ESTIMATING THE POTENTIAL BENEFITS OF MANAGED AQUIFER RECHARGE TO STORMWATER MANAGEMENT IN THE SOLANO SUBBASIN

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OVERVIEW

Managed Aquifer Recharge (MAR) is a practice that retains water on agricultural fields or within infiltration basins to allow water to infiltrate into the ground and replenish the groundwater system. This practice provides multiple benefits, including benefits to groundwater dependent ecosystems that rely on access to shallow groundwater. MAR can also provide a co-benefit for stormwater management by reducing runoff, thereby helping to reduce peak stormwater flows that can contribute to flooding events. In the Solano Subbasin, there are numerous opportunities to capture and utilize surplus stormwater to reduce localized flooding in conjunction with strategic groundwater recharge on agricultural fields.

Purpose

The purpose of this analysis is to quantify the benefit of MAR in mitigating the peak flow or duration of stormwater flows that have historically affected or could in the future affect various agricultural areas in the Solano Subbasin. The objectives are as follows:

1. Objective 1. Estimate the potential stormwater benefits from using MAR on agricultural fields in flood-prone areas around the Northwest Focus Area of the Solano Subbasin
2. Objective 2. Assess the potential for MAR to contribute to regional plans for reducing stormwater issues in the Tremont 3 watershed (north and east of the City of Dixon area)

Background

Groundwater management. The Solano Subbasin Groundwater Sustainability Plan (GSP) contains Project and Management Actions (PMAs) that recommend assessing the use of MAR in areas with localized groundwater decline in the northern portion of the Subbasin (LSCE Team, 2021). These PMAs are intended to provide groundwater sustainability agencies (GSAs) with the tools to prevent or reverse localized groundwater decline in the face of future uncertainty, and thereby prevent undesirable outcomes and maintain groundwater sustainability in the Subbasin. The PMAs focus on two actions (LSCE Team, 2021, GSP Chapter 8):

- using “Flood-MAR” in the Westside Streams area--west of Highway 505 and north and west of the City of Vacaville–to divert surplus winter stormwater flows onto fields for infiltration
- using “Rain-MAR” in the Northwest Focus Area to retain precipitation from large storm events on fields (or in sumps at the lower edge of fields) to increase infiltration[1]

[1] As described in the Solano GSP, Flood-MAR involves a grower diverting a portion of stormflows from a nearby stream to flood their fields, thereby supplying surplus water for direct groundwater recharge to the aquifer. “Rain-MAR”—a term coined by TFT—refers to a variation of MAR in which a grower installs a temporary earthen berm at the field edge to retain precipitation runoff on the field, or constructs a sump at the low edge of the field to gather precipitation runoff, for direct groundwater recharge to the aquifer.

Stormwater management. The use of MAR on agricultural fields can potentially provide a benefit to local stormwater management. By diverting surplus flows from channels during storm events, or capturing precipitation that would otherwise become runoff, MAR has the potential to reduce the volume of water that accumulates in flood-prone areas and agricultural drains.

There is a long history of stormwater management issues in the northern portion of the Subbasin, especially around the City of Dixon. In 2001, the City of Dixon, Dixon RCD, Maine Prairie Water District, and Reclamation District No. 2068 initiated the Dixon Watershed Management Plan, a cooperative to develop drainage projects that provide adequate outfall capacity for the City's three drainage systems while reducing flooding in downstream agricultural areas. In parallel, plans have been underway for development projects in the City of Dixon's Northeast Quadrant and the County's Agricultural Industrial Services Area, situated between Highway 80 and the rail lines (Figure 6).

The Tremont 3 watershed encompasses much of Dixon's existing footprint, as well as the proposed development zones, and surrounding agricultural areas. In the lower Tremont 3 watershed, the Dixon Resource Conservation District (RCD) and Reclamation District 2068 manage agricultural drainage systems that receive stormwater flows from these areas. The design for the Tremont 3 drain—which carries water from Dixon RCD to Reclamation District 2086's main canal—did not incorporate flow from the large agricultural area in the upper portion of the watershed. This, combined with subsequent land use intensification in the City, has contributed to persistent drainage and flooding issues downstream in the lower watershed (West Yost, 2004). Drainage is governed by discharge agreements, with discharge from the Northeast Quadrant limited to 23.1 - 37.2 cfs depending on the magnitude of storm event, and discharge from Dixon RCD's main drain to Reclamation District 2068's main canal limited to 120 cfs at "Point A," the distal end of the Tremont 3 watershed, (West Yost, 2019, "Discharge Limit Summary"). Local stormwater management agencies have a mutual interest in reducing discharge in these drainage systems during storm events.

In 2002, the Dixon RCD and Moorhead Engineering began analyzing potential strategies to reduce stormwater runoff from the agricultural area in the upper Tremont 3 watershed. The Moorhead study proposed re-purposing tailwater return ponds or constructing new detention basins on the edge of farm fields to capture runoff and reduce peak flows during storm events. (Dixon RCD, 2002; West Yost, 2012). In 2019, West Yost Associates updated the hydrologic and hydraulic model for the Tremont 3 watershed and prepared design-storm rainfall data (used in the present study). However, to date, the proposed distributed stormwater detention strategy has not been implemented. One of the objectives of this study is to analyze the potential for MAR to reduce stormwater discharge from the upper Tremont 3 watershed, and thereby help alleviate drainage issues in the Dixon area and in the agricultural drains in the lower watershed.

METHODS

Approach

This analysis complements the MAR analysis in the Solano Subbasin GSP (LSCE Team, 2021; Chapter 8) by focusing on agricultural fields in the vicinity of the Northwest Focus Area. These fields are identified as being suitable for MAR and drain to flood-prone areas or areas of concern to local stormwater management agencies.

The overall approach included:

- identification of areas of concern for stormwater management that are hydrologically connected to the Northwest Focus Area,
- mapping MAR-suitable agricultural fields within catchments upstream from those areas, and
- calculation of the potential cumulative effect on stormwater runoff if MAR practices were broadly adopted in those catchments.

