DRAFT Technical Memorandum

Upper Petaluma River Watershed Flood Control Project Scoping Study

Subject: **Project Concepts Identification and Description**

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1 Introduction

The Sonoma County Water Agency (Water Agency) is presently undertaking a Scoping Study within the Upper Petaluma River Watershed (Project) to identify stormwater management/groundwater recharge projects that provide flood hazard reduction and groundwater benefits (Key Project Purpose). The Project is in its initial scoping study phase of developing a set of project objectives, assessing potential project issues and concepts, and designing a stakeholder coordination process.

The purpose of this draft memorandum is to identify project concepts that help to achieve the Key Project Purpose and to describe the concepts to a level that enables comparison, screening, and prioritization of the concepts. Regional hydrology and hydrogeology are introduced here as they set the foundation upon which the project concepts are based.

1.1 Regional Hydrology

The Project area, Sonoma County's Flood Zone 2A, is the upper portion of the Petaluma River watershed. Zone 2A is approximately 90 square miles. Elevations vary from nearly sea level in the southwest corner of Zone 2A to over 2,200 feet in the northeast corner of Zone 2A.

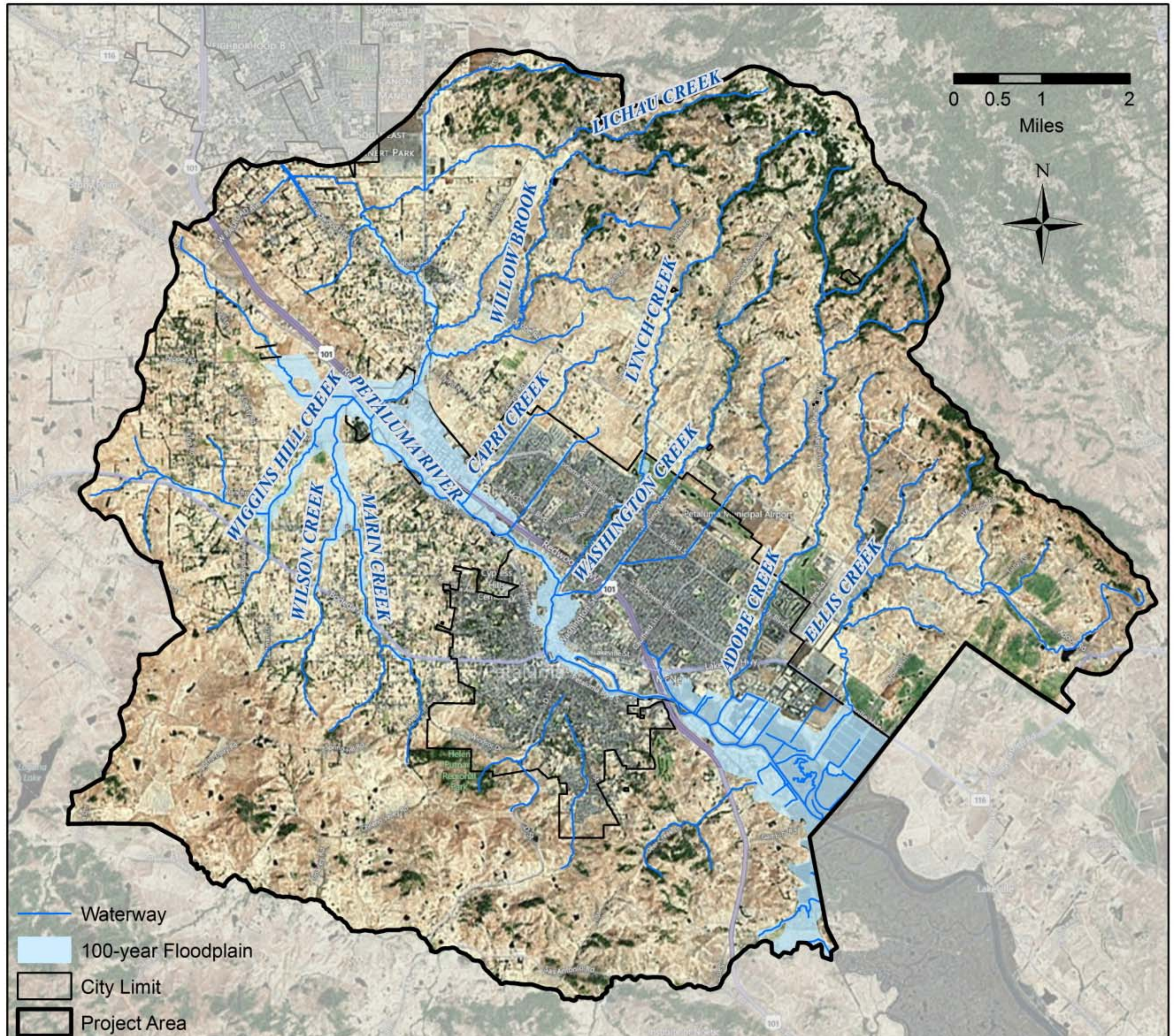
Major tributaries, shown in **Figure 1**, to the Petaluma River include Marin Creek, Willow Brook, Capri Creek, Lynch Creek, Washington Creek, Adobe Creek, and Ellis Creek. Zone 2A mean annual precipitation ranges from about 22.5 inches to about 45 inches (CA Department of Forestry and Fire Protection), with the higher rainfall averages falling in the higher elevation areas in the northeast. Stream flow is summarized in **Table 1**.

Table 1: Sample Flow Rates for Zone 2A

Waterway	Location	10-year Event	50-year Event	100-year Event
Wiggins Creek	U/S of Marin Creek	1,073 cfs	1,405 cfs	1,559 cfs
Marin Creek	U/S of Petaluma River	1,829 cfs	2,400 cfs	2,659 cfs
Lichau Creek	U/S of Willow Brook	1,738 cfs	2,310 cfs	2,543 cfs
Willow Brook	U/S of Petaluma River	2,250 cfs[1]	2,560 cfs[1]	2,560 cfs[1]
Petaluma River	D/S of Willow Brook	2,580 cfs	4,200 cfs	5,220 cfs
Capri Creek	U/S of Petaluma River	547 cfs	720 cfs	790 cfs
Lynch Creek	U/S of Petaluma River	1,223 cfs	1,595 cfs	1,754 cfs
Petaluma River	D/S of Lynch Creek	3,670 cfs	5,680 cfs	6,750 cfs

Source: From Table 4 of *Flood Insurance Study for Sonoma County, CA and Incorporated Areas* (FEMA, 2008)
Footnote: [1] Reduced flows due to upstream losses.

Figure 1: Upper Petaluma River and Tributaries



Source: Sonoma County, CASIL

1.2 Regional Hydrogeology

The project area overlies the Petaluma Valley Groundwater Basin, a northwest-trending structural depression in the southern part of the Coast Ranges of northern California. The basin is bounded on the west by the Mendocino Range, on the east by the Mayacamas and Sonoma Mountains, and on the south by San Pablo Bay.

The Petaluma Valley contains about 45 square miles of alluvial plain. It is approximately 16 miles long, and two to three miles wide over most of that length. Most of the upper part of the Petaluma Valley is between sea level and an altitude of 50 feet, while most of the lower part of the valley is at or as much as three feet below sea level. The Valley is drained primarily by the Petaluma River and its tributaries. It is tidal from its mouth to the city of Petaluma, the greater part of its length. Flow in the reach above tidewater is seasonal, generally beginning in the period from October to December and continuing until the following July.

In general, the Petaluma Valley is underlain by alluvial deposits of gravel, sand, silt and clay ranging in age from Pliocene to Recent. Underlying the valley fill are volcanic, continental, estuarine and marine rocks ranging in age from Jurassic to Pliocene. In general, the rock units underlying the Petaluma Valley and the adjacent Santa Rosa Valley have been divided into three classes, largely based on their relative capacity to hold and yield water (Cardwell, 1958):

- Consolidated rocks of the Jurassic and Cretaceous age which yield some water from joints and other fractures and are the poorest water-yielding rocks. This unit contains, in upward succession, the Franciscan formation, the Knoxville formation and the Novato conglomerate.
- Sedimentary and volcanic rocks of Tertiary age which are water-bearing in part but are not a major part of the groundwater basin. This unit contains, in upward succession, the Tolay volcanics, the Petaluma formation, and the Sonoma volcanics.
- Unconsolidated or poorly consolidated deposits of Tertiary and Quaternary age, which yield appreciable quantities of water and comprise the majority of the groundwater basin formations. This unit includes, in upward succession, the Wilson Grove (formerly Merced) formation, the older alluvium and the younger alluvium.

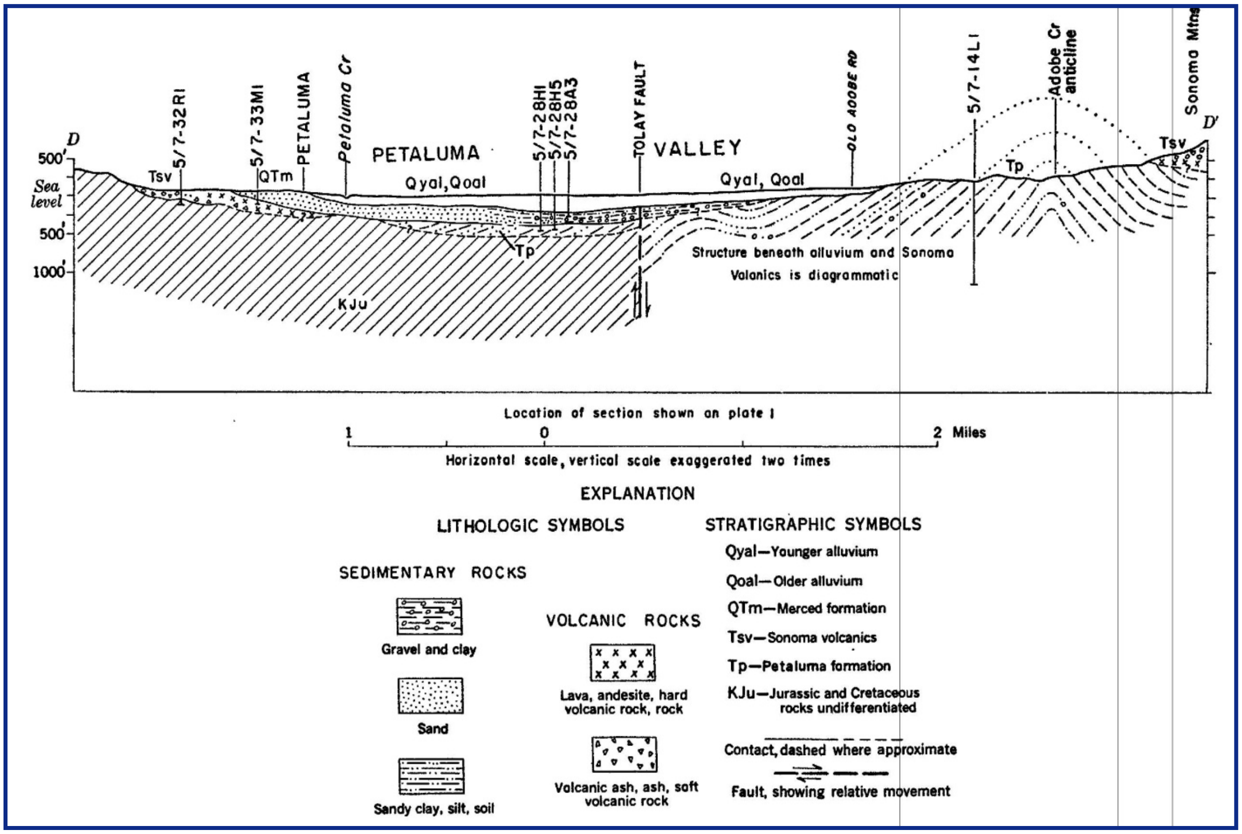
The following is a brief discussion of those units/formations found within the Petaluma Valley as described by Cardwell (1958) and DWR (1982):

- Younger alluvium - In general, the younger alluvium consists of stream-channel and flood-plain deposits, predominantly silt and clay but containing small discontinuous gravel lenses. The younger alluvium formation in the Petaluma Valley overlies the older alluvium, and typically has thicknesses up to 300 feet. The thickest part of the formation is in the southern part of the valley; however, proximity to San Pablo Bay makes part of this groundwater formation unusable as a water supply. In the northern part of the Petaluma Valley, groundwater yields from this unit are small to moderate, and most large wells penetrate the younger alluvium and are screened in the older alluvium or Wilson Grove (Merced) formation or both
- Older alluvium - The older alluvium is composed predominantly of unconsolidated deposits of silty or sandy clay, sand, and gravel that outcrop only locally on the northeastern side of the valley, but extend across the valley beneath the younger alluvium where they overlap deposits of the Wilson Grove (Merced) formation. The estimated maximum thickness of this formation is approximately 200 feet. The older alluvium yields moderate amounts of groundwater, however specific capacities are low. Additionally, water in the older alluvium is essentially unconfined, although the lenticularity and heterogeneity of the deposits causes poor interconnection and locally may produce slight confinement or zonation within the basin .

- Wilson Grove (formerlyMerced) formation - The Wilson Grove formation is the principal aquifer in the upland areas northwest of Petaluma, in the northwestern part of the valley and on the northeastern flank of the lower valley. This formation is composed predominantly of medium- to fine-grained fossiliferous marine sand, sandstone and silty clay with minor interbedded gravel and pebbly beds and is thought to be as much as 1,500 feet thick at its deepest. The Wilson Grove formation is known to be confined in the northern part of Petaluma Valley and is thought to be confined in other areas of the valley, such as near the bay. The upper portion of the formation has good yields and is tapped by most irrigation or other deep wells on the west side of the valley. The lower part of the formation is more generally compact and somewhat cemented, but can yield adequate domestic supplies.
- The Sonoma volcanics, generally underlying the Wilson Grove and Petaluma formations, are interbedded lava flows, tuff, tuff breccias and agglomerate. More permeable rock units in this formation can yield moderate amounts of water to wells, with excellent local yields from the tuffs. This formation has the highest yields in the area and is the formation most suitable for recharge. Except in the immediate vicinity of outcrops, volcanic rocks are not encountered in wells beneath the alluvial plain.
- Petaluma formation - The Petaluma formation consists of continental and brackish-water clay, shale, sand, and sandstone found on the east side of the Petaluma River. This formation can yield moderate quantities of water to wells where appreciable thicknesses of sand are penetrated. In general, though most of the wells in this formation are for domestic use, there have been several wells in this formation that have produced greater volumes of water. Considerable confinement or separation of water-bearing strata occurs in the Petaluma formation and heads in wells can vary significantly between locations.
- Basement formations – The basement formations (the Tolay volcanic and Franciscan Formation) are, respectively, volcanic rocks and consolidated sandstone, shale and chert, and yield little to no water.

Figure 2 shows a generalized geologic cross-section in the Petaluma Valley.

Figure 2: Generalized Geologic Cross-Section – Petaluma Valley



Source: Cardwell, 1958

2 Project Zones

As mentioned above, the two primary objectives of the Key Project Purpose are to provide flood hazard reduction and groundwater recharge. The sections below describe focus areas where flood and recharge project elements would be considered potentially feasible.

