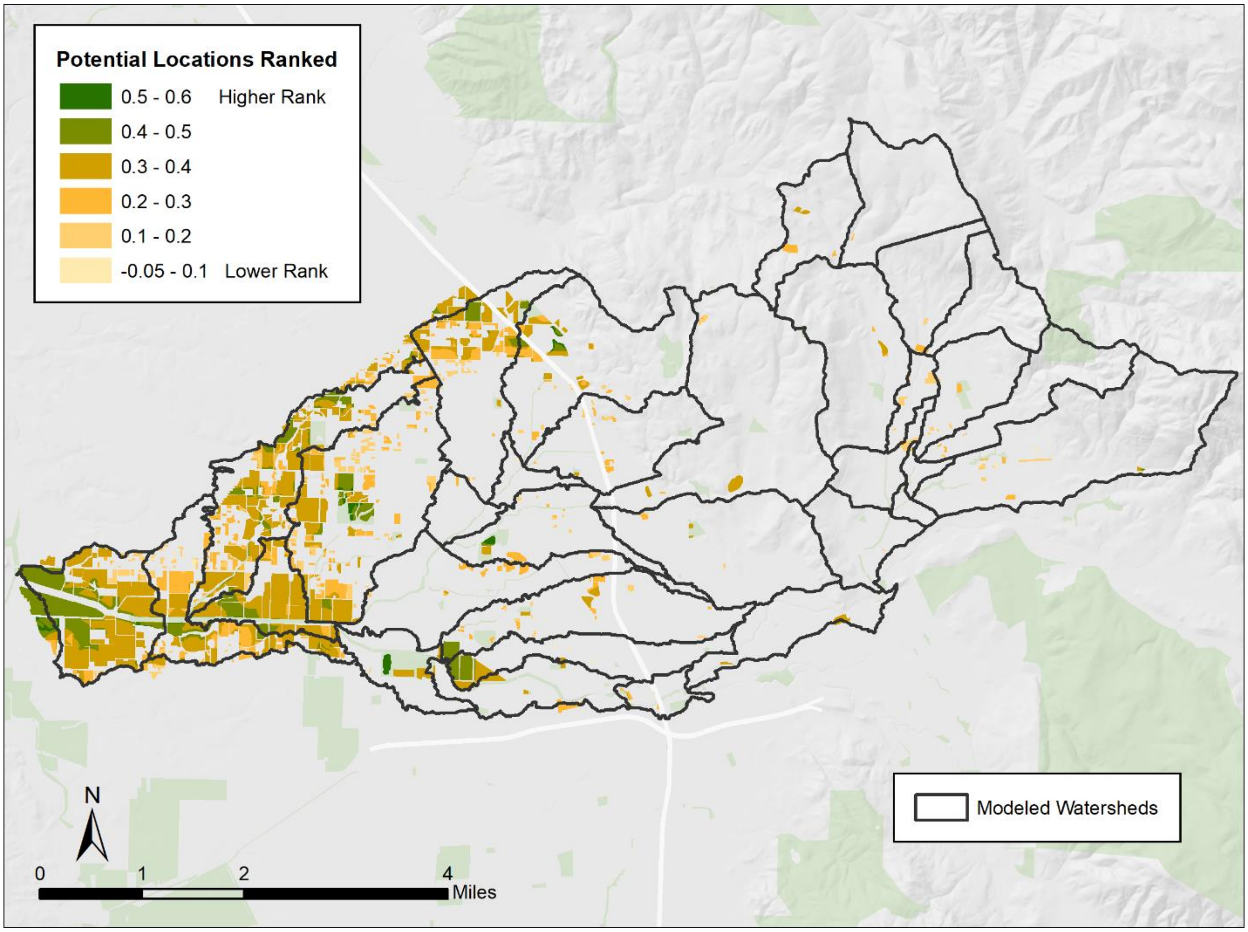

Figure 3-1. Site Locator Tool output. Ranked potential wetland restoration project areas in the Lower Santa Rosa Creek watershed and its sub-basins.

4. COST BENEFIT ANALYSIS

The cost-benefit analysis component of this project focused on identifying the best combinations of depressional wetland restoration projects within the study area to achieve various flow and load reduction goals. The GreenPlan-IT Optimization Tool was used to carry out the analysis. The information and key steps that are required for the tool application are described below.

4.1 Optimization Tool Input

Four components are required as inputs to run the optimization tool. They are (1) flow and nutrient loads at subwatershed level; (2) wetland physical attributes; (3) wetland costs; and (4) constraints on wetland locations.

4.1.1 Baseline flow and nutrient loads

The HSPF model completed in the phase 1 of the demonstration project provides estimated baseline ('existing') flow and nutrient load conditions from the Lower Santa Rosa Creek watershed. The time series of flow and nutrient loads for 35 sub-basins were generated as the initial reference point from which the effectiveness of the wetland restoration scenarios were estimated (Figure 4-1).