Figure 1 shows the overall approach to assessing the potential stormwater benefits from MAR. As discussed further below, the primary linkage between potential MAR sites and flood-prone areas occurs in the eastern portion of the Northwest Focus Area and in the vicinity of Dixon, where stormwater runoff from fields discharges into drainage infrastructure with insufficient capacity. Therefore, this analysis focuses on Rain-MAR in the watersheds around Dixon (i.e., the left and center branches of the decision tree).

Figure 1. Decision tree for assessing potential stormwater reduction from MAR

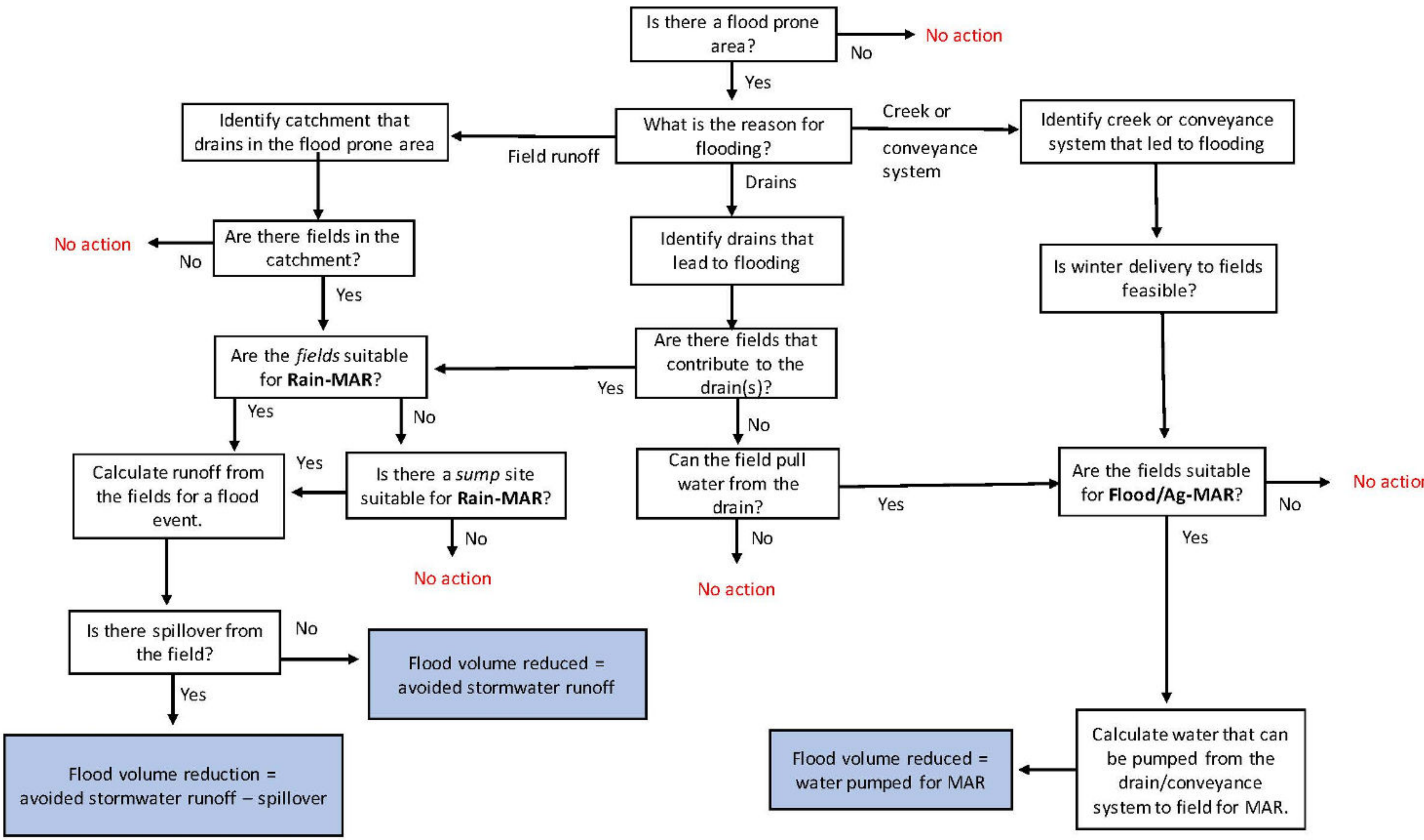


Figure 2. Areas of interest (AOIs) and stormwater management features.