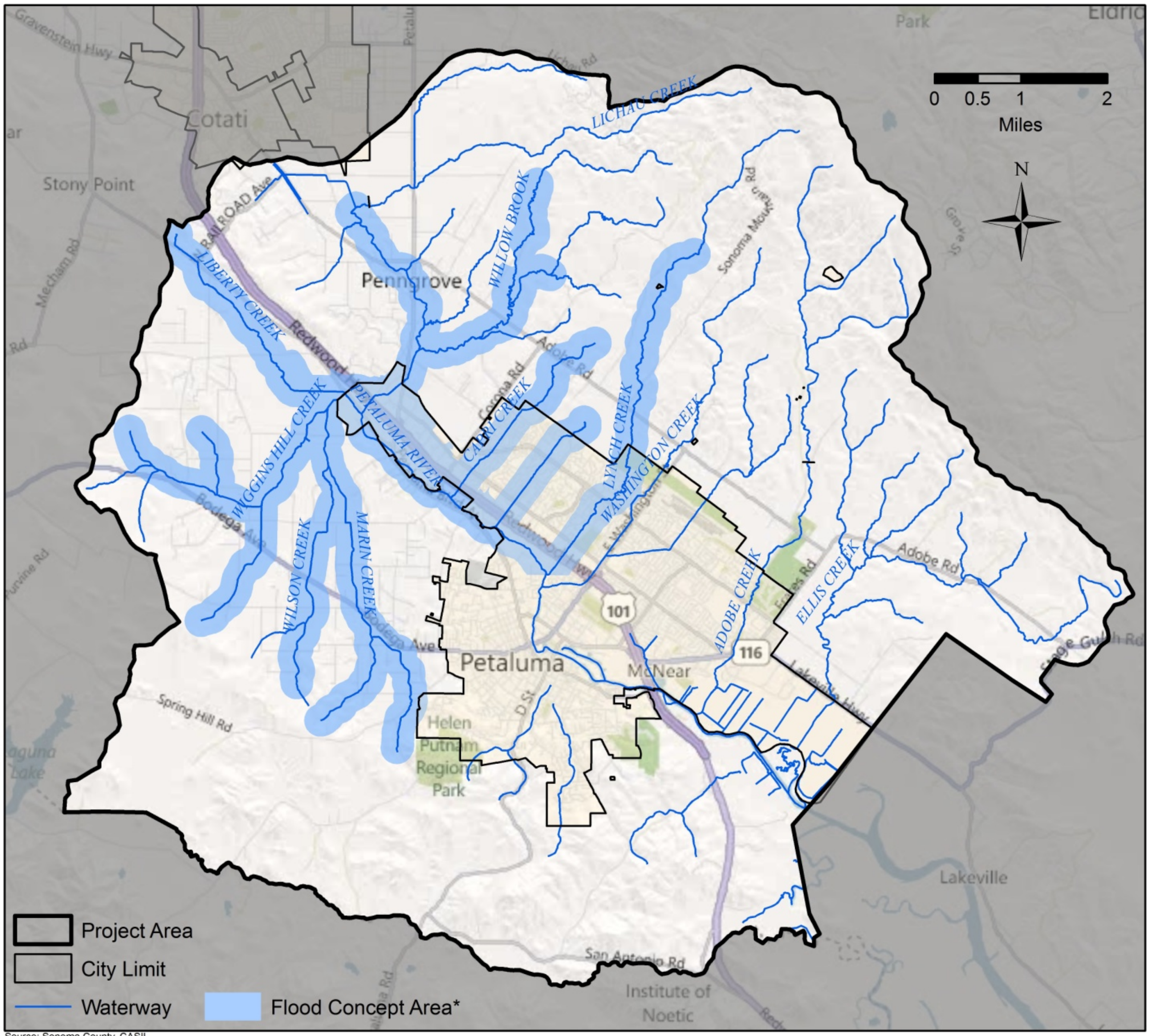
2.1 Flood Hazard Reduction Project Elements

Flood reduction benefits are achieved through one or more of the following strategies:

- Increased channel hydraulic capacity; and
- Reduction in peak flows.

Most flood hazard reduction concepts utilizing the above strategies are tied to the flood pathways. For the purposes of this memorandum, the FEMA 100-year floodplain and creeks with a defined 100-year floodplain will be used to focus the area to be evaluated for flood hazard reduction project concepts. Recognizing that not all flood hazard reduction project types are done in-stream, the focus area is broadened to include a 1,000-foot area around the streams. Stream reaches with smaller tributary areas and the upper reaches of some streams were removed from the focus area where it appeared that downstream concepts could be more effective. As established by the Water Agency, the focus of the flood hazard reduction element for this scoping study was upstream of and including the confluence of the Petaluma River and Lynch Creek. The final concept focus area, shown in **Figure 3**, reflects all of these assumptions and conditions.

Figure 3: Flood Hazard Reduction Project Element Focus Area



* Note that the flood concept area may be expanded to accommodate some specific concepts with flood benefits.

The flood hazard reduction focus area shown in **Figure 3**, above, is intended to help identify, at a conceptual level, those areas that could play a role in providing flood hazard reduction benefits both locally and regionally. In future phases of the Project, it is possible that more suitable or efficient locations will be found or that some of the areas will be eliminated from project siting consideration for one or more reasons, including but not limited to, willing landowner participation, zoning restrictions, or environmental limitations. Some project concepts identified in this memorandum are more regional in nature. In these cases, the focus area would not apply.

2.2 Groundwater Recharge Project Elements

Groundwater recharge benefits are achieved by directly or indirectly promoting the infiltration and percolation or movement of surface or stormwater through the ground surface into the underlying groundwater basin aquifers. Groundwater recharge can be achieved via one of two general methods:

- **Percolation** – Recharge via percolation involves the surface application of water, typically through ponding or managed releases of groundwater, retaining or detaining water to allow for percolation into the subsurface. Percolation can be achieved in specially-designed percolation ponds, by increasing floodplain detention, through in-stream or off-stream detention basins, and/or by promoting recharge via Low Impact Development (LID) projects,
- **Direct Recharge** – Direct groundwater recharge involves placing surface or storm water directly into the underlying groundwater aquifers through the use of recharge wells.

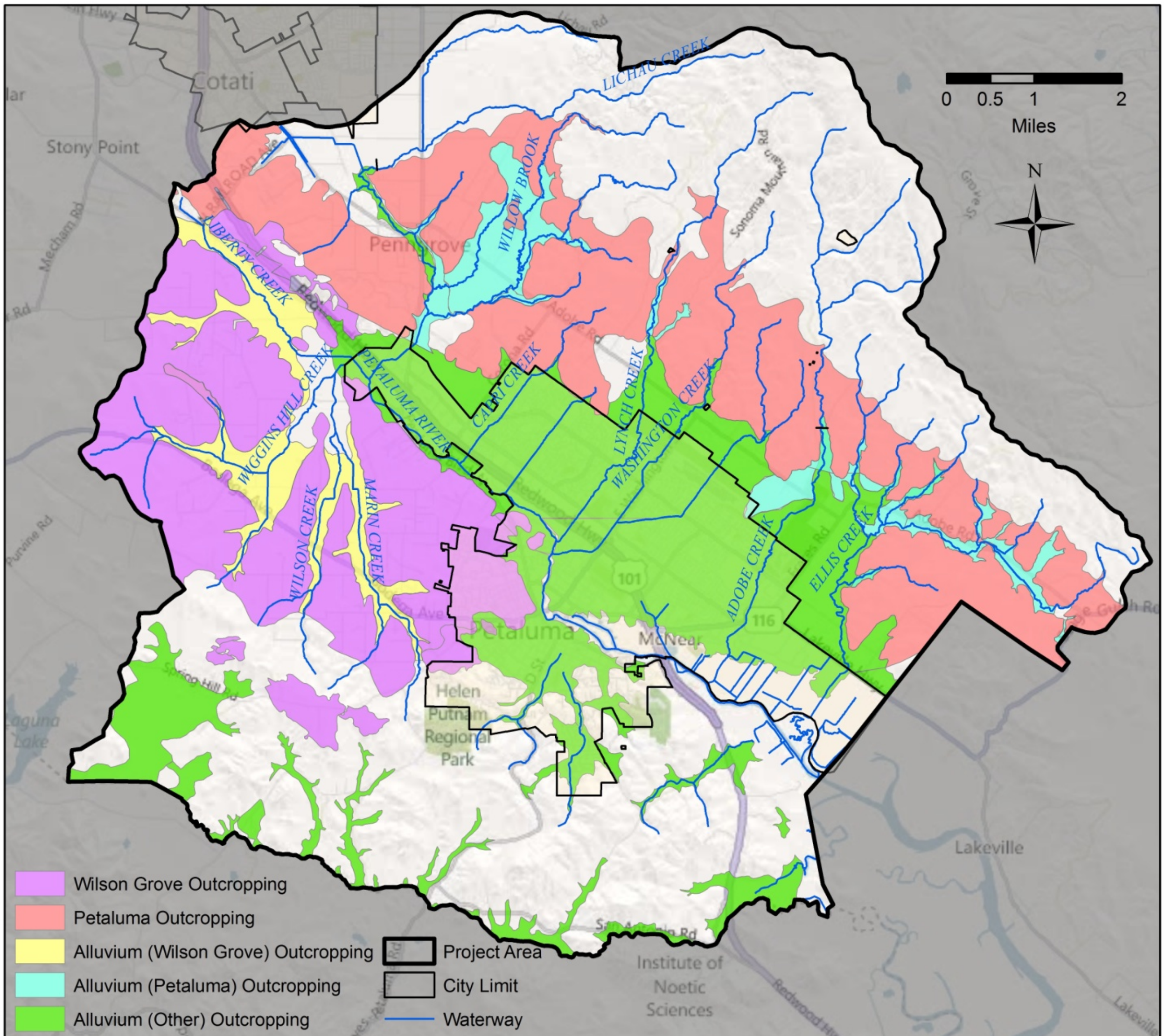
For the percolation of stormwater to be successful as a groundwater augmentation strategy for water supply, it is imperative that the infiltrating water reach the aquifers that are used for water supply. For the Petaluma Valley Groundwater Basin, the principal water-bearing deposits are the younger and older alluvium and the Wilson Grove formation, while locally, water-bearing formations are also found in the Petaluma formation (when an appreciable thickness of sand and gravel is encountered) and in the Sonoma volcanics (Cardwell, 1958). For the most part, the larger municipal wells in the valley are screened in the Wilson Grove formation.

For direct recharge for groundwater augmentation, the surface expression of a water-bearing formation is not required as wells are used to directly place the water into the selected formation for storage and later recovery. Key issues relating to direct recharge that are not, for the most part, as significant an issue for percolation, are the potential for water quality interactions between the recharge water and ambient groundwater and for the potential introduction of contaminants such as bacteria, into the subsurface.

Groundwater in the Petaluma Valley is recharged in large part by the deep infiltration of rainfall, but seepage loss from streams overlying permeable deposits also contribute to recharge. Groundwater in the basin typically moves from the northeast and southwest toward Petaluma Creek and downstream towards the tidal sloughs. For the purposes of this project, the principal water-bearing formations need to be targeted to make groundwater augmentation for water supply viable; however, even groundwater augmentation targeted at the shallower formations may be of benefit as these aquifers potentially contribute to the baseflows of streams and may percolate vertically to deeper formations (in areas where impeding aquitards are absent). Enhancing recharge of the shallower formations may also aid in combating potential saltwater intrusion in the southern portions of the valley, which has been observed historically in the alluvial fan deposits. To this end, all of the identified water-bearing formations in the Petaluma Valley (the younger and older alluvium, Wilson Grove formation, Sonoma volcanic and Petaluma formation) were considered for this study, save the Sonoma volcanic formation. This formation was eliminated from further consideration due to its structure (fractured formation) and low local yields.

As the key project purpose is to identify stormwater management/groundwater recharge projects that provide flood hazard reduction and groundwater benefits, those formations with surface expressions are of particular interest as these are the locations where surface recharge is likely to be feasible (that is, the percolation must occur over the surface exposures (outcrops) of these formations). **Figure 4** shows the locations of the Wilson Grove and Petaluma formation outcrops and the overlying younger and older alluvium in the study area.

Figure 4: Surface Expressions of Upper Petaluma Formations

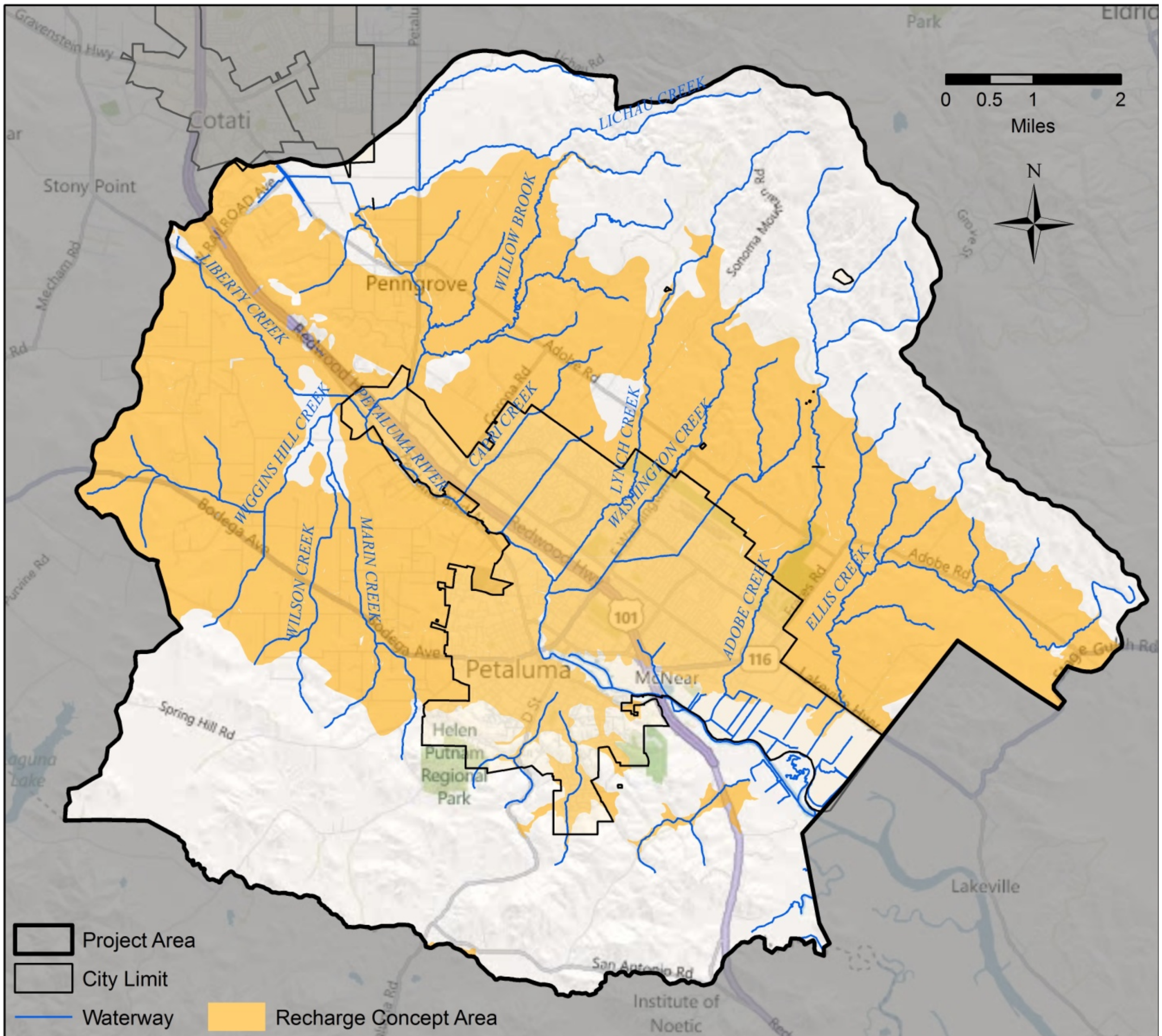


Source: Sonoma County, CASIL, USGS, Cardwell

Ref: USGS geology reports and Cardwell

The groundwater recharge focus areas, shown in **Figure 5**, are intended to help identify, at a conceptual level, those areas that could play a role in providing groundwater recharge benefits both locally and regionally. In all locations (and especially in those areas intended to target the Petaluma formation for storage), site-specific investigations (including geologic borings and soil testing) and other analyses such as water quality tests will be required to further determine the suitability of each location for groundwater recharge or to eliminate it from further consideration for one or more reasons, including but not limited to environmental or hydrogeologic limitations, willing landowner participation, or zoning restrictions.