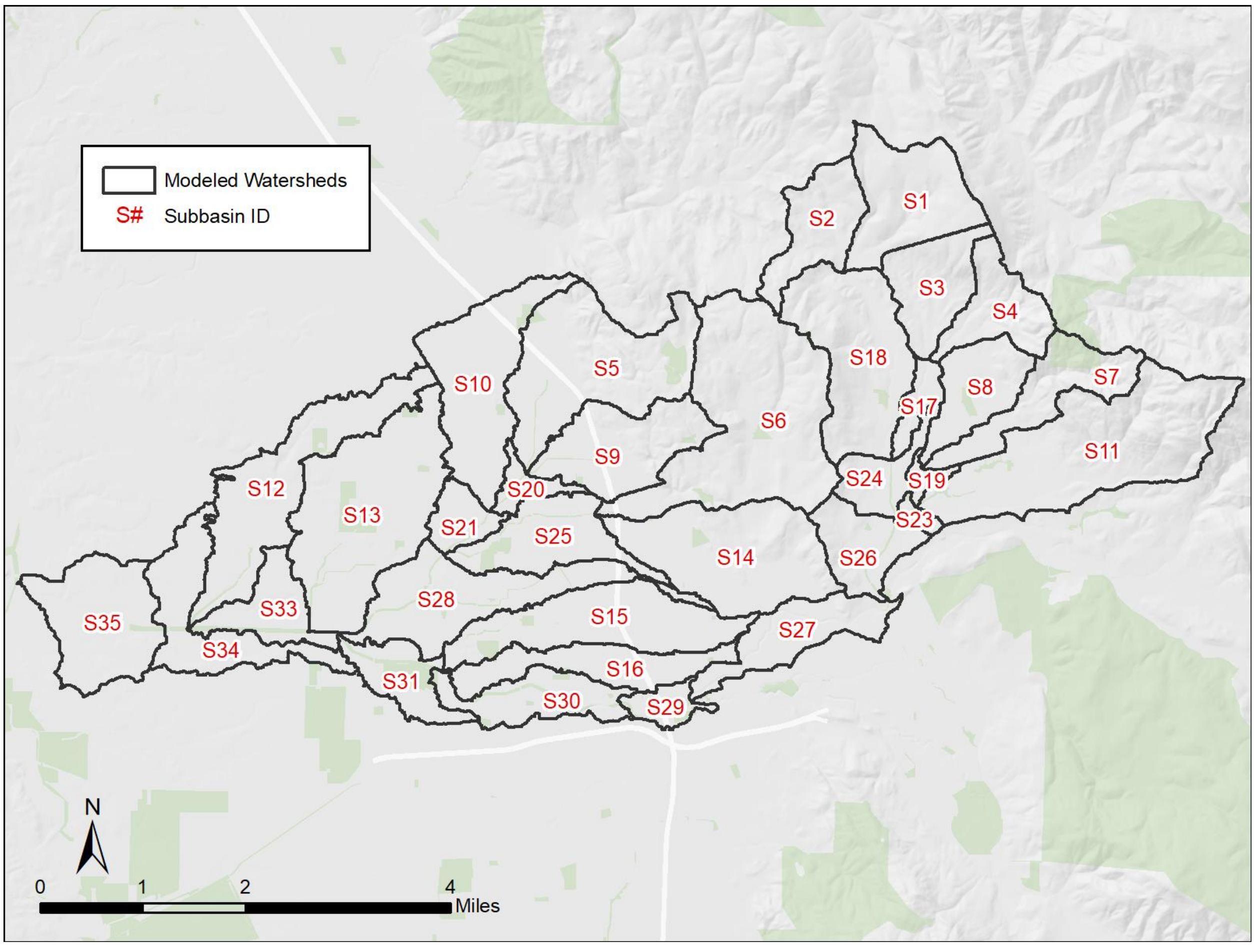

Figure 4-1. Map of the 35 sub-basins within the PEA.

In the phase 1, HSPF was run on a 3-year continuous simulation from 2008 to 2010. Since HSPF outputs are at an hourly time step, running the optimization process with 3-year data was computationally prohibitive. Therefore, it was decided that the optimization would only run a one-year continuous simulation with 2010 data, which was deemed sufficient for this demonstration project.

4.1.2 Wetland Representation

The primary purpose of this project was to demonstrate use of the tools and methodology. The goal was to keep the wetland representation simple, with the idea that wetland types, sizes or configurations could be adjusted in the future. In order to simplify the optimization process, only two wetland types (creation and enhancement), and three wetland sizes (small, medium, large), resulting in six unique types, were included in the study. In addition, each wetland was assumed to have a simple square shape. Key configuration parameters for each wetland type are specified (Table 4-1) based on best professional judgment, observation of existing wetlands in the Santa Rosa area, and previous experience. These design configurations remained unchanged throughout the optimization process. Thus, the decision variables were defined as the number of each wetland type. As such, the configuration of each wetland type will affect its performance and how they are utilized during the optimization process.