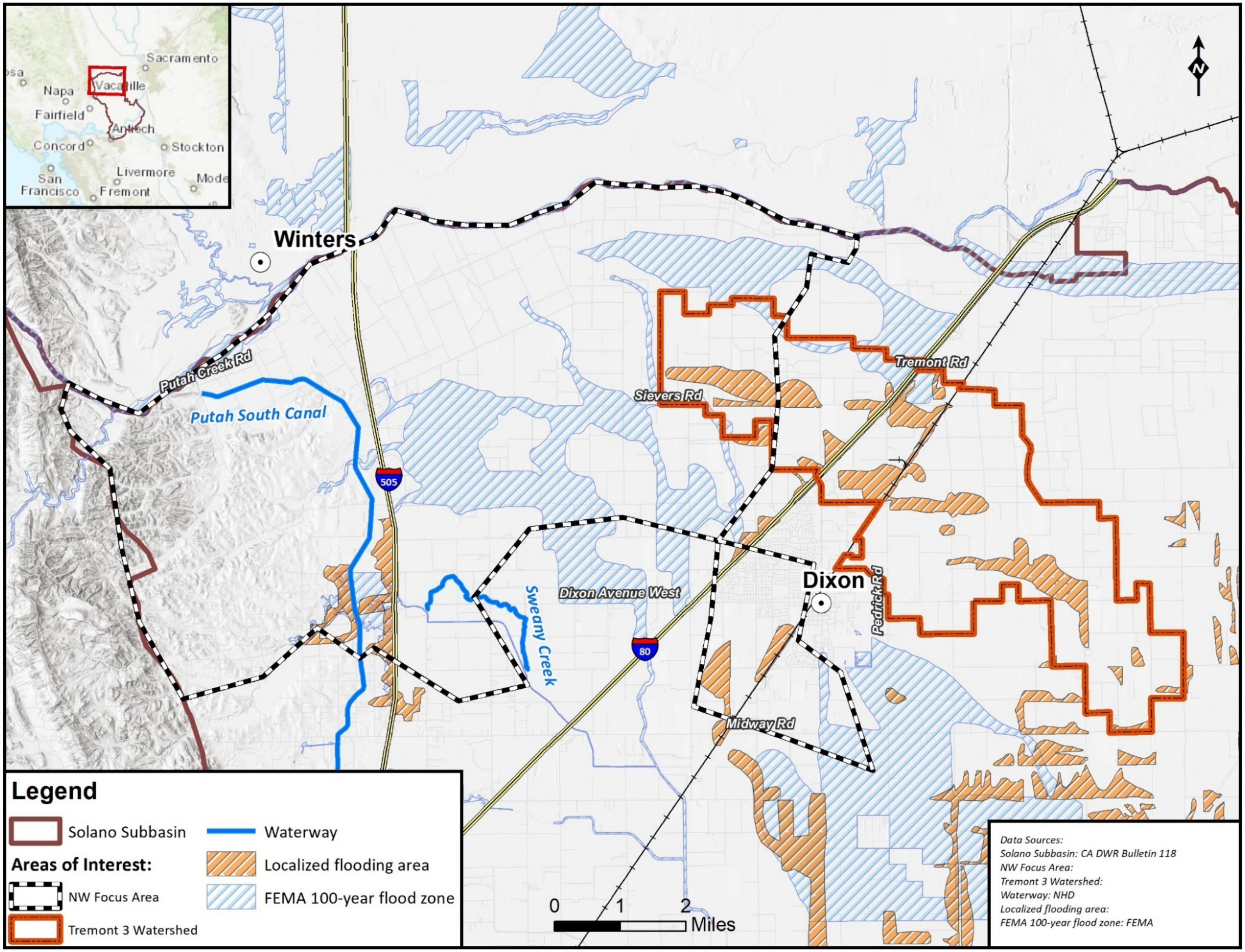
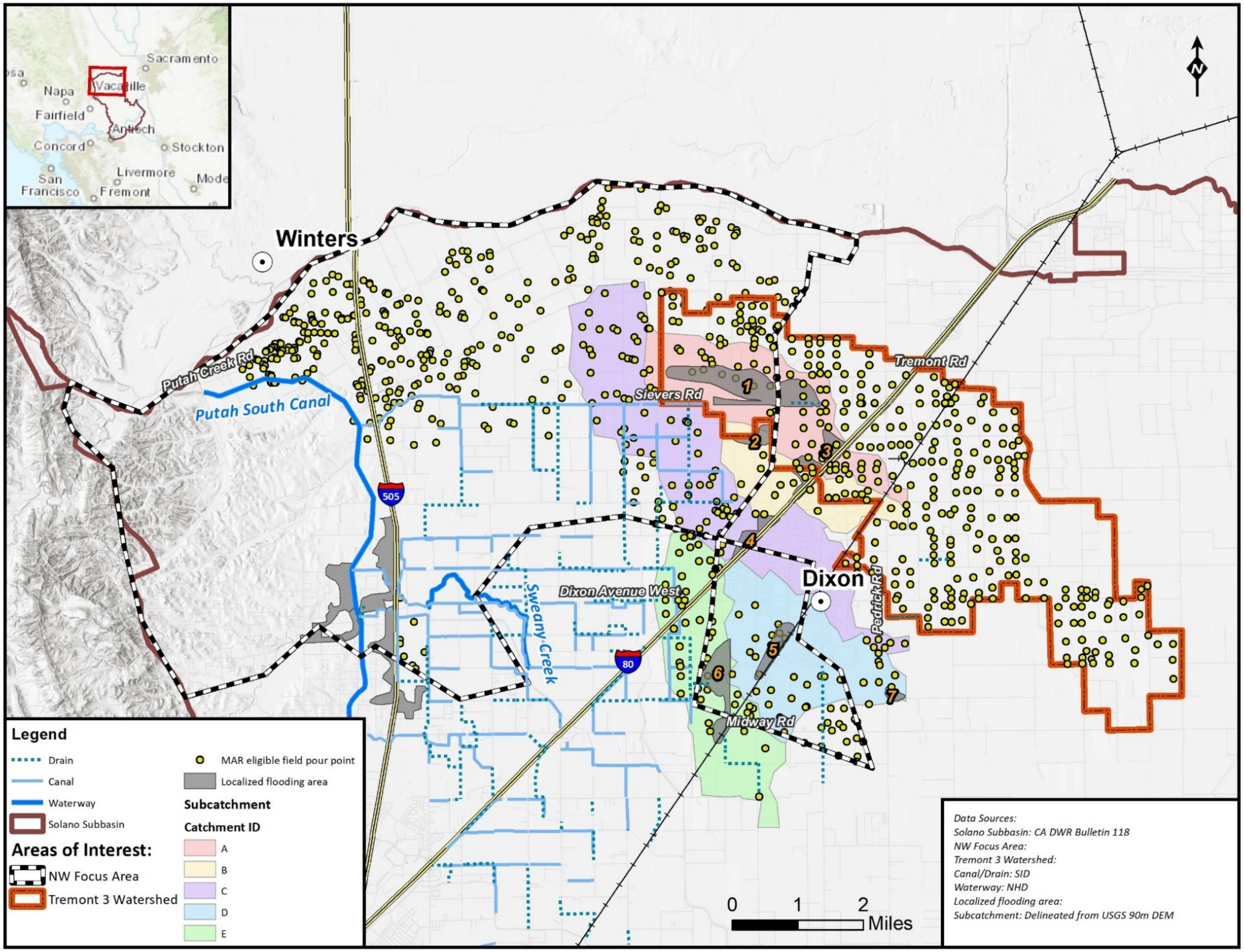


Figure 3. Catchments, field outlets, and channels.