Figure 5: Groundwater Recharge Project Element Focus Areas

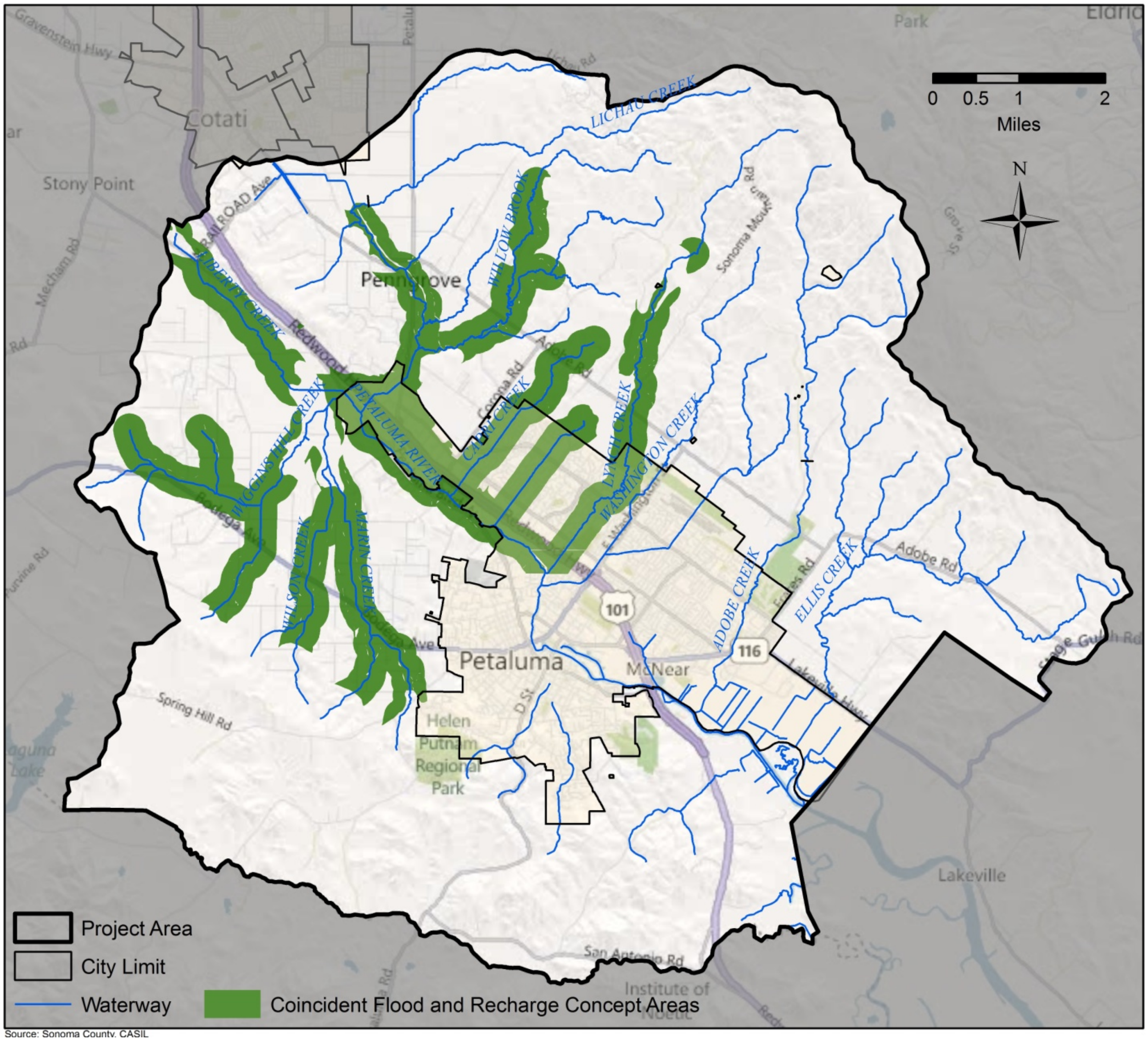


Source: Sonoma County, CASIL

2.3 Opportunity for Coincident Flood Hazard Reduction and Groundwater Recharge

Figure 6 highlights the overlap areas for both the flood hazard reduction and groundwater recharge focus areas. Project concepts sited in these areas will have the opportunity for coincident flood hazard reduction and groundwater recharge. Outside of these areas though, project elements in different locations will need to be paired to achieve both of the primary objectives of the Key Project Purpose.

Figure 6: Coincident Flood Hazard Reduction and Groundwater Recharge Focus Areas



Source: Sonoma County, CASIL

3 Concept Identification

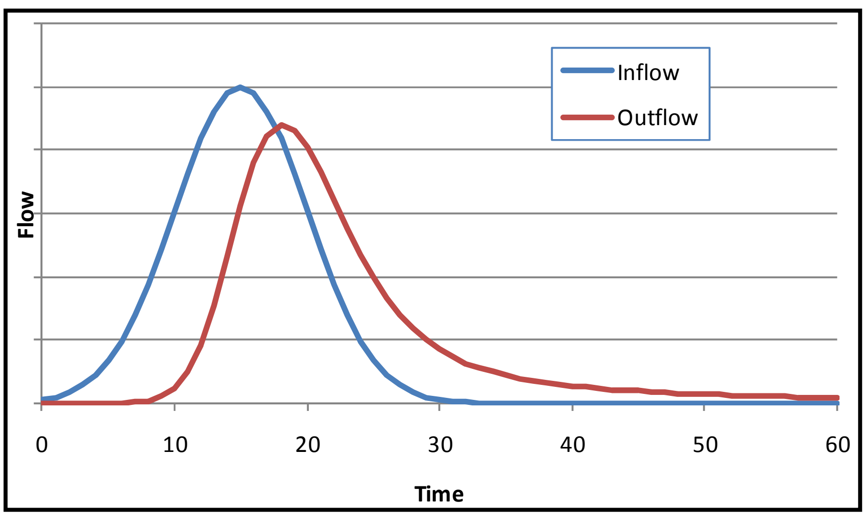
Flood hazard reduction concepts and groundwater recharge concepts are identified in this section based on potential ways to achieve the Key Project Purpose. Some concepts address both core objectives of the Key Project Purpose while others only address either flood hazard reduction or groundwater recharge. In the latter case, the concepts can potentially be co-located at a site or located in different sites. In this section of the memorandum, a wide range of concepts are identified at a high level. The next section describes the concepts as they could be applied to the Project area.

3.1 Flood Hazard Reduction Concepts

Flood reduction can occur either through increased hydraulic capacity or reduced peak flows. One way to increase hydraulic capacity is by altering the existing channel to increase the available cross-sectional area available for flow or by reducing the overall roughness of the channel. Another way to achieve the same benefit is to create a new contained pathway for flood waters. A number of the concepts described below achieve flood hazard reduction through increased hydraulic capacity.

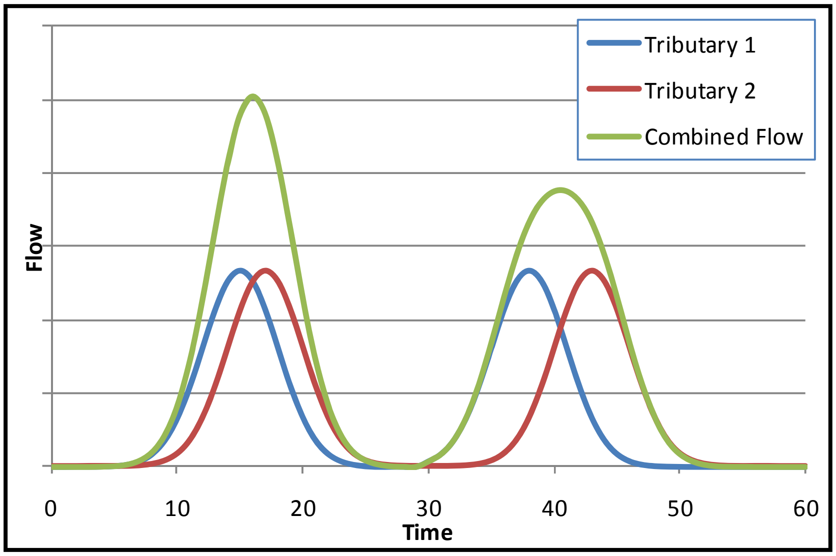
Several additional identified concepts achieve flood hazard reduction by reducing peak flows. Surface water runoff volume can be reduced by allowing additional water to infiltrate by, for example, reducing the amount of impervious area. Attenuation, or the reduction in the hydrograph peak, affects the magnitude of the flood flows as well as the timing of the peak flows. Reduction in peak flow forces the hydrograph to extend since the overall volume of water carried by the flood is the same. However, it is important to note that extending the duration of hydrographs can be considered to be just as undesirable as the high peaks (particularly near the channel-forming flow range) and therefore any modification to the hydrographs will have to be considered closely on a project-basis. **Figure 7** shows this potential hydromodification effect.

Figure 7: Hydrograph Attenuation



Timing of the peaks also has an impact on flooding since flows from tributary streams are additive. **Figure 8** shows how the timing of two small peaks can impact the resulting hydrographs. Separating the timing of the tributary peak flow contributions will generally lead to a lower peak on the combined hydrograph while the opposite is true as well. While analysis of these effects is beyond the scope of the Scoping Study, they will be studied at the feasibility level as specific project sites and geometries are identified. Past work however has indicated that peaks flows from the major tributary watersheds for the flood focus area (i.e. the Willow Brook and the Marin/Wiggins watersheds) are nearly coincident in timing (SCWA, 2010). Attenuation therefore in either watershed would likely reduce overall peak flows in the impacted tributary streams and the Petaluma River.

Figure 8: Hydrograph Timing Example



3.2 Recharge Concepts

As mentioned previously in the memorandum, groundwater recharge can occur either through surface percolation of water or through direct recharge. In general, groundwater augmentation via percolation is achieved by simply delaying or retaining the stormwater runoff and allowing time for the water to seep through the ground surface (infiltrate) and move down through the subsurface to the underlying groundwater basin (percolate). For surface percolation, there are several ways of promoting the percolation of stormwater runoff. These include using in-stream and off-stream detention basins, expanding floodplain area, modifying the floodplain, and using Low Impact Development (LID). Direct surface recharge techniques such as these are among the simplest and most widely applied methods for groundwater recharge.

Field studies of spreading techniques have shown that many factors govern the amount of water that will infiltrate and percolate to groundwater; however, two of these, the areas of the recharge and the length of time that the soils are in contact with the water, are key (Todd, 1980). In general, detention or spreading basins (or concepts that utilize the same ideas) for groundwater recharge utilize these two concepts, have relatively low construction costs and are easy to operate and maintain.

Groundwater augmentation via direct recharge, alternatively, conveys water directly into an aquifer. For this type of augmentation project, the quality of the recharge water is of primary concern as recharge water enters the aquifers without the filtration and oxidation that occurs when water percolates naturally through the unsaturated zone. Direct recharge methods access deeper aquifers and require less land than percolation methods, but are more expensive to construct and maintain. (*Source Book of Alternative Technologies for Freshwater Augmentation in Some Countries in Asia*, 2011)

All subsurface methods are susceptible to clogging by suspended solids, biological activities, and chemical impurities. Groundwater-recharge water geochemical interactions are also of key concern for direct recharge as they can result in the clogging of the well screen and/or adjacent formations.

3.3 Project Concepts

3.3.1 Managed Floodplain

Existing floodplains attenuate flood flows naturally. Without existing floodplains, peak flows are expected to be higher and travel times shorter than currently measured. To avoid loss of the attenuation and other benefits of floodplains, one project concept is to preserve the floodplains, either through flood easements or fee title acquisition. Both of these pathways would require partnerships with willing landowners. Additionally, while flooded, there could be recharge opportunities should conditions be appropriate.

3.3.2 Off-Stream Detention Basin

Detention basins are a classic example of attenuation projects. While storing water, the detention basins also provide an opportunity for recharge where geologic conditions are appropriate. Off-stream detention basins would be one or more excavated basins used to divert, slow and detain stormwater runoff to promote infiltration and reduce peak flood flows. The outlet of each basin is constrained in some manner to improve the attenuation effect.

This concept may include single basins that are seasonally scarified or raked (to remove or break up fines that accumulate at the bottom of the basin) or a series of basins in which the first is used to allow stormwater runoff to settle, removing sediments that will clog and reduce the percolation capacity of subsequent, downstream basins.

Off-stream detention basins can also be buried structures allowing other land uses above, such as parks or buildings. These basins would work in a manner similar to that previously described; however, due to the difficulty in maintaining subsurface basins, a settling basin upstream of the detention basins would be recommended to reduce the level of maintenance required.


3.3.3 In-Stream Detention Basin

In-stream detention basins work in a manner similar to the off-stream detention basins. This concept would consist of an engineered constructed basin, located in the riverway, that would slow stormwater runoff, thereby promoting percolation and allowing for sediment removal. Maintenance of the outer portions of the in-stream detention basin would occur during dry periods to help maintain the capacity of basin.

3.3.4 Floodplain Modification

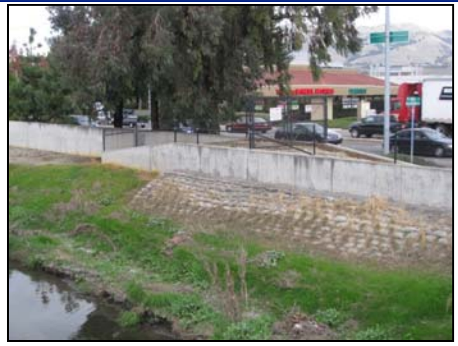
Floodplain modification involves lowering the floodplain elevation to provide additional flow area (hydraulic flow carrying capacity) and/or storage volume. Outlet control would not normally be included in this type of project. This concept is demonstrated in the City of Petaluma's Denman project.

Under appropriate conditions, both flood and recharge benefits are possible with this concept.

3.3.5 Levee/Floodwall

Levees and floodwalls are structural flood hazard reduction options that provide additional hydraulic capacity within the channel or remove an area from a floodplain. In the latter case, this could induce flooding elsewhere as the removed conveyance capacity is replaced by a new area. When levees and floodwalls are built, they allow the hydraulic grade line to increase without flooding surrounding areas. The higher hydraulic gradeline increases the velocity which yields a higher flow rate. These types of projects can either be stand alone projects or can be integrated with other methods at a smaller scale to remove certain areas from the floodplain.

Levees and floodwalls typically do not provide recharge benefits.



3.3.6 Channel Modifications

Channel modifications affect the shape or roughness of the channel, two key components in hydraulic capacity. The channel section can be modified in several ways, including widening the channel, reforming the basic shape and support for the channel walls and bottom (e.g. conversion to a reinforced U-shaped channel), and removal of accumulated sediment. Smoother channels are able to convey more flow than rougher channels. Removal of vegetation and channel straightening reduce overall roughness.

The types of channel modification described above do not typically provide recharge benefits.

Before and after vegetation and sediment removal.

3.3.7 Bypass Channel

This concept increases the hydraulic capacity of a channel by providing a parallel, controlled flowpath. The bypass channel diverts flow upstream of the area to be protected and reintroduces the flow downstream of the area to be protected. The flow is normally reintroduced to the same stream, but in some cases it may not.

Recharge concepts could be designed into a bypass channel as added features; although, a bypass channel typically would not provide recharge opportunities.

3.3.8 Bridge Improvement and Debris Removal

Bridges can create constriction points that can lead to flooding. This problem can be exacerbated by waterway approach and bridge design as well as a low level of maintenance. Realigning channels, implementing structural and programmatic changes for debris management and control, and increasing hydraulic capacity through bridges reduce the likelihood of flooding at crossing structures. Implementation of this concept would require, depending on recommended solutions, significant coordination with bridge owners and local land owners.

It is important to note that any modifications made under this concept are intended to alleviate debris constrictions but not increase the design hydraulic capacity of the bridge itself. This concept would improve conveyance and is not expected to improve recharge.

3.3.9 Low Impact Development

Low impact development (or LID) is a means of designing and constructing a project such that stormwater is collected and detained for reuse and/or for promoting recharge. LID projects are particularly effective at helping to manage stormwater for smaller events, in the 1 to 10-year range. Typical LID components include biodetention, vegetated swales, vegetated (green) rooftops, rain barrels, and permeable pavements. LID projects are generally implemented during initial construction of a structure or area, redevelopment of an area, or retrofit of a structure.

3.3.10 Policy Review and Development

Various city, county, and Water Agency policies can impact both flooding and recharge potential. Policies and practices may be in place to review activities such as development and land use changes with regards to impacts to flood and recharge conditions. Existing policies can be reviewed, new policies can be created, and enforcement of these policies can be refreshed where they may not have been previously.