Table 4-1. Wetland restoration project types, size, and design

Wetland type	Size (acre)	Width (ft)	Length (ft)	Depth (ft)
Creation Small	0.2	29	29	1
Creation Medium	1.0	209	209	2
Creation Large	10	660	660	3
Enhance Small	0.2	29	29	1
Enhance Medium	1.0	209	209	2
Enhance Large	10.0	660	660	3

4.1.3 Wetland Cost

Wetland cost information was collated from published peer reviewed studies (King and Bohlen 1994, Baca et al. 1994, Zentner et al. 2003, Steere 2004). In general, only limited cost information is published in the literature. Furthermore, the available information indicates a wide variation for wetland creation and restoration, in relation to site specific characteristics, design configurations, and other local conditions and constraints such as socioeconomics. The cost for wetland projects ranges from $10,000/acre to $170,000/acre, with an average cost of about $40,000/acre. Enhancement of an existing wetland is much cheaper (by a factor of three) than creation of a new wetland. Based on this information, the project team assumed a cost for wetland creation of $40,000/acre, and a cost of wetland enhancement of $14,000/acre for this study. The literature also described a nonlinear relationship between the cost and size of wetland projects (King and Bohlen, 1994), which indicates that increasing a project by 10% in size will result in a 3.4% decrease in cost per acre. This relationship was used to derive the cost for different sizes of wetlands (Table 4-2). Thus, for any wetland scenario generated during the optimization process, the total cost was calculated as the sum of the number of each wetland type multiplying the cost of that wetland type.

Table 4-2. Wetland restoration project costs

Wetland Type	Size (acres)	Cost ($)
Creation Small	0.2	12,000
Creation Medium	1.0	40,000
Creation Large	10	264,000
Enhance Small	0.2	4,200
Enhance Medium	1.0	14,000
Enhance Large	10	140,000

4.1.4 Constraints on wetland locations

For each wetland type, the number of possible sites was constrained by the maximum number of feasible sites identified on the basis of suitability criteria through the Site Locator Tool (Table 4-3). This constraint will confine the possible selection of wetland types and numbers within each sub-basin in the optimization process. Within each sub-basin, the number of possible sites for different wetland types listed in Table 4-3 are mutually exclusive, and the optimization process will determine which ones to pick based on their performance and cost.

Depending on the ratio of wetland surface area to its contributing drainage area, the total area that can be treated by wetland projects within each sub-basin also imposed implicit constraints on how many wetland projects are possible for any given sub-basin. Literature review shows a range of suggested values from 1% to all the way up to 15% (Mitsch and Gosselink 2000,White and Fennessey 2005, Scholz 2011)**.** Different states also have different guidance, with both Maryland and Virginia suggesting a ratio of 3%, Washington 2%, and Texas 5-10% (Virginia DCR 2011, Texas A&M Agrilife Extension 2017). Based on these information, a relatively conservative ratio of 5% was used for this study. During the optimization process, the combined numbers of wetland projects are forced to be less or equal to the maximum numbers that are calculated by applying this 5% ratio.

4. 2 Optimization Problem Formulation

For this study, the objectives of the optimization problem were to: 1) minimize the total cost of wetland projects; and 2) maximize the total flow reduction at the outlet of the Lower Santa Rosa Creek watershed. The total flow was chosen as the optimization object because nutrient loads are primarily reduced through retaining and infiltrating stormwater runoff. However, nitrogen or phosphate loads could be used as the optimization objective if so desired.

In the optimization, because wetland design (size, shape, depth) remains intact, the decision variable was simply the number of wetlands of each type. For each applicable wetland type, the decision variables ranged from zero (meaning no wetlands would be created or enhanced) to a maximum number of potential sites as shown in Table 4-3.

Table 4-3. Maximum number of possible depressional wetland restoration projects that fit into each sub-basin (Basin#) for each type/size of project.

Basin#	Creation Small	Creation Med	Creation Large	Ehancement Small	Ehancement Med	Ehancement Large
S1	49	0	0	0	0	0
S2	331	5	0	0	0	0
S3	138	2	0	0	0	0
S4	22	0	0	0	0	0
S5	1927	33	0	0	0	0
S6	394	6	0	0	0	0
S7	155	0	0	0	0	0
S8	232	1	0	0	0	0
S9	417	5	0	0	0	0
S10	4475	82	3	0	0	0
S11	423	5	0	40	0	0
S12	9640	174	8	63	1	0
S13	9066	151	6	0	0	0
S14	168	1	0	0	0	0
S15	1109	14	0	280	5	0
S16	612	10	0	584	11	1
S17	332	5	0	0	0	0
S18	176	2	0	0	0	0
S19	31	0	0	0	0	0
S20	62	0	0	0	0	0
S21	48	0	0	0	0	0
S23	0	0	0	0	0	0
S24	172	3	0	0	0	0
S25	740	11	0	0	0	0
S26	15	0	0	0	0	0
S27	174	3	0	0	0	0
S28	730	14	0	0	0	0
S29	121	1	0	0	0	0
S30	376	7	0	41	0	0
S31	562	10	0	228	4	0
S33	4516	86	7	165	3	0
S34	6212	107	5	297	5	0
S35	8233	152	11	1660	31	3

The optimization operational parameters, including population size, number of generations, crossover and mutation rates, define the search algorithm and have great impact on optimization results. The final decision on these parameters were made on the basis of literature values (Deb et al., 2002) and consideration for the optimization problem complexity and model run time. Several combinations of different population size and number of generations were also tested to identify the optimal parameter values. In the end, the parameters were set with number of generation = 200, population size =100, crossover probability=0.9 and mutation probability =0.1.