Data inputs

Areas of Interest. The Areas of Interest (AOIs) for this analysis include the easterly portion of the Northwest Focus Area and the Tremont 3 watershed (Figure 2). Within these AOIs, flood-prone areas and important drainage sites were identified and linked to MAR-suitable agricultural fields. These were linked by delineating smaller catchments within the AOI that drain into each flood-prone area or drainage site. The catchments were delineated using a 90m Data Elevation Model ([DEM] USGS, 2016) in ESRI ArcGIS. The DEM layer was pre-processed to remove local sinks, then a flow direction and flow accumulation grids were created. Based on flow accumulation, "pour points" at the outlet of each field were delineated and raster converted to catchment polygons (Figure 3).

Flood-prone areas. Two potential data sources were considered for flood prone areas: local data prepared by West Yost Associates for watershed management planning and data from Federal Emergency Management Agency (FEMA) 100-year flood maps. The local watershed planning data delineates known flood locations using records from major flood events in the winter of 1997. The empirically known flooding sites from the watershed management plan and the FEMA 100-year flood map data do not overlap (Figure 4). For purposes of analyzing the potential flood reduction benefits of MAR, the flood-prone areas defined in the watershed management planning data were selected, along with the surrounding catchment areas.

Canals and drainage channels. Due to variable levels of detail of the drainage network in the region, this analysis only considers natural stormwater drainage paths to link the fields to flood-prone areas. However, there is a possibility of water being routed from outside the catchment or study area, especially in low gradient topography such as the Northwest Focus Area. Many of the stormwater issues of local concern occur in the urbanized areas around the Cities of Dixon and Vacaville, while a substantial proportion of MAR-suitable fields are situated in the northwestern portion of the Northwest Focus Area. An important consideration for linking flood-prone areas to potential MAR sites is whether agricultural channels convey stormwater flows across natural stormwater drainage paths. To investigate this, TFT interviewed engineering and operations staff at Solano Irrigation District (SID), which provided the following information on its infrastructure:

- SID's highline canals, which include the main canals, laterals, and sub-laterals that deliver water to fields, are at a higher elevation than fields. Storm water generally will not enter these, except in the largest storm events. Under most conditions, subdrainage boundaries from the DEM are likely to be reasonably accurate on the broad scale.
- The drainage system is designed to remove irrigation runoff (tailwater). These drains also convey stormwater runoff from fields during winter storms. Capturing these flows with sumps or berms (via MAR) would potentially reduce peak flows in the drainage network.
- There are several dozen points in SID's network where the drainage network discharges to local creeks. These may influence where water accumulates within sub-drainages. SID is planning to

digitize the drain discharge points using its drain shapefile and aerial imagery of creeks within SID's GSA boundary; however, drainage files have not been digitized yet.[2]

Based on the evaluation of the DEM and drainage networks, and consideration of information from SID, there is limited west-to-east routing of stormwater flow. Therefore, this analysis focuses on catchments and flood-prone sites situated in the agricultural areas around Dixon.

MAR practices. For the Solano GSP, TFT developed a python-based model using various data inputs to assess the suitability of MAR on agricultural fields in the Solano Subbasin and estimate the infiltration volume that would result from MAR on those fields. In that analysis, TFT's considered two forms of MAR: one using berms to retain precipitation runoff on the cropped portion of a field for infiltration, the other using sumps to gather precipitation runoff at the low end of a field for infiltration. The methods for this analysis are documented in the Appendix 8b of the GSP (TFT, 2021). In the present analysis, all of MAR-suitable fields in the area of interest were best suited to using sumps, therefore, all calculations of stormwater benefit in this analysis assume the use of Rain-MAR with sumps.

Modeled storm events. In TFT's analysis for the Solano GSP, the calculation of infiltration volumes is based on California Department of Water Resources (DWR) water years, using average precipitation to estimate potential infiltration across the winter season. An analysis of the effect of MAR on stormwater runoff needs to be conducted based on discrete rainfall events. Therefore, for this analysis, the MAR infiltration model was re-configured using a set of hypothetical storm events to assess the influence of MAR on peak stormwater runoff under various soil moisture conditions.

The modeled storm events included a 1-year return rainfall taken from the National Oceanic Atmospheric Administration's (NOAA's) Precipitation Frequency Data Server (PFDS) for the Dixon area and 10- and 100-year rainfall events developed for the Dixon Watershed Management Plan (West Yost Associates, 2019; Addendum). The values used for these storm events are shown in Table 1 below.

Table 1: Rainfall events used in stormwater runoff analysis

Year	Total Acreage Reported	Gravity Acreage
1	1	2.0
10	1	3.23
10	4	5.27
100	1	4.58
100	4	7.75

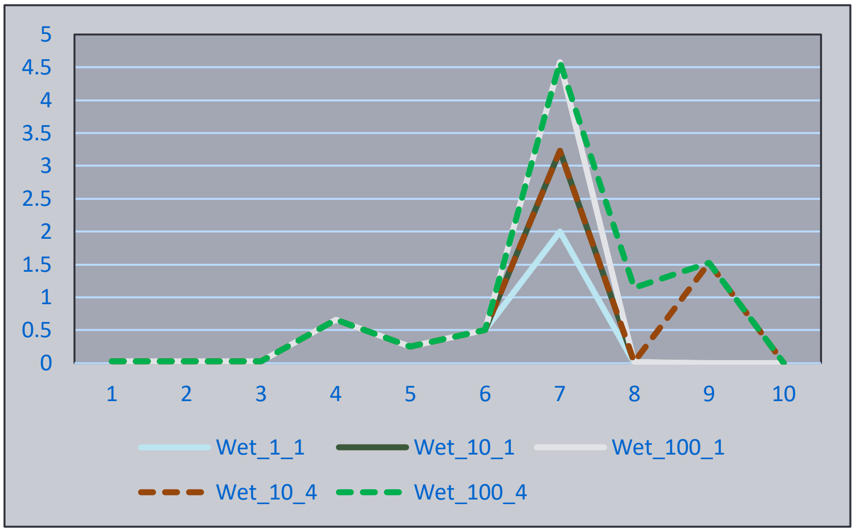
Soil moisture. Soil moisture influences the capacity of a site to infiltrate water and, thereby, the likelihood for the site to produce runoff during a storm event. To account for this, the hydrological model was configured to run two scenarios to simulate dry and wet soil conditions for a 10-day period surrounding the modeled storm event. For the 'dry' scenario, the initial days had zero rainfall followed by

[2] Santana, Gerardo, and Stuart Chaney. 2022. Personal Communication, Solano Irrigation District, Assistant Engineer and Agricultural Operations Supervisor, January 19, 2022.