3.3.11 Direct Recharge Wells

Direct recharge is used to introduce a surface water supply (recharge water) directly into a groundwater basin for storage and eventual reuse. Water is transmitted by recharge wells directly into the groundwater basin, and has the advantage of being able to place the source water directly into deeper formations of interest for storage and recovery (in this case, the Merced and Petaluma formations). One key advantage of this mode of groundwater augmentation is that smaller areas are required for recharge (as wells do not need as much space as percolation ponds). However, this method is typically more expensive to construct and maintain than percolation ponds, and are more easily clogged by untreated recharge water (especially stormwater runoff, which typically contains higher concentrations of suspended sediment and organics).

4 Concept Description

This section applies the concepts identified in the previous section to the Concept areas. Additional detail is provided for each of the concepts discussed, as well as alternative ways to implement the concept. Each concept is also analyzed against project objectives, as described in the *Project Objectives Report* (RMC, 2011), and the relative cost for concept construction as compared to the value of flood protection and increased recharge benefits obtained are provided (and ranked as being high, medium, low or unknown for the base concept). Finally, the additional benefits afforded by the concept and potential concept constraints are evaluated.

Hydraulic modeling and quantification of benefits and impacts have not been performed for this Scoping Study. These analyses will be performed in a later Project phase. Hydraulic modeling will be necessary for any concept or concepts (with potential for hydromodification) to be deemed feasible and to confirm that existing flood protection levels are not reduced within the Project area.

4.1 Managed Floodplain

Concept Elements and Alternatives

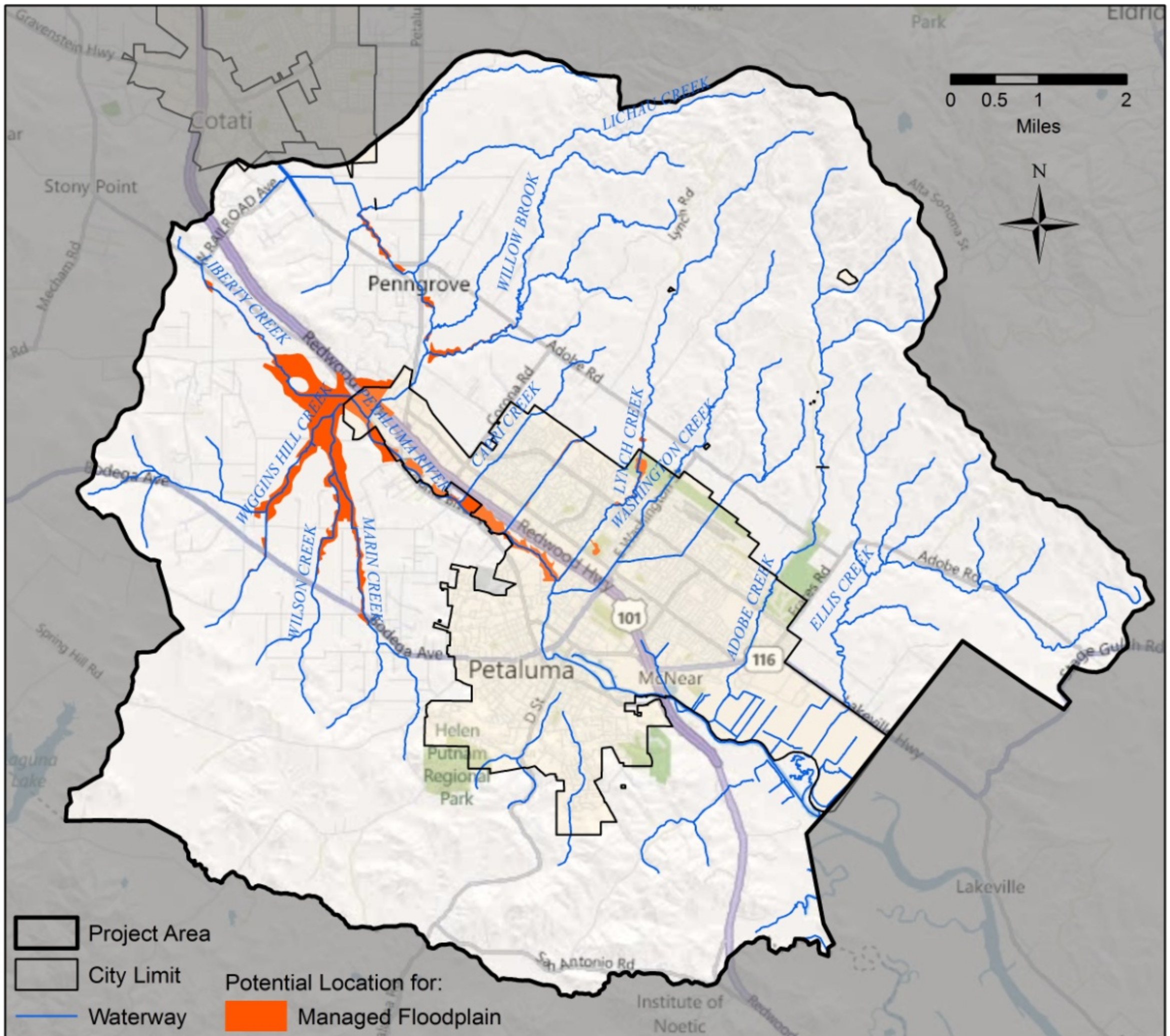
The concept area, as shown in **Figure 9**, is generally the 100-year floodplain but does not include land with existing structures. The goal of this concept is to partner with willing landowners to preserve the attenuation characteristics of the existing floodplain in undeveloped and agricultural areas. This would be achieved through flood easements (which would allow land owners to continue use of the land) or fee title acquisitions. In the latter case, appropriate land use decisions would need to be made in determining whether the acquired parcel would be converted to another use or if it should continue to be used in the same manner as when it was acquired. This concept would not include land form or land use modifications to increase downstream flood hazard reduction benefits.

In certain areas, the 100-year floodplain overlies surface expressions of the Wilson Grove or Petaluma formations, or the alluvial deposits directly overlying these formations. Promoting infiltration in these areas could lead to recharge of key water-bearing formations. In these cases, properties that are flooded more frequently will provide additional recharge benefit. Where permitted, surface treatments such as scarifying will improve the passive percolation rates. Additional testing is needed to confirm the viability of this benefit in these areas.

Where recharge is not an option but the owner is amenable to some grading, pools could be created to provide livestock watering alternatives to groundwater and potable supply use. The pools could also be used to develop varied habitat so long as the additional attenuation provided by the pool was not offset by new vegetation.

Depending on local considerations such as nearby environmental corridors, recreational areas, and concerns of the local landowners, additional features could be included to create multiple benefit projects. Some of these features could include recreational open space, trails, and educational features. Other benefits, such as channel stability at and downstream of the concept site, as well as reduced turbidity in surface waters, are part of the natural function of floodplains.

Figure 9: Potential Locations for Managed Floodplains



Source: Sonoma County, CASIL

Concept Objective Analysis

Table 2 summarizes how managed floodplains achieve or could achieve the core and supporting objectives identified for this Project.

Table 2: Managed Floodplain Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Limited	The concept maintains the baseline flow condition, making downstream flood management easier.
Groundwater Recharge	Limited	Location dependent.
Water Quality	Unsure	Contaminants such as nitrates may be adsorbed to soil particles. Enhancing percolation could degrade aquifer water quality should the contaminants become mobilized.
Water Supply	Maybe	Feature dependent. Additional testing necessary to confirm.
System Sustainability	Yes	Floodplains can act as natural sediment banks, leading to more stable channels. This concept also requires no imported energy and little to no maintenance.
Ecosystem	Yes	This concept would protect the existing ecosystem within the floodplain and potentially provide some habitat diversity.
Agricultural Land	Yes	The concept preserves existing land use to maintain flood hazard reduction benefits.
Undeveloped Land	Yes	The concept preserves existing land use to maintain flood hazard reduction benefits.
Community Benefits	Maybe	Feature and land owner preference dependent.

Comparison Construction Cost Estimate

The base concept involves acquisition of agricultural and undeveloped land. The cost of this concept relative to increased flood protection is high, as is the cost of this concept relative to increased recharge. This is because the concept only maintains existing benefits and does not increase them.

Additional Benefits and Constraints

Table 3 summarizes additional considerations when evaluating the managed floodplain concept. The description of these considerations is based on the level of detail developed at this conceptual stage.

Table 3: Additional Concept Considerations for Managed Floodplain

Area	Description
Environmental Considerations	Environmental impacts would be relatively minor for this type of project concept, particularly if the existing land use is maintained. There are opportunities for environmental benefits.
Permitting	Permitting would be required only if modifications were made to the existing stream or if there was other off-stream grading or development of concept features.
Right-of-way	Right-of-way would be required for all acquired parcels. Access to the site would need to be obtained as well.
Construction	Construction is dependent on the features that are to be included with the project concept. Construction would likely be limited to earth grading and some light construction for trails and interpretation sites as necessary.
Operations & Maintenance	Very little O&M is required for this concept, particularly if the site is left as is. If soil treatment was necessary to achieve recharge, then some O&M would be scheduled to refresh the conditions. Additional features such as trails and interpretation sites would need to be maintained.
Funding	Funding sources are dependent on the final purpose and features of the project. State grants have been available for concepts of this type in the past. The multi-benefit opportunities of the concept (i.e. inclusion of recreational opportunities) will increase the number of funding sources.
Regulatory	Little to no regulatory agency involvement would be anticipated for this concept. As described above, additional features could trigger additional oversight.
Willing Land Owner	Willing land owners are necessary for this concept to be successful.
Integration with Other Concepts	Downstream projects, such as the U.S. Army Corps of Engineers' Payran flood control project, have identified upstream floodplains and attenuation as key to the success of their project. Loss of the attenuation provided by upstream floodplains would need to be mitigated or the effectiveness of downstream flood hazard reduction projects could be threatened.
Additional Studies	Additional hydraulic studies are necessary to quantify the benefit of the upstream floodplains. Geologic studies are necessary to refine the understanding of recharge potential on a site to site basis. Additional water quality testing is necessary to better understand existing and potential threats to aquifer water quality. Geomorphological studies are required to assess sediment transport characteristics of the system with this concept.

4.2 Off-Stream Detention

Concept Elements and Alternatives

The goal of this concept is to create temporary holding ponds for stormwater runoff during high-flow events; these ponds will reduce the peak hydrograph by temporarily diverting some of the flow that would otherwise create downstream flooding conditions. Detention basin locations would be outside of the direct stream channel, but would be connected to the creeks and floodways via inlet and outlet structures. The basins would be seasonally wetted, and allowed to dry out to permit maintenance. Pond locations would be obtained via flood easements (which would allow land owners to continue use of the land) or fee title acquisitions, and could be designed so as to allow multiple uses throughout the season. For example, the detention basins could be designed and constructed so as to flood in the winter, providing flood management benefits, but be dry in the summer for use as a seasonal park or sports field.

In certain areas, potential off-stream detention basin sites overlie the surface expression of the preferred water-bearing formations in the Petaluma Valley (Alluvium, Wilson Grove and Petaluma Formations). At these locations, seepage from the bottom of the detention basins will percolate downward into the near-surface primary water-bearing formations underlying the Valley, recharging the groundwater basin. The ponds/detention basins created under this scenario would both serve to reduce downstream hydrographs by diverting peak flows from the streams feeding the Petaluma River, while increasing the wetted area in the valley and extending the time over which stormwater runoff is allowed to infiltrate. Additional testing is needed to confirm the viability of this benefit concept in identified concept areas.

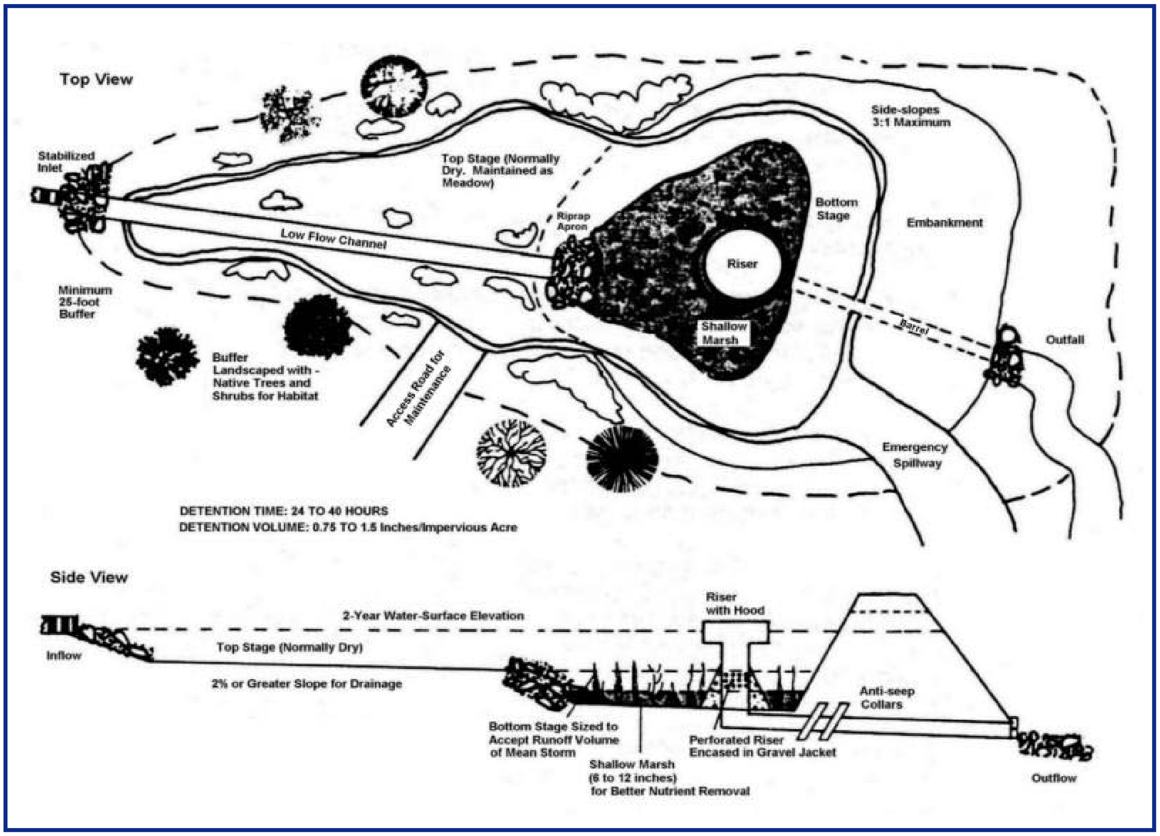
Where recharge is not an option but flooding reduction is the objective and the land owner is amenable to some grading, pools could be created to provide livestock watering alternatives to groundwater and potable supply use. The pools could also be used to develop varied habitat so long as the additional attenuation provided by the pool was not offset by new vegetation.

In all cases, off-stream detention ponds can be designed to provide multiple benefits, including recreational open space, trails, educational features, and wildlife habitat. The addition of such benefits will, however, depend on local considerations such as nearby environmental corridors, recreational areas, and concerns of the local landowners. **Figure 10** is one example of a conceptual design of an at-grade detention basin. Other designs could allow improved sediment transfer.

Another form of off-stream detention basins is the use of sub-surface detention basins. These basins perform similar to at-grade detention basins, but are engineered structures located beneath the ground. As with at-grade detention basins, these basins provide peak hydrograph reductions (reducing downstream flooding potential) and, if placed above the appropriate geologic formations, will provide some groundwater augmentation. It is strongly encouraged to include a settling basin upstream of the storage basin to reduce maintenance required within the structure. The advantage of subsurface detention basins is that they can be placed in areas with existing land use or where there are proposed developments. Typical land uses above subsurface detention basins include sports fields and parking lots but could also include structures. **Figure 11** is an example of a sub-surface off-stream detention basin.

The concept area, as shown in **Figure 12**, depicts areas that are generally relatively flat (around 2% slope or less) and have around 5 acres of land or more within around 1,000 feet of a waterway and without existing structures. If suitable sites for projects cannot be identified in this defined concept area, the range of sites will be expanded to include those with slopes of up to 10%.