4.3 Optimization Results and Discussion

4.3.1 Cost-effectiveness Curve

The optimization process outputs a range of optimal watershed planning solutions along a cost-effectiveness curve. The curve relates the levels of flow or pollutant reduction to various combinations of wetland restoration projects (total number and type) throughout the watershed and their associated, combined cost. Figure 4-2 illustrates the optimal trade-off between project cost and stormwater volume reduction. All individual watershed solutions are plotted together (each solution shown as an individual dot), with the *optimum solutions* forming the left- and upper-most boundary of the search domain (the upper edge of the curve). Each point along the cost-effectiveness curve represents a unique combination of wetland restoration projects (creation or enhancement, small, medium, and large) across the study area. Although the goal of this optimization run was to optimize for flow reduction versus wetland restoration project costs, nutrient loads are also reduced as a result of the flow reduction. Separate cost-effectiveness curves were plotted as ancillary results of the optimization (Figure 4-3, Figure 4-4).

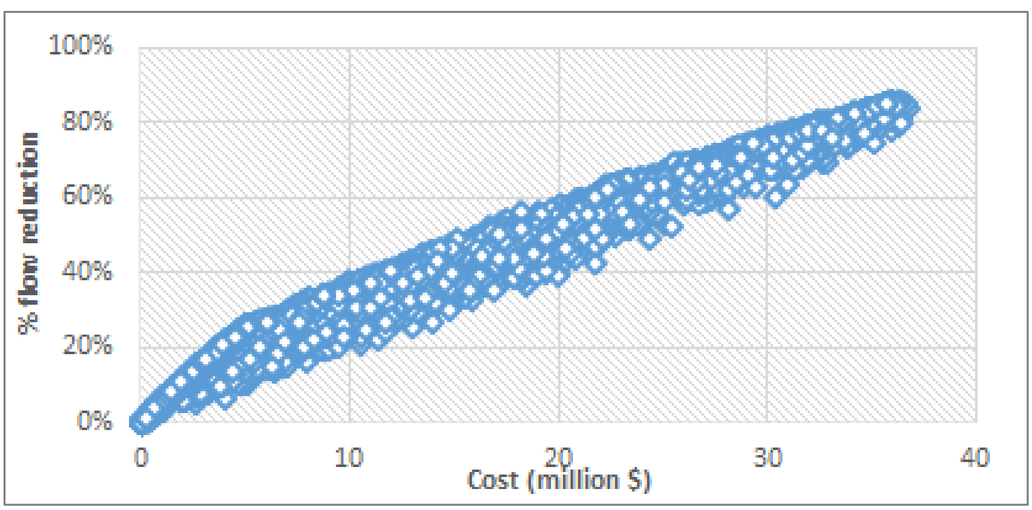

Figure 4-2. Flow cost-effectiveness curve

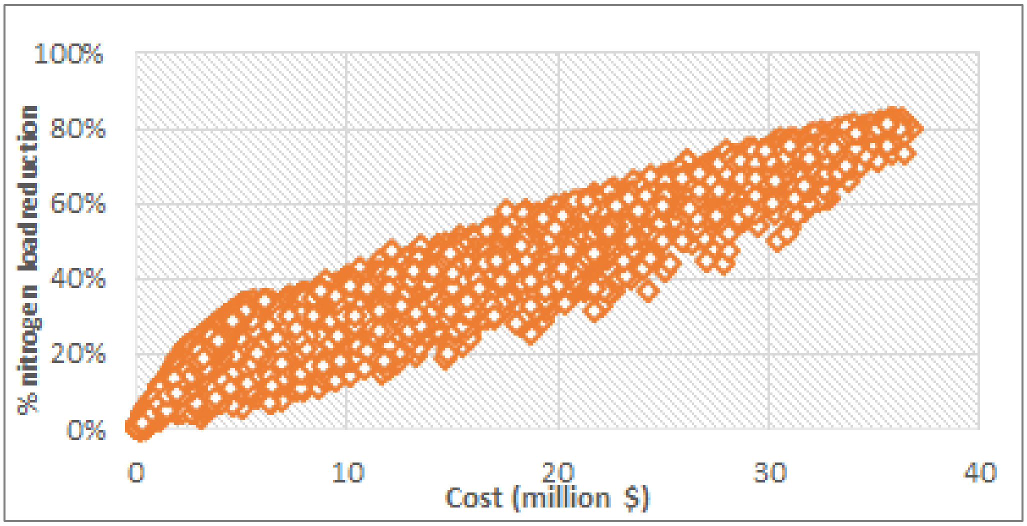

Figure 4-3. Nitrogen load cost-effectiveness curve.