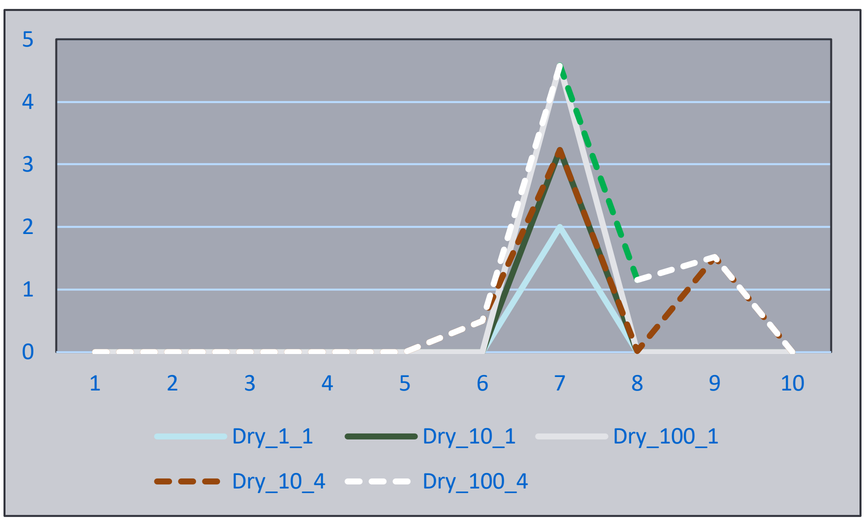
a storm event on the 7th day (for 1-day duration) and the 6th to 9th days (for a 4-day duration) followed by dry day(s). For the 'wet' scenario, the initial days were run with low intensity rainfall followed by a storm event, like 'dry' scenario. The time series of 10-day rainfall forcing to the model is shown in Figure 4.

Figure 4: Modeled precipitation ten days prior to MAR action

Curves used to estimate soil moisture conditions for MAR analysis.



a. Modeled precipitation for wet soil conditions preceding MAR



b. Modeled precipitation for dry soil conditions preceding MAR

Analysis

Avoided stormwater runoff. Once flood-prone areas and drainage concerns are identified, MAR-suitable fields are linked to these areas by catchments. The potential cumulative effect of MAR on stormwater runoff is then estimated. For the model run, MAR-suitable fields (as determined in the prior Solano GSP analysis) are re-analyzed using 1-, 10-, and 100- year storm events rather than water years. For each field, "*avoided stormwater runoff"* is calculated. *Avoided stormwater runoff* is defined as follows:

Avoided stormwater runoff = (stormwater runoff without MAR) – (stormwater runoff with MAR)

The resulting value from each field is aggregated to calculate the cumulative volume of water that is prevented from running off MAR-suitable fields linked to each flood prone area.

Avoided stormwater runoff is the equivalent to the volume of water captured and infiltrated by MAR. TFT's infiltration model is based on a field-specific water balance equation that incorporates input volumes of precipitation and irrigation to estimate discharges through crop evapotranspiration, subsurface flows, percolation to groundwater, and surface runoff. Surface runoff is estimated using the runoff curve method described in the National Engineering Handbook (USDA-NRCS, 2004).

Cost. Cost estimates used for this analysis are derived from an analysis of MAR opportunities in Solano Subbasin conducted for the Solano GSP (TFT, 2022; Solano GSP Appendix 8b). Cost estimates were developed using a cost-benefit analysis framework. A generalized budget for site preparation, excavation, and maintenance is developed with data from California NRCS Annual Practice Scenarios and adapted for local conditions based on stakeholder feedback and internal expertise. Annual values are output as a net present value, using a 3 percent discount rate over a ten-year period. A full account of the methods is presented in the GSP's technical appendix (LSCE Team, 2021).

RESULTS

Local flood-prone areas

The potential stormwater benefits to local flood-prone areas are presented in Table 2 below. It provides a summary of each catchment, the number of MAR-suitable fields, the cumulative acreage of those fields (i.e., "field area (acres)"), and the flood-prone area linked to those fields. The principal output of the analysis is the cumulative *avoided stormwater runoff* for all MAR-suitable fields linked to a flood-prone area. This value is calculated for two hypothetical soil conditions (dry and wet) and five storm scenarios (1-year, 10-year/1-day; 10-year/4-day; 100-year/1-day; 100-year/4-day). Table 2 also includes an estimate of the *avoided stormwater runoff per acre* averaged across all five catchments for each modeled storm scenario; this metric can be used to compare with stormwater reduction strategies in other local plans. Based on the model results, the MAR action reduced runoff to zero (i.e. no spillover from sumps) for all scenarios, therefore, the *avoided stormwater* runoff is equivalent in volume to the runoff that would have occurred without MAR. Figure 5 shows the catchments, the flood-prone areas, and the "pour points" of fields (where stormwater runoff leaves each MAR-suitable field).

The five catchments presented in Table 2 contain a total of 192 MAR-compatible fields encompassing 8,334 acres that drain to seven flood-prone areas. In summary, the *avoided stormwater runoff* ranges from 22 acre-feet for flood-prone area 2 (for a 1-year storm lasting 1 day) to 912 acre-feet for the flood-prone area 4 (for a 100-year storm lasting 4 days). Collectively, the total potential *avoided stormwater runoff* if MAR were implemented on all the suitable fields in the five catchments would be between 697 and 2651 acre-feet for a 1- and 100-yr, 4-days storm event, respectively.