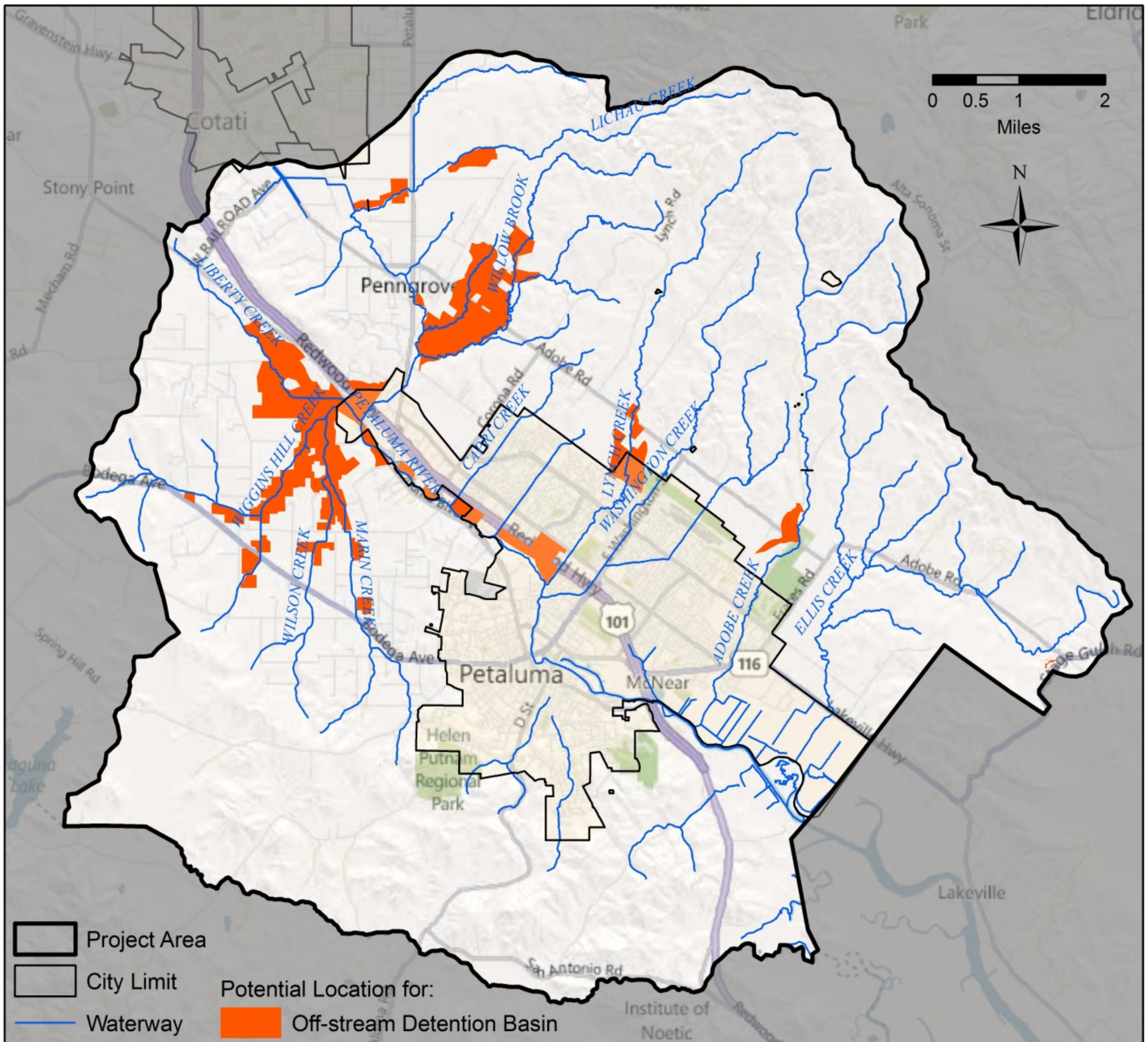
Figure 10: Concept Sketch for At-Grade Off-Stream Detention



Source: Michigan Department of Environmental Quality, 1999

Figure 11: Subsurface Off-Stream Detention Structure

Figure 12: Potential Locations for Off-Stream Detention



Source: Sonoma County, CASIL

Concept Objective Analysis

Table 4 summarizes how off-stream detention basins achieve or could achieve the core and supporting objectives identified for this Project.

Table 4: Off-Stream Detention Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Yes	The concept would be designed to reduce the peak hydrograph, reducing downstream flooding potential. However, while achieving the flood hazard reduction objective (for a specific area), this concept also needs to be evaluated for the potential to result in flood impacts outside of the concept area.
Groundwater Recharge	Maybe	Location dependent.
Water Quality	Yes	The detention basin will provide settling, reducing some runoff contaminants. Depending on design, the pond may provide other water quality benefits such as biofiltration and uptake of constituents such as nitrates.
Water Supply	Maybe	Feature and location dependent; additional testing necessary to confirm.. The concept can be designed to provide seasonal agricultural water supply in addition to groundwater recharge benefits.
System Sustainability	Yes	Detention basins are passive and use no energy to function. Off-stream basins also allow low flow but geomorphically significant flow to continue in the natural channel. Should downcutting be an issue, there is an opportunity to include grade control at the inlet and outlet structures at the creek.
Ecosystem	Yes	The concept can be designed to provide some habitat diversity in the channels to and from the basin, as well as at the basin itself. Passage of low flows in the original channel will help to maintain existing habitat to meet environmental requirements.
Agricultural Land	Maybe	In some cases, basins could be configured to allow agricultural use, especially grazing, to continue, thus minimizing net use of the land. However, design considerations will have to be made (on a site-by-site basis) in these cases to ensure that grazing livestock do not contribute stream instability, erosion or water quality impacts.
Undeveloped Land	Yes	Existing undeveloped land could be preserved or enhanced as designated open space, depending on design features.
Community Benefits	Maybe	Feature and land owner preference dependent.

Comparison Construction Cost Estimate

The base concept will involve the acquisition of agricultural and/or undeveloped land; the amount of land required is dependent on the size of the detention basin and other basin design features that may be selected for a multi-benefit project. The cost of this concept relative to increased flood protection is low for an at-grade basin and high for a sub-surface basin, as is the cost of the concept relative to increased recharge. Detention basins are an effective method to attenuate peak flows and this is reflected in the relative cost of the concept. Burying a structure increases the cost of the concept significantly.

Additional Benefits and Constraints

Table 5 summarizes additional considerations when evaluating the off-stream detention basin concept. This information is based on the level of detail developed at this conceptual stage.

Table 5: Additional Concept Considerations for Off-Stream Detention Basin

Area	Description
Environmental Considerations	Environmental impacts will be dependent on the project size, design and location. There are opportunities for environmental benefits under this concept.
Permitting	Permitting will be required for grading and construction of concept features. Additionally, a Section 404 Permit from the U.S. Army Corps of Engineers, a Section 401 Water Quality Certification from the Regional Water Quality Control Board and a Section 1601 Streambed Alteration Agreement from the California Department of Fish and Game will likely be required as part of the project’s outlet and inlet facilities design and construction. Coordination with National Marine Fisheries Service would be necessary on steelhead streams and U.S. Fish and Wildlife Service in other sensitive areas. Coordination with the California Division of Safety of Dams and compliance with dam safety regulations may be required if embankment heights, where used, exceed minimum standards.
Right-of-way	Parcels for the project will need to be acquired, along with necessary right-of-ways for accessing the acquired parcels and/or connecting the detention basin to the creek(s).
Construction	Construction is dependent on the features that are to be included with the concept and will vary depending on the type and design of basin utilized (e.g. at-grade or subsurface). Construction would likely be limited to excavation, hauling, grading, replanting and some light construction for trails and interpretation sites as necessary.
Operations & Maintenance	Regular O&M is required for this concept to maintain its effectiveness, particularly if the basin is to be designed and use for groundwater recharge. Additional features such as trails and interpretation sites would need to be maintained. Subsurface detention basins will require more costly O&M, and may require special training (e.g. confined space entry).
Funding	Funding sources are dependent on the final purpose and features of the concept. State grants have been available for projects of this type in the past. The multi-benefit opportunities of the concept will increase the number of funding sources.
Regulatory	Regulatory agency involvement is anticipated for this concept, especially as it relates to construction of detention basin inlet and outlet facilities. As described above, additional features could trigger additional oversight.
Willing Land Owner	Willing land owners are necessary for this concept to be successful.

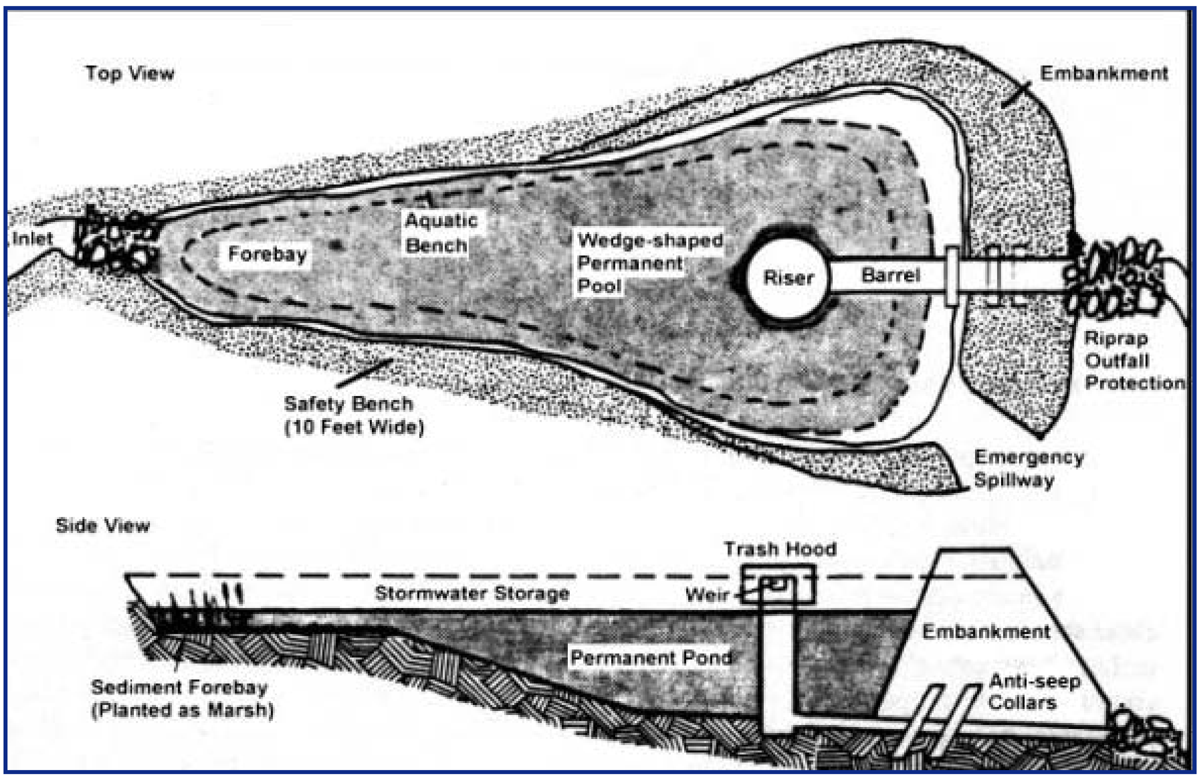
Area	Description
Integration with Other Concepts	This concept can be integrated with other concepts to provide a regionally-comprehensive flood hazard reduction project.
Additional Studies	Hydraulic studies are necessary to quantify the flood benefit of the concept to downstream reaches. Geologic studies are necessary to refine the understanding of recharge potential on a site-by-site basis. Additional water quality testing is necessary to better understand existing and potential threats to aquifer water quality.

4.3 In-Stream Detention

Concept Elements and Alternatives

The goal of this concept is to create temporary in-stream holding ponds for stormwater runoff during high-flow events; this will reduce the peak hydrograph by affecting the timing of the flood peak moving downstream to lessen downstream flood conditions. In-stream detention basins can be constructed by building an embankment across a channel so that a temporary storage pond is formed. Spillways would be incorporated into the storage embankment design to pass large floods exceeding the design runoff without threatening the integrity of the embankment. **Figure 13** is an example sketch of such an in-stream detention basin. Other basin configurations could improve geomorphological processes over the one shown.

Figure 13: Concept Sketch for In-stream Detention



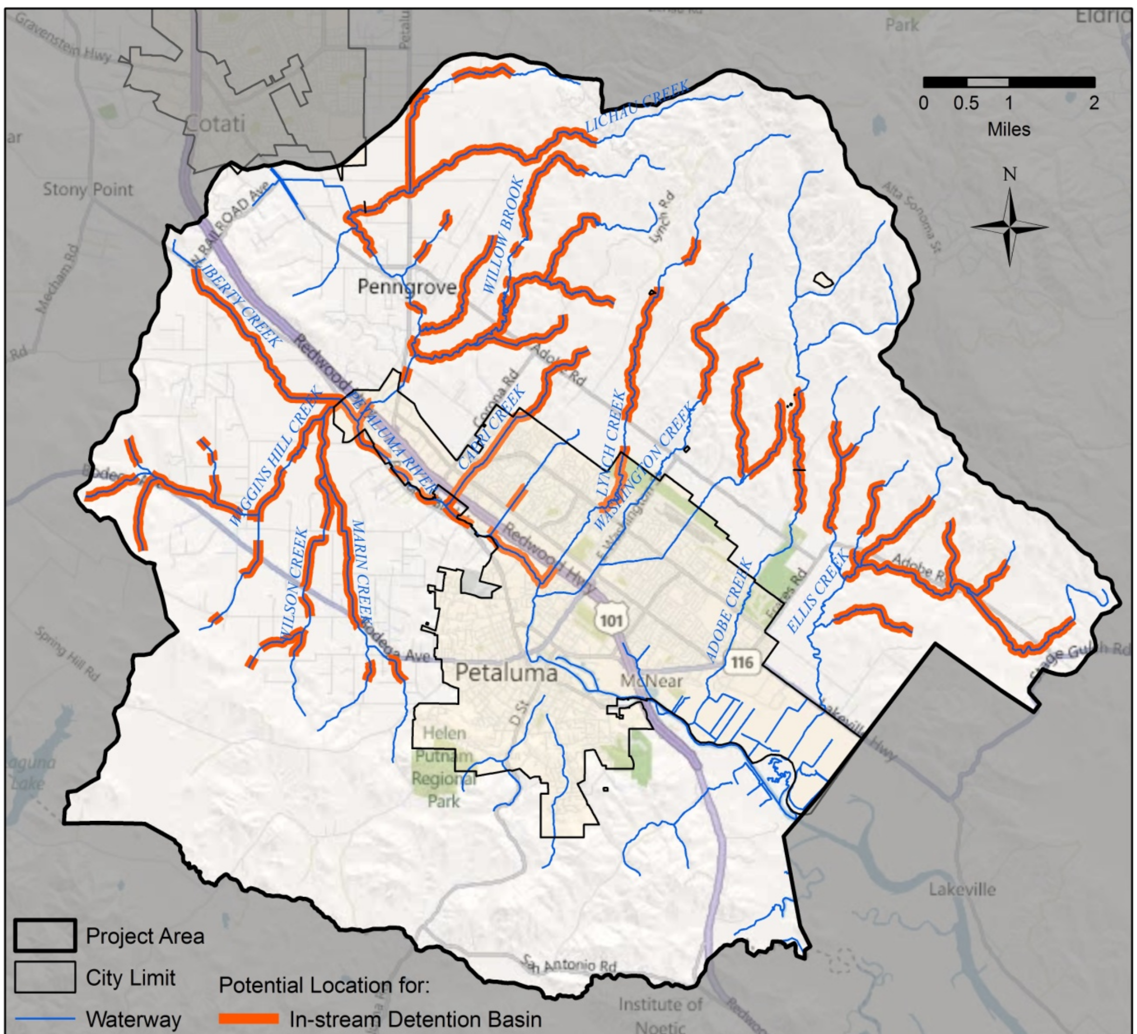
Source: Michigan Department of Environmental Quality, 1999

In-stream detention pond locations would be located within the creek and floodway. For ponds crossing private lands, flood easements (which would allow land owners to continue use of the adjacent land) or fee title acquisitions would be obtained. Additionally, the detention systems could be designed so as to provide recreational facilities (i.e. trail) or allow use as an alternative water source for non-potable uses.