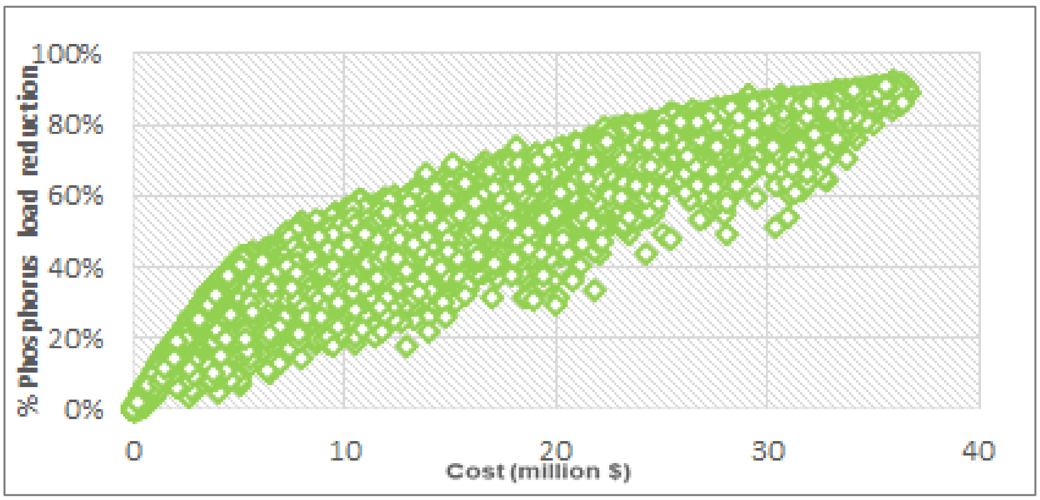

Figure 4-4. Phosphorus load cost-effectiveness curve.

The cost-effectiveness curve for flow suggests a relatively linear relationship between level of implementation (represented as total cost) and runoff volume reduction after about $5 million in cost (Figure 4-2). The maximum achievable runoff volume reduction at the outlet of the watershed, given the objectives and constraints associated with the study is approximately 90% (at a cost of about $37 million). The range of solutions is also tight, due to the comparatively homogeneous nature of runoff production in the study area. These solutions, however, become more widely spread when plotted for nitrogen and phosphorus load reductions (Figures 4-3, 4-4), because of a relatively large variation in nutrient load generation across the watershed.

At the same level of cost (say $10 million), the percentage removal could vary as much as 20% for flow, 30% for nitrogen, and 40% for phosphorus. Similarly, for the same level of reduction in flow (say 40%), the difference in total cost could be well over $10 million between an optimal solution and a non-optimal solution. This highlights the need and benefit of using an optimization approach to help identify the most cost-effective watershed based wetland restoration planning solutions for achieving flow and water-quality improvement.

The slope of the optimal frontier in Figures 4-2 to 4-4 represents the marginal value of wetland projects, and the decreasing slope of the frontier, after the first $5 million, indicates diminishing marginal returns associated with increasing the number of wetland projects - as reflected in the increasing cost. For example, a 40% flow reduction efficiency can be achieved with about $10 million dollars, but only 20% additional flow reduction can be expected for the next $10 million dollar investment. This makes sense given the fact that runoff is not uniform across the landscape. After treating the 'hotspot' areas, subsequent implementation of wetland projects will become less efficient, resulting in higher cost per unit water volume treated. With the help of this information, decision makers can set realistic goals on how much flow or load reduction might be achieved and the level of investment required, as well as determine at what point further investment will become less desirable as the marginal benefit decreases.

4.3.2 Example scenario – 40% flow reduction

The optimal combination of wetland restoration project types and numbers for any user-defined reduction goals can be examined to gain insight into the reasoning and order for selecting individual projects. In this example, one optimal scenario with a goal of 40% flow reduction was selected (one dot in Figure 4-2). The optimal solution consists of a total of 1,006 wetland projects, including 519 enhancement wetlands and 487 creation wetlands. This combination of depressional wetland projects should reduce nitrogen loads by 43% and phosphorus loads by 60%, as a result of the 40% flow reduction (Figures 4-2, 4-3, and 4-4, respectively).

The percent utilization of each wetland type is quantified (Figure 4-5). For this solution, enhanced small wetland project areas are the dominant wetland type and account for about 50% of total wetlands identified, followed by creation small that account for 40%. This result is somewhat surprising as the large, downstream wetlands are expected to be more effective based on the HSPF simulation. However, the selection of each wetland type is determined by the combined factors of wetland representation, unit cost, and constraints. For this study, it appears that the number of feasible locations (constraints) played a big role in the wetland selection. While large wetlands (both enhancement and creation) may be more cost effective in retaining stormwater runoff, the number of feasible locations is very small (Table 4-3), and so are the areas available for treatment within the sub-basins where large wetlands are feasible. These two factors severely limited their chance of being selected, especially when the required drainage area for large wetlands are not available. On the other hand, there are large numbers of potential small wetland areas available which treat small drainage areas and have a low cost, making it easy for them to be selected without many constraints.