Note that *avoided stormwater runoff* is directly related to the "field area" within each catchment because the sump dimensions in the model are scaled to the size of the fields that drain to them. The results also show that preceding soil conditions (dry and wet) do not impact the overall volume. This is because the MAR practice configured in the model uses sumps at the low end/corners of fields (as opposed to berms along a field edge). The capacity of modeled sumps limits the volume of runoff that can be stored on any given field.

Agricultural areas in the Tremont 3 watershed

The Tremont 3 watershed was analyzed to illustrate the potential for stormwater reduction from MAR in an area with persistent drainage issues. The Tremont 3 watershed encompasses portions of the City of Dixon as well as agricultural areas to the north and south. Figure 6 shows the boundary of the watershed in relation to Dixon city limits, a planned development in the northeast quadrant of Dixon, a County-planned development called the Agricultural Industrial Service Area, and the Dixon RCD drainage network, which discharges at Point A into the Reclamation District 2068.

The cumulative *avoided stormwater runoff* for all MAR-suitable fields in the Tremont 3 watershed are presented in Table 3. The northern portion of the Tremont 3 watershed (north of Highway 80) contains a total of 73 MAR-suitable fields that encompass 3,288 acres, with the potential to achieve up to 158 to 612 acre-feet of *avoided stormwater runoff*, depending on the storm event. In the southern portion of the watershed, 162 MAR-suitable fields comprise 5,648 acres that could retain up to 38 to 147 acre-feet of stormwater flows depending on the storm event. As above, the MAR action reduced the volume of runoff to zero.

Table 2: Potential avoided stormwater runoff (acre-feet) to flood-prone areas from MAR-suitable agricultural fields.

Includes dry or wet soil conditions prior to the storm event and with modeled rainfall of 1-year and 1-day duration; 10 and 100 years with 1- and 4-day duration.

				Dry soil conditions					Wet soil conditions						
			Storm event:	1-yr	10-yr		100-yr		1-yr	10-yr		100-yr		Est. Cost*	Cost per ac**
			Duration (days):	1	1	4	1	4	1	1	4	1	4		
Catchment ID	# fields	Field area (acres)	Flood area Map ID	Acre-feet (AF)											
A, C	1,454	27	1	123	253	307	405	471	123	253	307	405	471	$2,312,191	$1,590
B	308	2	2	22	48	48	79	79	22	48	48	79	79	$272,182	$883
A, B	886	25	3	84	165	215	260	327	84	165	216	260	328	$1,797,884	$2,028
C	3,076	67	4	243	511	579	828	912	243	511	579	828	912	$5,153,531	$1,676
D	488	15	5	38	80	90	130	140	38	80	90	130	140	$1,070,214	$2,194
E	1,233	34	6	110	222	277	352	431	110	222	277	352	431	$2,493,858	$2,022
D	888	22	7	75	154	185	247	290	75	154	185	247	290	$1,676,478	$1,887
SUM				694	1,433	1,701	2,301	2,651	694	1,433	1,702	2,301	2,652	$14,776,338	$1,773
Avg avoided stormwater runoff (AF/acre):				*0.08*	*0.17*	*0.20*	*0.28*	*0.32*	*0.08*	*0.17*	*0.20*	*0.28*	*0.32*		

** Cost model assumes that no fields currently have sumps and that all fields would require establishment of new sumps.*

***Cost per acre: average of the cumulative cost of sumps across the cumulative acreage of the fields that drain to them.*

Table 3. Potential avoided stormwater runoff (acre-feet) in the Tremont 3 watershed from MAR-suitable agricultural fields.

Includes dry or wet soil conditions prior to the storm event and with modeled rainfall of 1-year and 1-day duration; 10 and 100 years with 1- and 4-day duration

				Dry soil conditions					Wet soil conditions						
			Storm event:	1-yr	10-yr		100-yr		1-yr	10-yr		100-yr		Estimated Cost*	Cost per acre**
			Duration (days):	1	1	4	1	4	1	1	4	1	4		
Catchment ID	# fields	Field area (acres)	Flood area Map ID	Acre-feet (AF)											
Above Hwy 80	3,228	73	1, 3	158	318	398	504	611	158	318	399	504	612	$5,754,902	$1,783
Below Hwy 80	5,648	162	-	38	80	96	130	147	38	80	96	130	147	$11,659,700	$2,064
SUM	8876	235		196	398	494	634	758	196	398	495	634	759	$17,414,601	$1,962
*Above Hwy 80 – average ASR*** (AF/acre):*				0.05	0.10	0.12	0.16	0.19	0.05	0.10	0.12	0.16	0.19		
*Below Hwy 80 – average ASR*** (AF/acre):*				0.01	0.01	0.02	0.02	0.03	0.01	0.01	0.02	0.02	0.03		

** Cost model assumes that no fields currently have sumps and that all fields would require establishment of new sumps.*

***Cost per acre: average of the cumulative cost of sumps across the cumulative acreage of the fields that drain to them.*

*** ASR: Avoided stormwater runoff*

Figure 5. Location of MAR-suitable sump sites by catchment area.