In certain areas, the 100-year floodplain intersects and overlies the surface expression of the preferred water-bearing formations in the Petaluma Valley (Alluvium, Wilson Grove and Petaluma Formations). At these locations, seepage from the bottom of the detention basins will percolate downward into the near-surface primary water-bearing formations underlying the Petaluma Valley, recharging the groundwater basin. The ponds/detention basins created under this scenario would both serve to alter downstream hydrographs by diverting peak flows from the streams feeding the Petaluma River, while increasing the time over which stormwater runoff is allowed to infiltrate. Additional testing is needed to confirm the viability of this benefit in identified concept areas.

Figure 14 shows the potential locations for in-stream detention basins. Identified locations show areas where there appears to be no structure close to the channel and where the basin would provide either flood or recharge benefit.

Figure 14: Potential Locations for In-Stream Detention



Source: Sonoma County, CASIL

Concept Objective Analysis

Table 6 summarizes how in-stream detention basins achieve or could achieve the core and supporting objectives identified for this Concept.

Table 6: In-Stream Detention Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Yes	The concept would be designed to reduce the peak hydrograph, reducing downstream flooding potential. However, while achieving the flood hazard reduction objective (for a specific area), this concept also need to be evaluated for the potential to result in flood impacts outside of the concept area.
Groundwater Recharge	Maybe	Location dependent. Additional testing necessary to confirm.
Water Quality	Yes	The detention basin will provide settling, reducing some runoff contaminants. Depending on design, the pond may provide other water quality benefits such as biofiltration and uptake of constituents such as nitrates.
Water Supply	Maybe	Feature and location dependent. The concept can be designed to provide seasonal water supply in addition to groundwater recharge benefits.
System Sustainability	Maybe	Detention basins are passive and use no energy to function. Where excessive sedimentation is known to be an issue, in-stream detention basins can also act as sediment traps.
Ecosystem	No	There are some opportunities to create new habitat but the in-stream work will damage the existing ecosystem. If permittable, mitigations could be expected to be high.
Agricultural Land	Maybe	In some cases, basins could be configured to allow agricultural use, especially grazing, to continue, thus minimizing net use of the land. However, design considerations will have to be made (on a site-by-site basis) in these cases to ensure that grazing livestock do not contribute stream instability, erosion or water quality impacts.
Undeveloped Land	Yes	Undeveloped land could be preserved or enhanced, depending on design features.
Community Benefits	Maybe	Feature and land owner preference dependent.

Comparison Construction Cost Estimate

The base concept involves construction within the stream bed. The cost of this concept relative to increased flood protection is medium, as is the cost of the concept relative to increased recharge. Detention basins are an effective method to attenuate peak flows. Permitting and mitigation costs make this concept more expensive than off-stream detention basins.

Additional Benefits and Constraints

Table 7 summarizes additional considerations when evaluating the in-stream detention basin concept. This information is based on the level of detail developed at this conceptual stage.

Table 7: Additional Concept Considerations for In-Stream Detention Basin

Area	Description
Environmental Considerations	Environmental impacts will be dependent on the project size, design and location. As the project would be constructed directly in the stream bed, there will likely be impacts to site and downstream aquatic and riparian habitat.
Permitting	A Section 404 permit will be required from the U.S. Army Corps of Engineers, a 401 Water Quality Certification will be required from the Regional Water Quality Control Board, and a Section 1601 Streambed Alteration Agreement will be required from the California Department of Fish and Game. Coordination with National Marine Fisheries Service would be necessary on steelhead streams and with U.S. Fish and Wildlife Service in other sensitive habitat areas. Additionally, permits will be required for grading and construction of concept features. Coordination with the California Division of Safety of Dams and compliance with dam safety regulations may be required if embankment heights, where used, exceed minimum standards.
Right-of-way	Parcels for the project will need to be acquired, along with necessary right-of-ways for accessing the acquired parcels.
Construction	Construction is dependent on the features that are to be included with the concept. Construction would likely be limited to earth grading, replanting and some light construction for trails and interpretation sites as necessary, in addition to concept features.
Operations & Maintenance	Regular O&M is required for this concept to maintain its effectiveness; typically, sediment removal could be expected on a periodic basis. Additional features such as trails and interpretation sites would need to be maintained.
Funding	Funding sources are dependent on the final purpose and features of the project. State grants have been available for projects of this type in the past. The multi-benefit opportunities of the concept will increase the number of funding sources.
Regulatory	Regulatory agency involvement is required for this concept, especially as it relates to construction of detention basin inlet and outlet facilities. As described above, additional features could trigger additional oversight.
Willing Land Owner	Willing land owners are necessary for this concept to be successful.
Integration with Other Concepts	This concept can be integrated with other concepts to provide a regionally-comprehensive flood hazard reduction project.

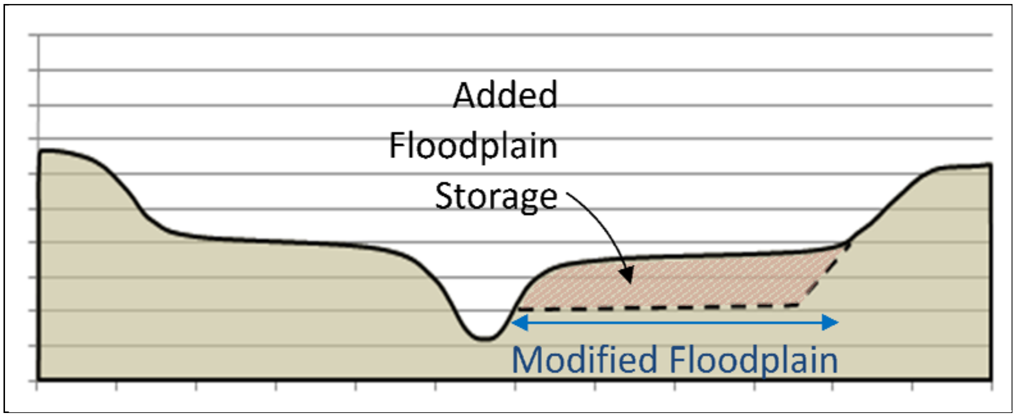
Area	Description
Additional Studies	Additional hydraulic studies are necessary to quantify the flood benefit of the project to downstream reaches. Geologic studies are necessary to refine the understanding of recharge potential on a site-by-site basis. Geomorphological studies are required to assess sediment transport characteristics of the system with this concept. Additional water quality testing is necessary to better understand existing and potential threats to aquifer water quality. Biological surveys will be required to determine the potential extent of aquatic and riparian impacts resulting from construction and operation of the project.

4.4 Floodplain Modification

Concept Elements and Alternatives

The floodplain modification concept is similar to the in-stream detention concept in that the flood management occurs within the creek and floodplain, but differs in that there is not a controlled outlet structure (i.e. embankment). The goal of this concept is to create additional storage volume for stormwater runoff during high-flow events. The concept involves modifying the floodplain areas to provide a larger cross-sectional area. These modifications may include lowering and widening the floodplain to create depressions for temporary flow storage, as shown in **Figure 15**.

Figure 15: Floodplain Modification Concept Section

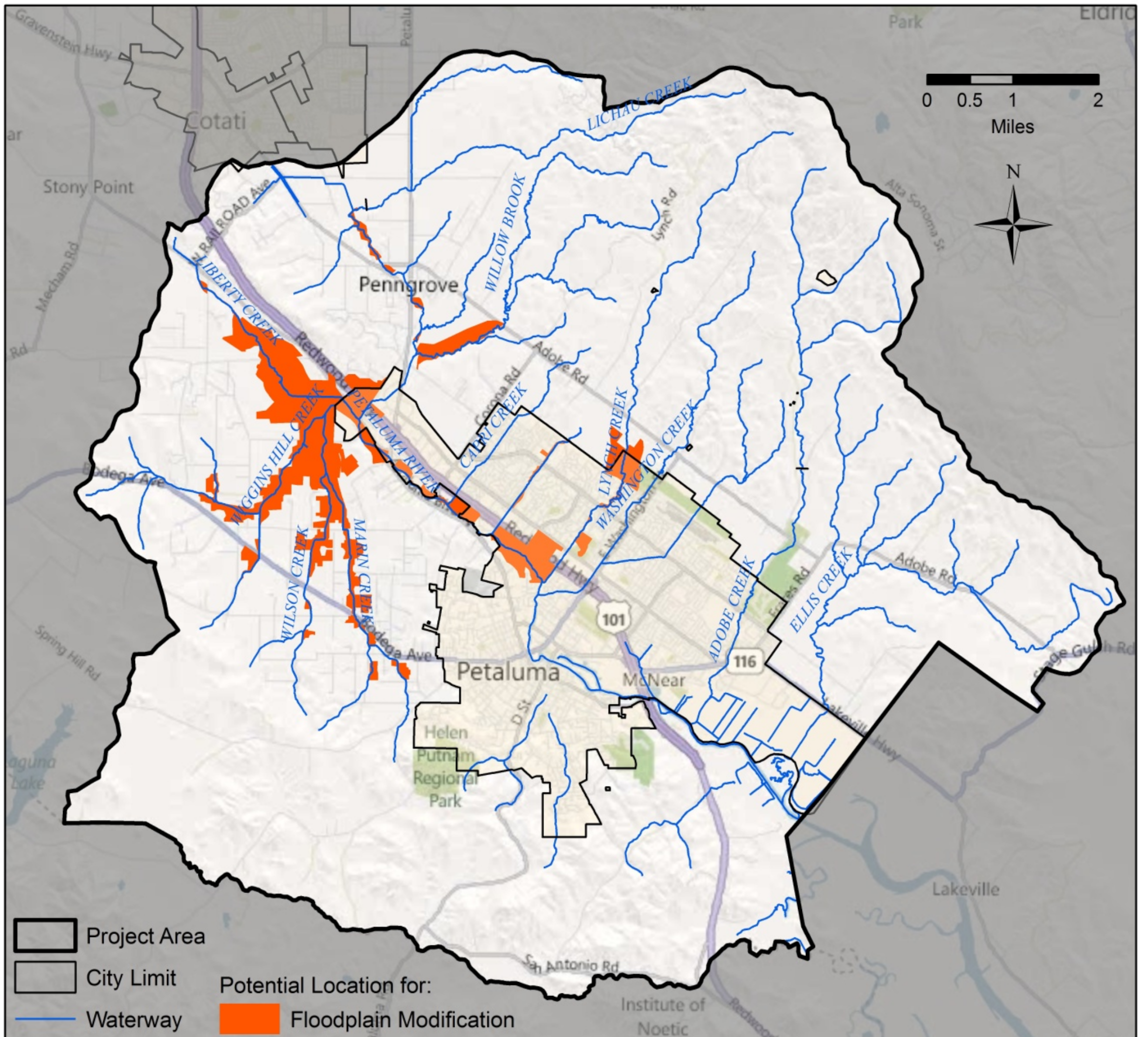


For modifications crossing private lands, flood easements (which would allow land owners to continue use of the adjacent land) or fee title acquisitions would be obtained. Additionally, the modified floodplains could be designed so as to provide recreational facilities, parks, or improved or enlarged habitat.

In certain areas, the 100-year floodplain intersects and overlies the surface expression of the preferred water-bearing formations in the Petaluma Valley (Alluvium, Wilson Grove and Petaluma Formations). At these locations, seepage from the bottom of areas where runoff is retained will percolate downward into the near-surface primary water-bearing formations underlying the Valley, recharging the basin. The additional flooded areas created under this scenario would both serve to alter downstream hydrographs by attenuating peak flows, while increasing the time over which stormwater runoff is allowed to infiltrate. Additional testing is needed to confirm the viability of this benefit in identified concept areas.

Figure 16 shows the potential locations identified for potential floodplain modifications. These locations are generally extensions of existing floodplains in relatively flat areas (about 2% slope or less) that do not overlie existing structures. If a suitable project site cannot be found within this concept area, the concept area will be extended to include areas with slopes up to 10%. Some areas may be outside of the 1,000-foot zone applied to other concepts.

Figure 16: Potential Locations for Floodplain Modifications



Source: Sonoma County, CASIL

Concept Objective Analysis

Table 8 summarizes how floodplain modifications achieve or could achieve the core and supporting objectives identified for this Project.

Table 8: Floodplain Modification Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Yes	The concept would be designed to reduce the peak hydrograph, reducing downstream flooding potential. However, while achieving the flood hazard reduction objective (for a specific area), this concept also need to be evaluated for the potential to result in flood impacts outside of the concept area.
Groundwater Recharge	Yes	The modified floodplain concept will increase the wetted area in the streambed, thereby promoting additional groundwater recharge.
Water Quality	Yes	The modified floodplain will provide opportunity for additional settling, reducing some runoff contaminants. Depending on design, the lower floodplain may provide other water quality benefits such as biofiltration and uptake of constituents such as nitrates.
Water Supply	Maybe	.Floodplain modification may have the potential to recharge groundwater by providing a greater wetted area for recharge and slowing flows such that there is an extended period of time over which recharge may occur. Extent of recharge for supply is location dependent.
System Sustainability	Yes	This long-term solution could be designed to enhance sediment management and transport within the system by acting as a sediment bank (sediments deposited on the created bench would be available for entrainment by future high flows with sediment transport capacity).
Ecosystem	Yes	While there could be some riparian impacts they would be relatively high on the channel banks, reducing overall impact. What was lost could be mitigated for with new plantings and habitat creation in the benched floodplain. Impacts are only on one side of the channel.
Agricultural Land	Yes	The concept would not require agricultural lands for implementation unless they were within the identified area for protection. Once lowered, the floodplain could potentially be returned to agricultural use.
Undeveloped Land	Yes	The concept would not require undeveloped land unless they were within the identified area for protection. Once lowered, the floodplain could be maintained as a designated open space.
Community Benefits	Maybe	Feature and land owner preference dependent.

Comparison Construction Cost Estimate

The estimated construction cost for this concept will vary, to some degree, by who owns the aquatic and riparian lands at and immediately adjacent to the proposed project site. The base concept involves construction within the riparian corridor. The cost of this concept relative to increased flood protection is medium, as is the cost of the concept relative to increased recharge. Floodplain modification is anticipated to provide fewer additional benefits than detention basins for approximately the same cost.

Additional Benefits and Constraints

Table 9 summarizes additional considerations when evaluating the floodplain modifications concept. This information is based on the level of detail developed at this conceptual stage.

Table 9: Additional Concept Considerations for Floodplain Modification

Area	Description
Environmental Considerations	Environmental impacts will be dependent on the project size, design and location.
Permitting	A Section 404 permit will likely be required from the U.S. Army Corps of Engineers, and a Section 401 Water Quality Certification will likely be required from the Regional Water Quality Control Board. Further, a Section 1601 Streambed Alteration Agreement may also be required from the California Department of Fish and Game. Coordination with National Marine Fisheries Service would be necessary on steelhead streams and with U.S. Fish and Wildlife Service in other sensitive habitat areas. Additionally, permits will be required for grading and construction of concept features.
Right-of-way	Parcels for the project would need to be acquired as either easement or fee title, along with necessary right-of-ways for accessing the acquired parcels.
Construction	Construction is dependent on the features that are to be included with the concept. Construction would likely be limited to earth grading, replanting and some light construction for trails and interpretation sites as necessary, in addition to concept features.
Operations & Maintenance	Minimal O&M is required for this concept to maintain its effectiveness. Additional features such as trails and interpretation sites would need to be maintained.
Funding	Funding sources are dependent on the final purpose and features of the project. State grants have been available for project of this type in the past. The multi-benefit opportunities of the concept will increase the number of funding sources.
Regulatory	Regulatory agency involvement is anticipated for this concept. As described above, additional features could trigger additional oversight.
Willing Land Owner	Willing land owners are necessary for this concept to be successful.
Integration with Other Concepts	This concept can be integrated with other concepts to provide a regionally-comprehensive flood hazard reduction project.