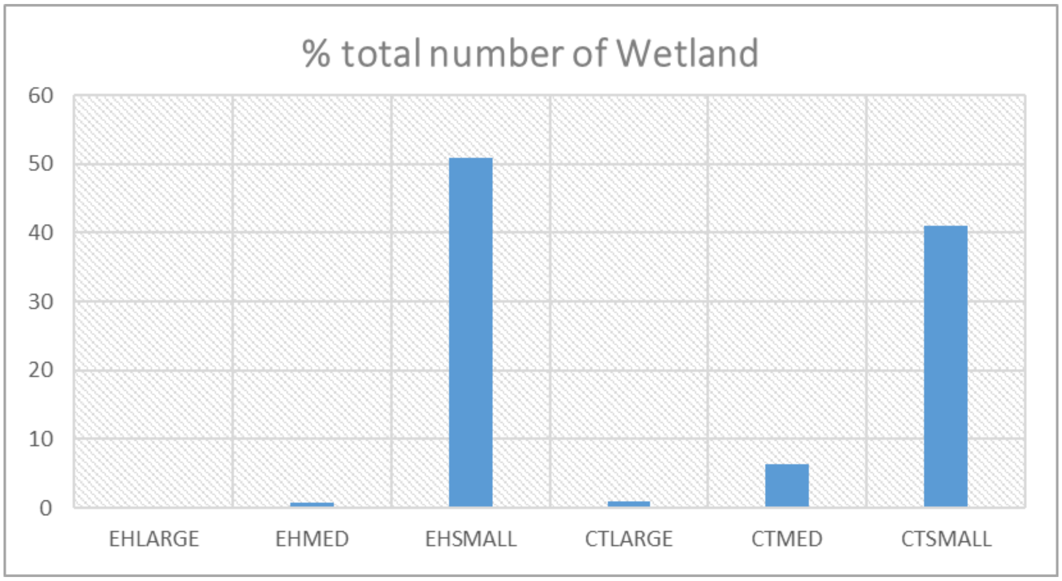

Figure 4-5. Percentage of each wetland type selected for 40% reduction solution.

The percent utilization of each wetland type can also be evaluated in terms of area treated (Figure 4-6). While enhancement small accounts for 50% of all wetland selected for the 40% flow reduction solution, it treated less than 30% of total available areas. Creation large, which accounts for only 1% of selected wetlands, treated 28% of the available area. Creation small treated 23% of the total available area even though it accounts for 40% of selected wetlands.

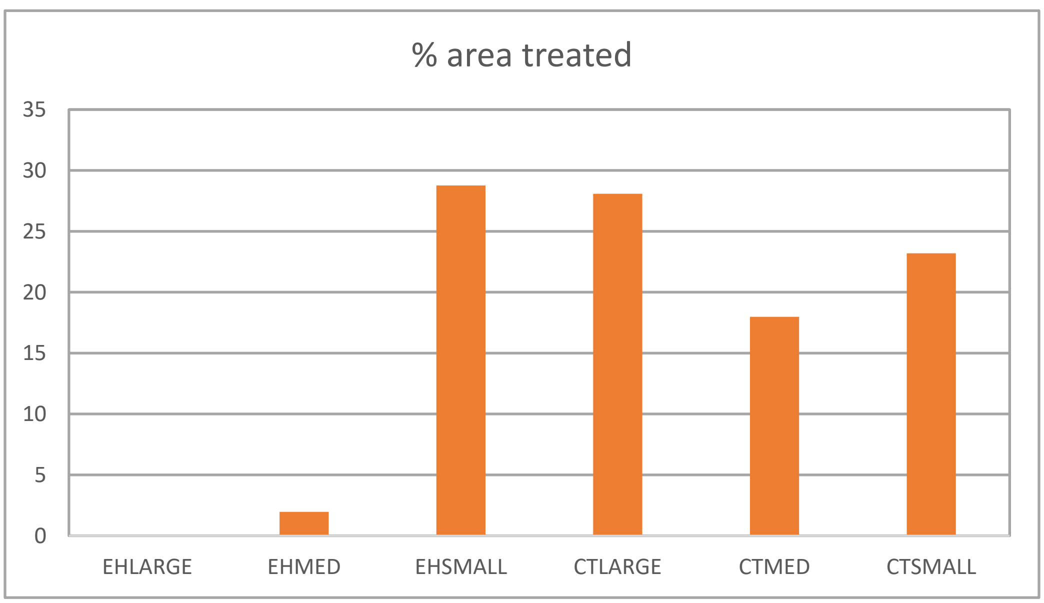

Figure 4-6. Percentage of area treated by each wetland type for 40% reduction solution.

Wetland utilization results can be mapped by sub-basin to gain insight into the optimal spatial placement of these practices derived under the defined objective and constraints. Figure 4-7 shows the number of wetlands identified in each sub-basin for the 40% flow reduction scenario. Note that the total number of wetlands identified are dependent on the unit size used for each wetland type and the optimal solutions will be different in wetland numbers and compositions if a different design for any wetland type is used.