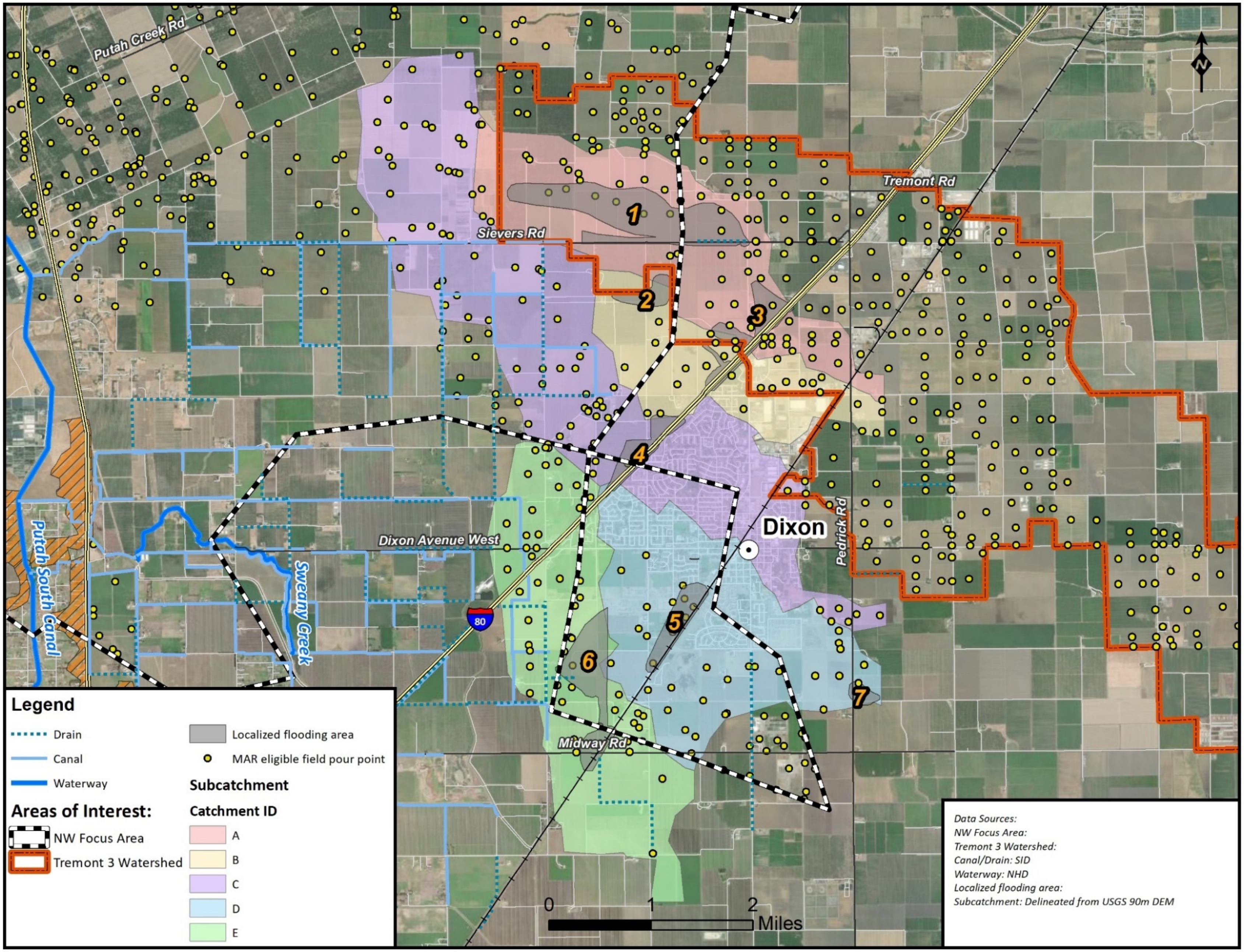
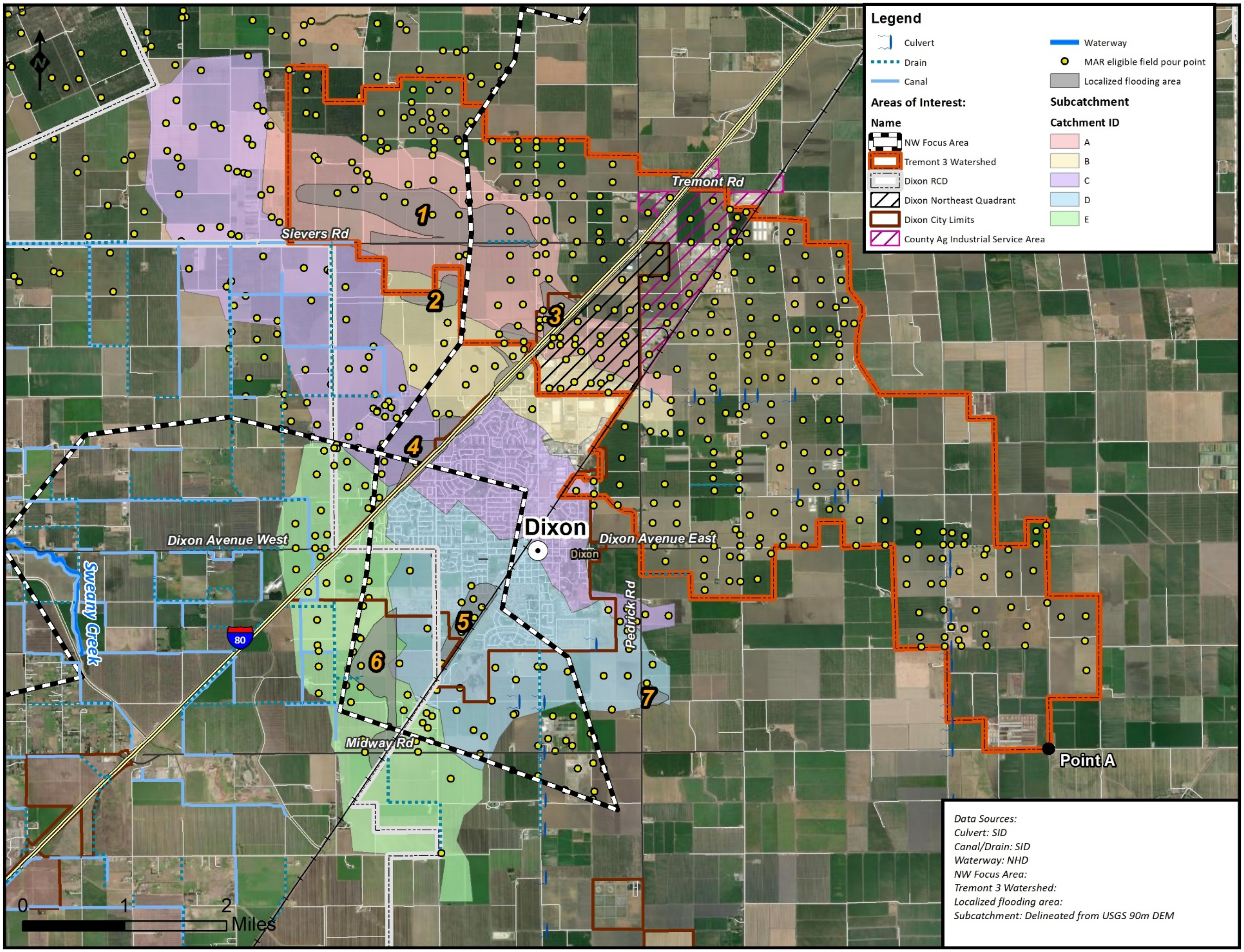


Figure 6. Location of MAR-suitable sump sites in relation to areas of concern for local stormwater management agencies.