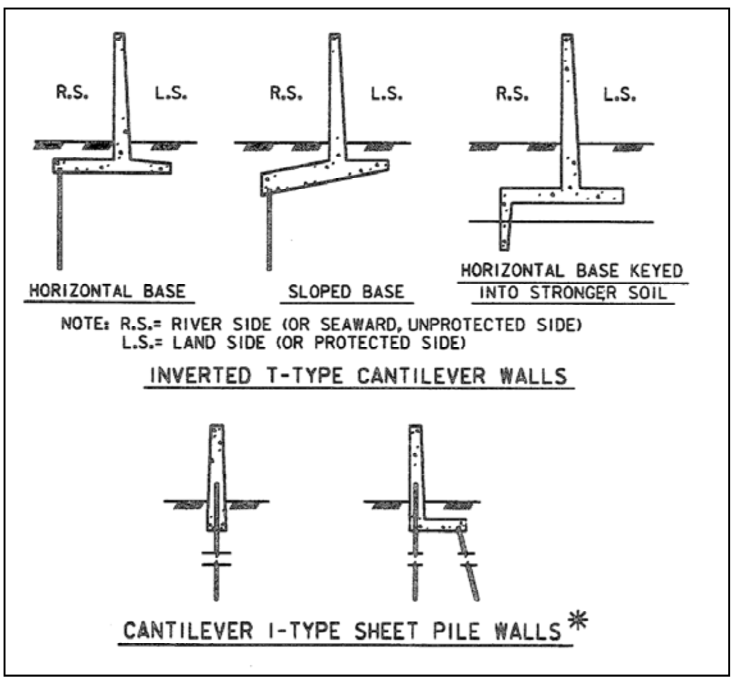
Area	Description
Additional Studies	Additional hydraulic studies are necessary to quantify the benefit of the project to downstream reaches. Geologic studies are necessary to refine the understanding of recharge potential on a site-by-site basis. Geomorphological studies are required to assess sediment transport characteristics of the system with this concept. Additional water quality testing is necessary to better understand existing and potential threats to aquifer water quality. Biological surveys will also be required to determine the potential extent of aquatic and riparian impacts resulting from construction of the project.

4.5 Levee/Floodwall

Concept Elements

Levees and floodwalls constrain flow to a narrower pathway than the existing floodplain. Levees are earthen structures that are generally trapezoidal in shape. A road is often located on the top of the levee for both observation purposes and maintenance access to both sides of the structure. Recreational trail access could be included by designing the road to be dual function. Floodwalls have a smaller overall footprint than levees. Access roads for maintenance and potentially trails would be located next to the flood wall. **Figure 17** show a cross section for several types of floodwalls. The location of the levee or floodwall relative to the waterway is dependent on the limitations of the surrounding area. Where constricted, the structures can be placed closer to the channel. Where there is a local floodplain where flooding is acceptable, setback levees are a good option to minimize riparian impacts and potentially offer additional benefits. Channel stability would need to be examined as part of the design process and likely improved. This could be through bio-technical stabilization methods or less natural methods where necessary.

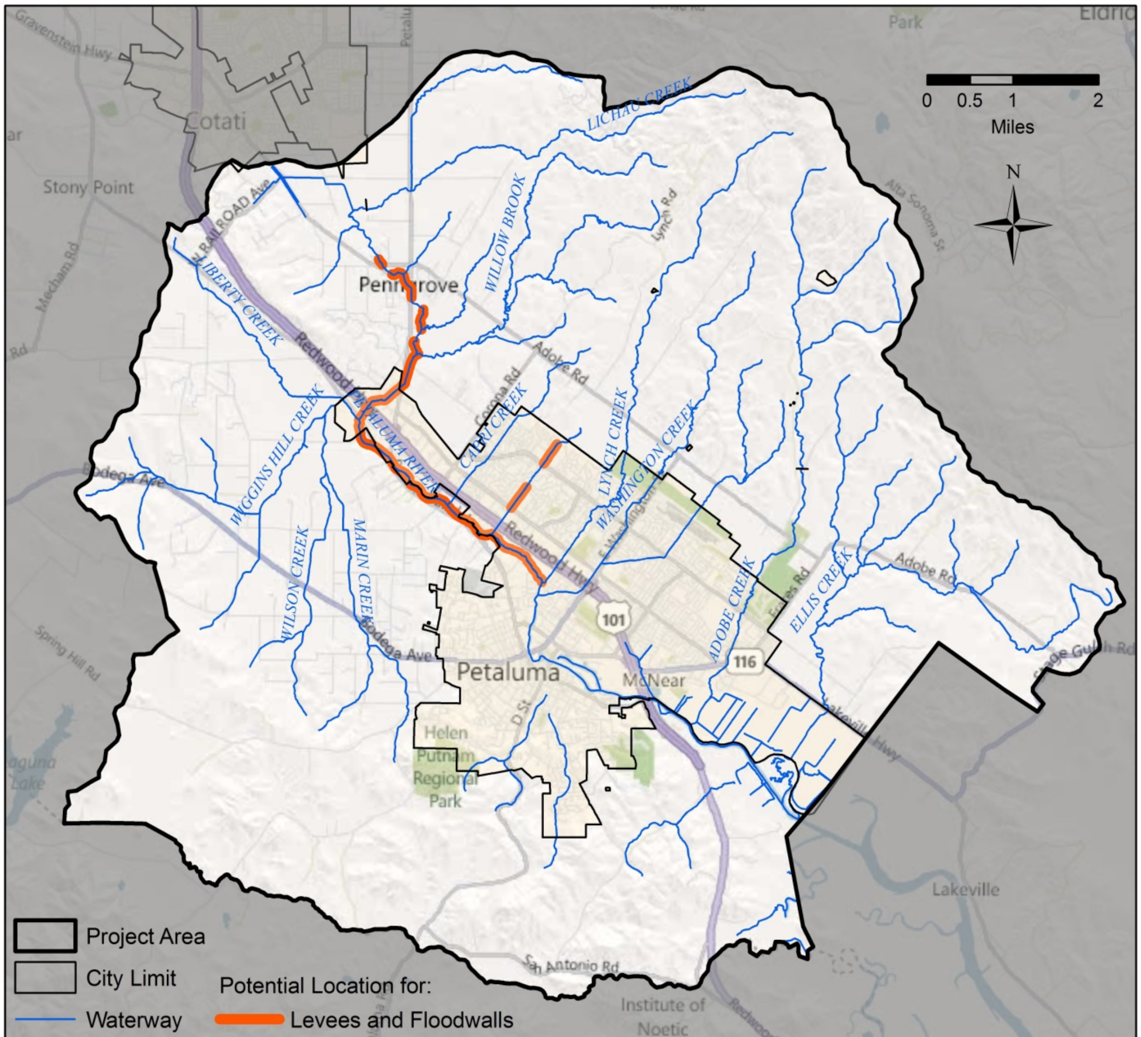
Figure 17: Common Types of Floodwalls



Source: Army Corps of Engineers, 1989

While it is possible to travel longitudinally along this concept, it is difficult to cross a levee, and especially a floodwall. Therefore levees and floodwalls are least disruptive where crossings are more controlled, such as via bridges. Pasture lands and farms that cross waterways are typically not ideal locations for levees and floodwalls. **Figure 18** shows potential locations where levees or floodwalls could be considered for this Project. These are generally areas with identified 100-year floodplains and within an urban area.

Figure 18: Potential Locations for Levees and Floodwalls



Source: Sonoma County, CASIL

Concept Objective Analysis

Table 10 summarizes how levees and floodwalls achieve or could achieve the core and supporting objectives identified for this Concept.

Table 10: Levees and Floodwalls Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Yes	The level of flood hazard reduction and the areas with reduced flooding hazards would depend on the location of the project and the design. However, while achieving the flood hazard reduction objective (for a specific area), this concept also need to be evaluated for the potential to result in flood impacts outside of the concept area.
Groundwater Recharge	No	The concept does not provide additional infiltration surface, improve surface characteristics for recharge, or detain water for additional percolation time.
Water Quality	Maybe	In areas where water is conveyed more quickly, it is possible that fewer contaminants would be mobilized in the ground due to infiltrated groundwater.
Water Supply	No	Recharge and offsetting water supplies are not envisioned to be a part of this concept.
System Sustainability	Yes	Stabilization of the channel would be an important component of the concept. Geomorphological processes would be considered during design. No imported energy is necessary for this concept to function.
Ecosystem	Maybe	Setback levees and floodwalls could provide for additional habitat if land use were converted within the concept area. .
Agricultural Land	Yes	The concept would likely not require agricultural lands as they are not the identified protection area.
Undeveloped Land	Yes	The concept would likely not require undeveloped land as they are not the identified protection area.
Community Benefits	Maybe	Trails and other recreational and educational features could be incorporated into levee design.

Comparison Construction Cost Estimate

The estimated construction cost for this concept will vary based on the type of structure selected (levee versus floodwall) and the cost of the land required for its location. The base concept involves construction within the riparian corridor. The cost of this concept relative to increased flood protection is low. The cost of this concept relative to increased recharge is, however, very high as there are no recharge benefits associated with this concept. Levees and floodwalls are anticipated to have relatively low cost compared to the earthwork required to provide the same conveyance capacity through enlarging the channel.

Additional Benefits and Constraints

Table 11 summarizes additional considerations when evaluating the levees and floodwalls concept. The description of these considerations is based on the level of detail developed at this conceptual stage.

Table 11: Additional Concept Considerations for Levees and Floodwalls

Area	Description
Environmental Considerations	Current standards often limit vegetation around both levees and flood walls. This could have serious implications on the amount and quality of habitat near the waterway as well as in-stream conditions. The concept can also potentially impact the movement of some species. Floodwalls, as they are constructed vertical structures, are particularly susceptible to this.
Permitting	Construction and regulatory permits would be required for this concept. Some regulatory agencies that would require permits include California Department of Fish and Game, Regional Water Quality Control Board, and the US Army Corps of Engineers. Coordination may also be required with the National Marine Fisheries Service and U.S. Fish and Wildlife Service.
Right-of-way	Right-of-way would be required for at least the footprint of the levee/floodwall and the creek in between the opposing structures for maintenance purposes.
Construction	Construction would require large earth moving and grading equipment for levees and floodwalls. Depending on materials, floodwalls may require additional equipment to work with the metals or concrete.
Operations & Maintenance	Levees and floodwalls would need to be inspected and maintained regularly. Sediment and vegetation within the conveyance area would need to be maintained and sometimes removed. Use of appropriate design concepts would minimize the need for extreme maintenance except under special circumstances.
Funding	Funding may be available for this concept under some state funding programs such as Proposition 1E..
Regulatory	Placement of the levees and floodwalls can determine the amount and types of impacts that the concept would create, thus adjusting the amount of regulatory scrutiny. This concept would generally involve significant regulatory agency participation.
Willing Land Owner	A willing land owner is necessary for this concept. Since there is a change in land form and responsibility for maintenance, fee title acquisition would be preferred as opposed to an easement.
Integration with Other Concepts	Implementation may or may not induce flooding elsewhere depending on site specific conditions. If it is shown to do so, due to the reduction of attenuation, the concept could be paired with an attenuation-type project to offset the impacts downstream. This concept can be integrated with other concepts to provide a regionally-comprehensive flood hazard reduction project.

Area	Description
Additional Studies	Additional modeling is necessary to confirm that downstream flooding is not induced through implementation of this concept. Geomorphological studies are required to assess sediment transport characteristics of the system with this concept. Biological surveys will also be required to determine the potential extent of aquatic and riparian impacts resulting from construction of the project.

4.6 Channel Modifications

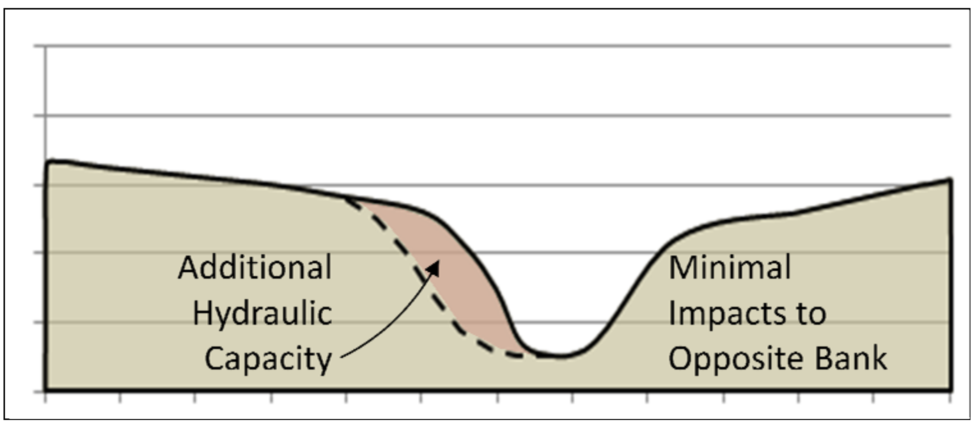
Concept Elements

This concept is assumed to be expansion of the channel rather than vegetation or sediment removal. Vegetation and sediment removal are considered maintenance activities and should be performed regularly according to the permitted maintenance plan.

Channel expansion involves excavation of the channel or reshaping of the channel section to provide additional hydraulic capacity. Since flood hazard reduction activities for this Project are focused on areas where channel width is not overly restricted (e.g. outside of downtown Petaluma), it is preferable to expand the channel in a more natural shape and maintain earthen banks rather than create smoother, more vertical walls as in a U-shaped channel. This will facilitate better sediment balance and opportunity for vegetation and habitat maintenance or improvement.

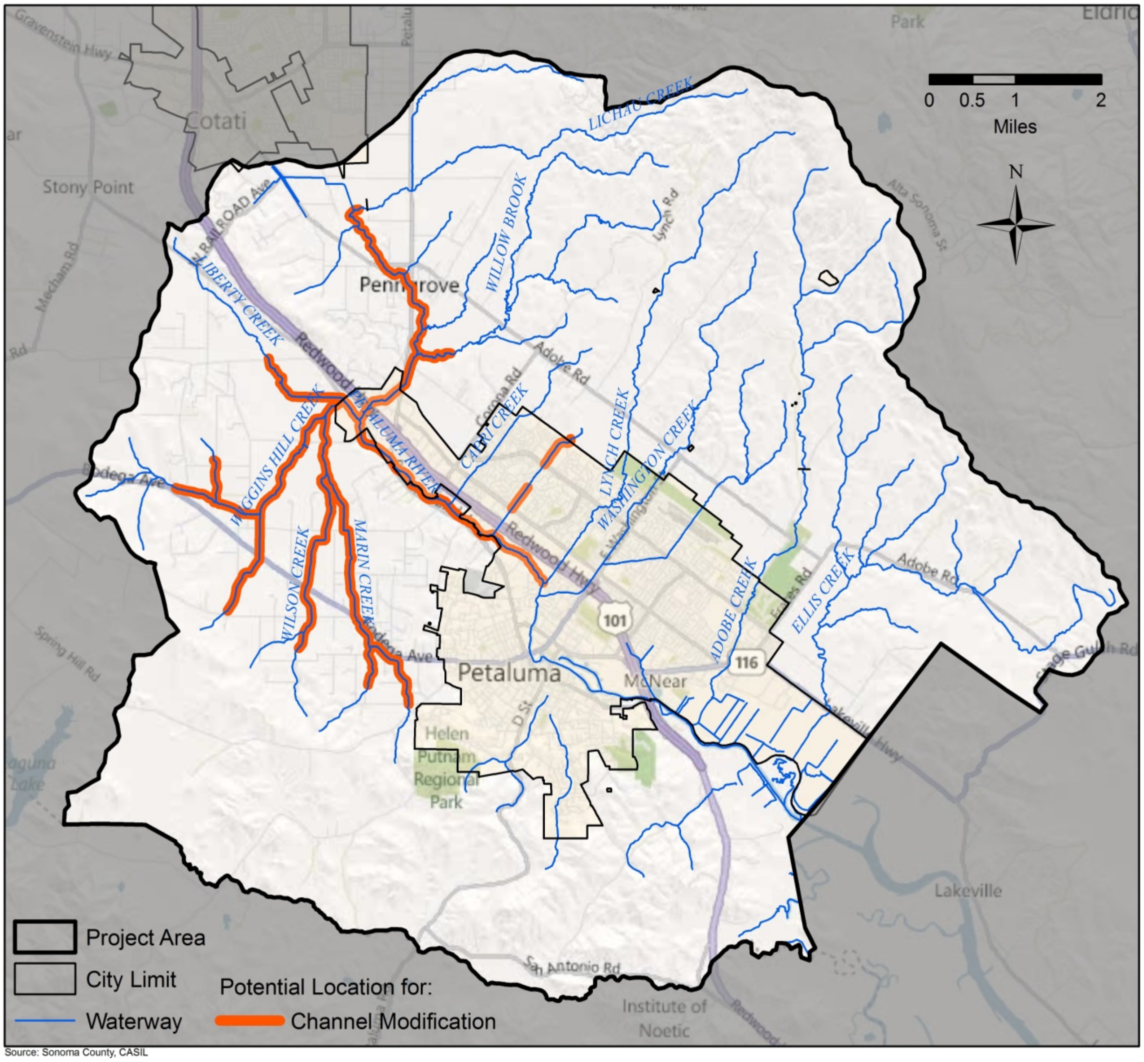
Expanding the channel will increase its cross-sectional area and provide for increased hydraulic capacity. Channel widening is achieved through excavation. By excavating on only one side of the channel it is possible to minimize impacts to resources on the opposite bank, such as the existing vegetation, as shown in **Figure 19**. There is also an opportunity to establish grade control or adjust channel slope over short distances to adjust sediment transport characteristics of the channel. Maintenance roads are an important tool to maintain the channel. A high maintenance road will allow access during all flow conditions and a good observation point during high flows. A low maintenance road provides access to the lower parts of the channel during low flows and provides access without damaging vegetation during creating of new access roads. One or more of the access roads could be used as a trail.