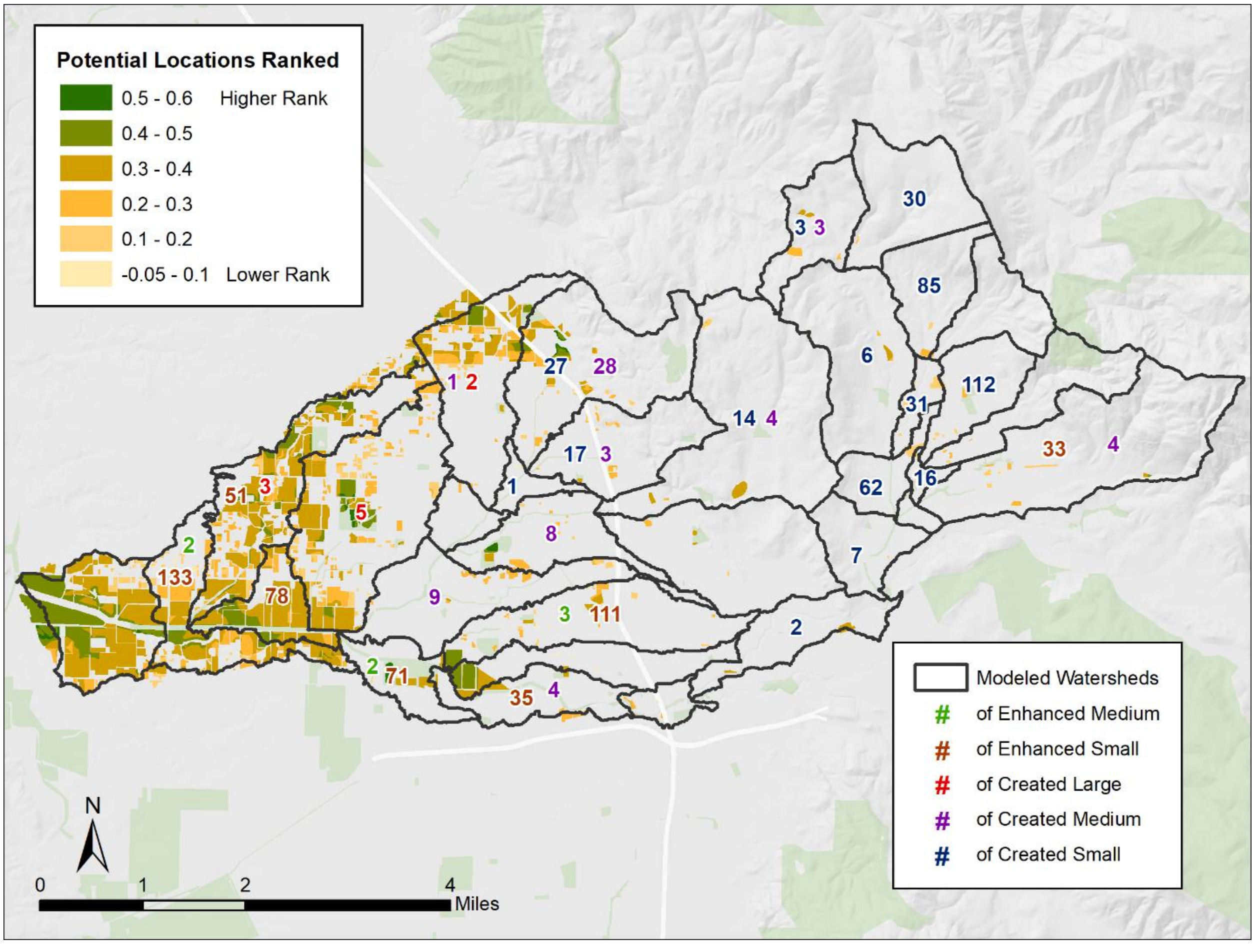

Figure 4-7. Map of the example optimal scenario for 40% flow reduction costing $12 million. The colored numbers represent the number of restoration projects (by type and size) required in each sub-basin to achieve the 40% flow reduction goal.

It is important to emphasize that the optimization results must be interpreted in the context of specific problem formulation, assumptions, constraints, and optimization goals unique to this case study. Within the optimization process, the selection of wetlands is determined by the combined factors of cost, performance (configuration), and constraints. Changing any of these will change how each wetland type is utilized for any given solutions. For example, if the optimization target was designed as reducing nitrogen loads instead of total runoff volume, the optimization might have resulted in a completely different set of solutions in terms of wetland selection, distribution, and cost. It also should be noted that because of the large variation and uncertainty associated with unit wetland cost information, the total relative cost associated with various reduction goals calculated from the unit cost do not necessarily represent the true cost of an optimum solution for the basin evaluated and are not transferable to other basins. Rather, these costs should be interpreted as a common basis to evaluate and compare the relative performance of different wetland scenarios.

4.3.3 Prioritize management actions

The optimal solutions identified the number of wetland projects at sub-basin level without specifying the actual locations of specific wetland restoration projects. To help prioritize management actions, one can work at a sub-basin level to identify and evaluate potential wetland restoration areas based on their ranking assigned by the Site Locator Tool, once a reduction goal is set (e.g. 40% flow reduction by 2030).