DISCUSSION AND RECOMMENDATIONS

Co-benefits

This analysis shows that the beneficial use of surplus stormwater for MAR in portions of the northern Solano Subbasin would have a positive effect on local stormwater issues by reducing the peak volume of stormwater runoff during large storm events. This has the potential to benefit flood-prone areas north of Highway 80 and help alleviate pressure on drainage systems in the Dixon RCD area near Dixon.. GSAs and local stormwater agencies could use the data from this analysis, combined with the groundwater infiltration data from MAR analyses, to inform decisions about how the co-benefits of a distributed MAR program on agricultural fields in the Solano Subbasin compares with other strategies to recharge groundwater and manage stormwater.

The 2002 Moorhead Report proposed a strategy to construct 45 sumps at the low end of agricultural fields encompassing 2,396 acres in the catchment above a flood-prone culvert at the intersection of Currey Rd. and Interstate 80. That analysis also proposed expanding six existing ponds and 52,750 linear feet of drainage channel to increase capacity for managing stormwater runoff. Using a 10-year, 1-day rain event, that analysis showed a reduction of peak flows from 850 cubic feet per second (cfs) to 118 cfs, which corresponds to a reduction from 1,534 acre-feet to 213 acre-feet in volume discharging to the culvert (Dixon RCD, 2002, Figure 4). At full build-out, this would amount to about 1,320 acre-feet of *avoided stormwater runoff*" (as defined herein) or 0.55 acre-feet per acre, averaged over the entire plan area.

This study proposes a similar strategy and uses similar method as the Moorhead study, except with an explicit purpose to address groundwater recharge and stormwater management as conjunctive benefits. In the present analysis, cumulative *avoided stormwater runoff* in the upper Tremont 3 watershed is estimated between 157.9 and 611.6 acre-feet, depending on the magnitude of the storm event. This amounts to 0.05 to 0.19 acre-feet per acre, averaged across 3,228 acres of MAR-suitable fields in the Tremont 3 watershed north of Highway 80. The Morehead study's higher per-acre volumetric benefit is likely the result of the expansion of existing ponds and drainage channels as additional stormwater-specific storage structures, and different assumptions about sump dimensions. Nonetheless, the present study illustrates the volumetric contribution that MAR could make to stormwater management in conjunction with groundwater benefits.

The present analysis also includes MAR-suitable fields in the lower Tremont 3 watershed. Although these fields are outside the Solano Subbasin GSP's "Northwest Focus Area," the Subbasin-wide MAR analysis identified 162 fields in this area that are potentially suitable for Rain-MAR with sumps (Figure 6). The estimated volume of *avoided stormwater runoff* is relatively low for fields in this area, ranging from 38 AF to 176 AF, depending on the model storm event, and averaging between 01 – 0.2 AF per acre. Widespread application of MAR is unlikely for this area, due to the volumetric benefits and high cost. Nonetheless, local stormwater agencies could incorporate these data into stormwater models to assess the potential influence of distributed sumps on watershed discharges and local drainage issues.

Assumptions, uncertainties, and data needs

Model assumptions. As noted above, the principle metric in this analysis—avoided stormwater runoff—is the equivalent to the volume of water captured and infiltrated by MAR, calculated using the NRCS runoff curve method (USDA-NRCS, 2004, National Engineering Handbook). The runoff curves are a function of a hydrologic soil group (i.e., runoff potential), general crop class (row, grass, orchard, etc.), infiltration potential (based on vegetation cover, slope, crop residue, and grazing intensity), and antecedent soil condition. Each of these data inputs contains assumptions and uncertainty factors, which, compounded, could lead to outcomes that differ from model predictions. On-farm demonstration projects involving the collection of measured precipitation, runoff, and infiltration values would help to validate hydrological model outputs for infiltration and avoided stormwater runoff and improve model calibration.

Practice adoption. Distributed conservation strategies involve the implementation of conservation practices across the landscape to achieve regional goals, sometimes as a complement to, or in lieu of, larger-scale built-infrastructure projects. Distributed strategies are dependent on voluntary adoption by a wide array of agricultural producers and landowners. This analysis presents the maximum potential volume of stormwater runoff reduction that would accrue if the modeled MAR practice were adopted fully within any given AOI. However, this analysis does not attempt to make projections about the proportion of growers or landowners within an area that would adopt MAR practices on the fields. Guidelines for setting up a MAR incentive program are provided in a separate report (TFT, 2022).

Costs of Implementation.
The cost estimates in Tables 2 and 3 present the costs of maximum build-out, which would include dozens of sumps on agricultural fields within each catchment, amounting to tens of millions of dollars. These cost estimates are based on conservative assumptions that are likely to overestimate cost. For instance, since there is no comprehensive dataset available to positively identify sumps across the Subbasin; this analysis assumed that no fields currently have sumps and thus all would require establishment of new sumps. This assumption may overestimate the excavation costs of implementing sumps on fields where sumps already exist. An inventory of existing sumps would help to calibrate this cost assumption.

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Federal Emergency Management Administration (FEMA). 2022. FEMA Flood Map Service Center. Accessed in January 2022 at https://msc.fema.gov/portal/search?AddressQuery=dixon%20california#searchresultsanchor

United States Geological Survey. 2016. 90 Meter Resolution United States Digital Elevation Models. Accessible at http://usgsquads.com/digital-map-products/elevation/us-elevation-data/90m-resolution-united-states-dems

ATTACHMENTS

Spatial Data

Deliverable(s): *ArcGIS geodatabase: MXD and shapefiles.*