For instance, in assuming that a 40% flow reduction goal has been set, take Sub-basin 12 as an example of the number of wetlands needed in this sub-basin to achieve the goal. A total of 51 small enhancement wetlands and 3 large creation wetlands are needed to achieve the overall flow reduction goal. For the large creation wetland type, there are 8 potential areas in this sub-basin, each with its own ranking. Managers could begin with field visits to evaluate the highest ranking large wetland areas to evaluate their potential suitability. If one potential location is not suitable, the manager could continue down the ranked list, until the best three locations are identified. A similar process could be applied for selecting the best small enhancement wetland project areas within the sub-basin, as well as selecting sites in other sub-basins based on the optimal solution.

Besides these rankings, other factors that were not included in the GIS-based Site Locator Tool rankings and cost-benefit analysis, such as funding opportunities, public-private partnership, can also be taken into account in evaluating restoration project site suitability. This process allows for the best wetland restoration areas that reflect local priorities and management goals to be identified, providing a guide for the restoration planning in the watershed.

5. SUMMARY

GreenPlan-IT is a planning level tool that can be used to support wetland restoration planning in a watershed context for multiple benefits including runoff and pollutant load reduction. The Site Locator Tool ranks potential wetland restoration project areas based on multiple regional and/or ecological priorities and helps identify the most promising areas for restoration. The cost-benefit Optimization Tool helps focus in on regions (sub-basins) where wetland restoration could have the most impact on runoff and nutrient load reductions. The outputs of the GreenPlan-IT applications provide decision makers with important information regarding tradeoffs among competing objectives and help plan and prioritize wetland restoration effort. The watershed approach is particularly advantageous in that it helps develop more comprehensive wetland restoration plans that take into account the physical interaction and dynamic processes occurring within a watershed.

As illustrated by this demonstration, the Optimization Tool can be very powerful when combined with hydrologic modeling and cost analysis. Successful and meaningful application of the Optimization Tool largely depends on accurate representation of the watershed baseline condition, wetland configurations, and the associated wetland restoration costs. As such, it is important to emphasize that the optimization results must be interpreted in the context of specific problem formulation, assumptions, constraints, and optimization goals unique to this demonstration. It also should be noted that because of the large variation and uncertainty associated with wetland restoration cost, the total cost associated with various reduction goals do not necessarily represent the true cost of an optimum solution. Rather, these costs should be interpreted as a common basis to evaluate and compare the relative performance of different wetland restoration scenarios.

6. REFERENCES

Baca, B., Florey, S., King, D., and Bohlen, C., 1994. Economic Analyses of Wetlands Mitigation Projects in the Southeastern US. Report prepared for the Maryland International Institute for Ecological Economics. http://images.library.wisc.edu/EcoNatRes/EFacs/Wetlands/Wetlands21/reference/econatres.wetlands21.bbaca.pdf

Deb, K., Pratap, A., Agarwal, S., and Meyarivan, T., 2002. A fast and elitist multiobjective genetic algorithm: NSGA-II, IEEE Transactions on Evolutionary Computation, 6(2) (2002) 182-197. http://vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec13CONSTRUCTEDWETLAND.html

King, D.M., and Bohlen, C.C., 1994. A Technical Summary of Wetland Restoration Costs in the Continental United States. University of Maryland, CEES Technical Report UMCEES-CBL-94-048, April 1994.

Mitsch, W.J., and Gosselink, J.G., 2000. The value of wetlands: importance of scale and landscape setting. Ecological Economics, v. 35, pp. 25-33.

Scholz, M., 2010. Wetland Systems: Storm Water Management Control. Springer Science and Business Media, 235 pp.

SFEI, 2017. Simulating Wetland Assimilation Capacity in the Lower Santa Rosa Creek Watershed Pilot Demonstration Area Using the HSPF Model. Technical memo prepared by the San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA. SWRCB STD Agreement Number: 15-021-250-1.

Steere, J., 2004. Estimating Wetland Restoration Costs at an Urban and Regional Scale: The San Francisco Bay Estuary Example. Proceedings of the Salmon Habitat Restoration Cost Workshop. http://www.st.nmfs.noaa.gov/st5/Salmon_Workshop/23_Steere.pdf.

Texas A&M Agrilife Extension, 2017. Texas Community Watershed Partners. Accessed 10/1/17. http://tcwp.tamu.edu/stormwater/wetlands/design/

US EPA, 1999. Storm Water Technology Fact Sheet: Storm Water Wetlands. United States Environmental Protection Agency, Office of Water, Washington, D.C. EPA 832-F-99-025.

Virginia DCR. 2011. Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands, version 1.8. Accessed 10/1/17. http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_13_CONSTRUCTED_WETLAND_Final_Draft_v1-8_04132010.htm

Virginia Department of Environmental Quality, 2011. Constructed Wetlands. Virginia DEQ Stormwater Design Specification No 13. Version 1.9

White, D., and Fennessey, S., 2005. Modeling the suitability of wetland restoration potential at the watershed scale. Ecological Engineering, v. 24, pp. 359-377.

Zentner, J., Glaspy, J., and Schenk, D., 2003. Wetland and Riparian Woodland Restoration Costs. Ecological Restoration, v. 21, no. 3. https://www.researchgate.net/publication/250231092_Wetland_and_Riparian_Woodland_Restoration_Costs.