Figure 19: Channel Modification Concept Section



This concept is hydraulically feasible in any location with flooding. **Figure 20** shows channels within in the 100-year floodplain in the flood protection focus area where there may be an opportunity to expand the channel.

Figure 20: Potential Locations for Channel Modifications



Source: Sonoma County, CASIL

Concept Objective Analysis

Table 12 summarizes how channel modifications achieve or could achieve the core and supporting objectives identified for this Project.

Table 12: Channel Modification Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Yes	The concept would be designed to reduce the peak hydrograph, reducing downstream flooding potential. However, while achieving the flood hazard reduction objective (for a specific area), this concept also need to be evaluated for the potential to result in flood impacts outside of the concept area.
Groundwater Recharge	Maybe	Channel modification may have the potential to recharge groundwater by providing a greater wetted area for recharge and slowing flows such that there is an extended period of time over which recharge may occur..
Water Quality	Maybe	In areas where water is conveyed more quickly, it is possible that fewer contaminants would be mobilized in the ground due to infiltrated groundwater.
Water Supply	Maybe	Channel modification may have the potential to recharge groundwater by providing a greater wetted area for recharge and slowing flows such that there is an extended period of time over which recharge may occur. The degree to which a water supply benefit is achieved is location dependent.
System Sustainability	Yes	Sediment transport and channel stability would be considered during design. No imported energy is necessary for this concept to function.
Ecosystem	Maybe	Excavation on one side of the channel will minimize impacts to existing vegetation. Channel improvements such as shade and in-stream features could improve habitat.
Agricultural Land	Yes	The concept would not require agricultural lands unless they were within the identified protection area.
Undeveloped Land	Yes	The concept would not require undeveloped land unless they were in the identified protection area.
Community Benefits	Maybe	Trails could be incorporated into the concept design.

Comparison Construction Cost Estimate

The estimated construction cost for this concept assumes that channel modifications will occur within the public right-of-way, and therefore there will be no associated land acquisition costs or easements necessary. The cost of this concept relative to increased flood protection is medium while the cost of this concept relative to increased recharge is high. Channel modification is anticipated to have a cost:value ratio comparable to the floodplain modification concept for flood hazard reduction. Recharge benefits are anticipated to be lower however.

Additional Benefits and Constraints

Table 13 summarizes additional considerations when evaluating the channel modification concept. The description of these considerations is based on the level of detail developed at this conceptual stage.

Table 13: Additional Concept Considerations for Channel Modifications

Area	Description
Environmental Considerations	The excavation and removal of existing vegetation will need to be mitigated based on conversations and negotiations with regulatory agencies.
Permitting	A Section 404 permit will likely be required from the U.S. Army Corps of Engineers, and a Section 401 Water Quality Certification will likely be required from the Regional Water Quality Control Board. Further, a Section 1601 Streambed Alteration Agreement may also be required from the California Department of Fish and Game. Coordination may also be required with the National Marine Fisheries Service and U.S. Fish and Wildlife Service. Additionally, permits will be required for grading and construction of concept features.
Right-of-way	Right-of-way would be required for the existing and widened creek sections for maintenance purposes.
Construction	Construction would likely be limited to earth grading, replanting and some light construction for trails and interpretation sites as necessary, in addition to concept features.
Operations & Maintenance	Channel wall stability would need to be inspected and maintained. Sediment and vegetation within the conveyance area would need to be maintained and sometimes removed. Use of appropriate design concepts would minimize the need for extreme maintenance.
Funding	Funding may be available for this concept under some state funding programs such as Proposition 1E.
Regulatory	This concept would generally involve significant regulatory agency participation.
Willing Land Owner	A willing land owner is necessary for this concept. Since there is a change in land form, fee title acquisition would be preferred as opposed to an easement.
Integration with Other Concepts	Implementation should not induce flooding elsewhere. If it is shown to do so, due to the reduction of attenuation, the concept could be paired with an attenuation-type project to offset the impacts downstream.
Additional Studies	Additional hydraulic studies are necessary to quantify the benefit of the project to downstream reaches. Geomorphological studies are required to assess sediment transport characteristics of the system with this concept. Biological surveys will also be required to determine the potential extent of aquatic and riparian impacts resulting from construction of the project.

4.7 Bypass Channel

Concept Elements and Alternatives

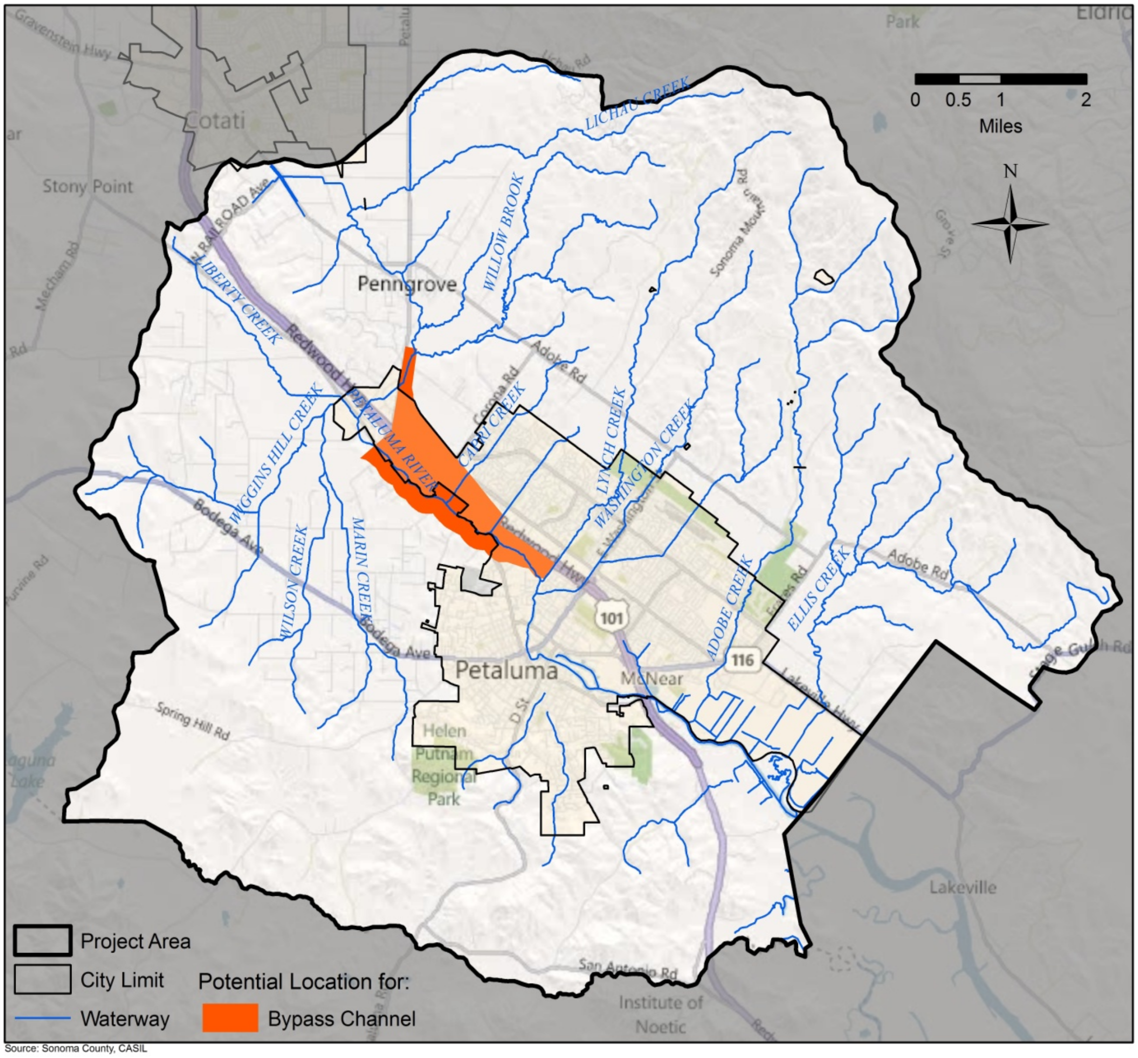
A bypass channel could be constructed to add additional hydraulic capacity to the waterway system. The concept would be limited to a high flow bypass. This means that use of the capacity of the existing stream would be maximized and the bypass would only be used to convey the additional flow that would have caused flooding. This arrangement continues to allow environmental flows in the existing channel. A passive weir structure would set the water surface elevation that triggers use of the high flow bypass. Depending on fish stranding concerns, an exclusion device could be located at the downstream end of the bypass.

The concept would be realized differently in developed and rural areas as described:

- Developed – The bypass channel would be a buried culvert. It would likely be located in a public right-of-way, for example underneath a street. This configuration would allow surface uses to continue after construction of the bypass. Utility relocation is an added cost that is dependent on the location and size of the culvert as well as the type of utility. The actual bypass would likely be constructed from a precast reinforced concrete box culvert to minimize the time necessary for the street to be open. The box culvert, as opposed to a circular culvert, would also facilitate maintenance.
- Undeveloped – The bypass channel would be an open cut channel. In agricultural areas, channel banks with shallow slopes would allow continued joint use for livestock or mowing. In undeveloped areas, the footprint of the channel could be increased to allow both the necessary hydraulic capacity as well as new habitat that would benefit from periodically inundated conditionsAt least one maintenance/access road would be needed, depending on the size of the channel and local conditions.

Figure 21 shows potential locations for bypass channels in a relatively urban area. The location shown is in a floodplain with undeveloped land and/or roads near the river and creeks. Bypass locations in rural areas are not shown due to the potential impacts to existing land uses.

Figure 21: Potential Locations for Buried Bypass Channels



Concept Objective Analysis

Table 14 summarizes how bypass channels achieve or could achieve the core and supporting objectives identified for this concept.

Table 14: Bypass Channel Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Yes	The concept would be designed to reduce the peak hydrograph, reducing downstream flooding potential. However, while achieving the flood hazard reduction objective (for a specific area), this concept also need to be evaluated for the potential to result in flood impacts outside of the concept area..
Groundwater Recharge	Maybe	Depending on design and location, there may be an opportunity for recharge, particularly in rural areas. However, the degree to which recharge may be achieved is small due to the design of the bypass channel as a conveyance structure rather than a detention structure.
Water Quality	Yes	The bypass could be oversized to allow for reduced vegetation clearing in the original channel. This would allow additional sedimentation and surface runoff contaminants, particularly trash, to be caught closer to the point of entry into the water system.
Water Supply	Maybe	A bypass channel may have some potential to recharge groundwater, provided the bottom is unlined, due to the additional wetted area available for recharge.
System Sustainability	Yes	Sediment transport and channel stability would be considered during design, both in the original channel and the bypass. No imported energy is necessary for this concept to function.
Ecosystem	Yes	The bypass could be oversized to allow for reduced vegetation clearing in the original channel. This would allow additional habitat preservation and lower maintenance requirements in the original channel.
Agricultural Land	Yes	The concept would not require agricultural lands unless they were within the identified protection area. Partnering with neighboring land owners on design concepts could allow joint use.
Open Space	Yes	The concept would not require undeveloped land unless they were in the identified protection area. Oversizing the channel could lead to enhancements by providing additional space for riparian habitat.
Community Benefits	Maybe	Trails could be incorporated into the concept design. The diversion and re-entry points of the bypass channel would be good locations for interpretive signs, particularly in developed areas.

Comparison Construction Cost Estimate

Land costs associated with this concept will vary considerable based on the size, location, and type of bypass channel constructed. The cost of this concept relative to increased flood protection is medium, as is the cost of this concept relative to increased recharge. The cost:value ratios are anticipated to be comparable to those of the floodplain modification concept.

Additional Benefits and Constraints

Table 15 summarizes additional considerations when evaluating the bypass channel concept. The description of these considerations is based on the level of detail developed at this conceptual stage.

Table 15: Additional Concept Considerations for Bypass Channels

Area	Description
Environmental Considerations	Environmental considerations will be different between a buried culvert bypass in a developed setting vs. an open cut bypass in a rural setting. A rural open cut channel has a higher potential for environmental impacts as the developed area has already impacted the natural environment. Since the bypass will be for high flows only, in-stream environmental conditions (e.g. minimum flow rates, temperature limits, etc) will be maintained.
Permitting	Construction and regulatory permits would be required for this concept, especially as they related to the inlet and outlet of the bypass channels. A Section 404 permit will likely be required from the U.S. Army Corps of Engineers, and a Section 401 Water Quality Certification will likely be required from the Regional Water Quality Control Board. Further, a Section 1601 Streambed Alteration Agreement may be required from the California Department of Fish and Game. Additional permits and/or coordination may be required from/with National Marine Fisheries Service and U.S. Fish and Wildlife Service.
Right-of-way	In developed areas, the bypass would be located in public rights-of-way, such as roads, or private property, such as parking lots. This concept reduces the amount of acquisition necessary In rural areas, right-of-way would be required for the channel and access along the channel. Both easement or fee title could be acceptable.
Construction	In developed areas, construction would require excavation equipment and cranes to assemble the precast culvert pieces. There would likely be some impact to local businesses and residents depending on the alignment. In rural areas, construction would require large earth moving and grading equipment.
Operations & Maintenance	Operations and maintenance would be based on regular visual inspections to confirm that hydraulic capacity is available in the bypass and original channel. Some sediment removal could be necessary from the bypass, but use of appropriate design concepts would minimize the need for extreme maintenance.
Funding	Funding may be available for this concept under some state funding programs such as Proposition 1E.

Area	Description
Regulatory	Regulatory participation would be dependent on the alignment of the bypass and the associated impacts. The diversion and re-entry points would likely draw much of the attention of the regulatory agencies as those are the points where the stream would be impacted by the project.
Willing Land Owner	A willing land owner is necessary for this concept.
Integration with Other Concepts	Implementation should not induce flooding elsewhere. If it is shown to do so, due to the reduction of attenuation, the concept could be paired with an attenuation-type project to offset the impacts downstream.
Additional Studies	Additional hydraulic studies are necessary to quantify the benefit of the project to downstream reaches. Geologic studies are necessary to refine the understanding of recharge potential on a site-by-site basis. Geomorphological studies are required to assess sediment transport characteristics of the system with this concept. Biological surveys will also be required to determine the potential extent of impacts resulting from construction of the project.

4.8 Bridge Improvement and Debris Removal

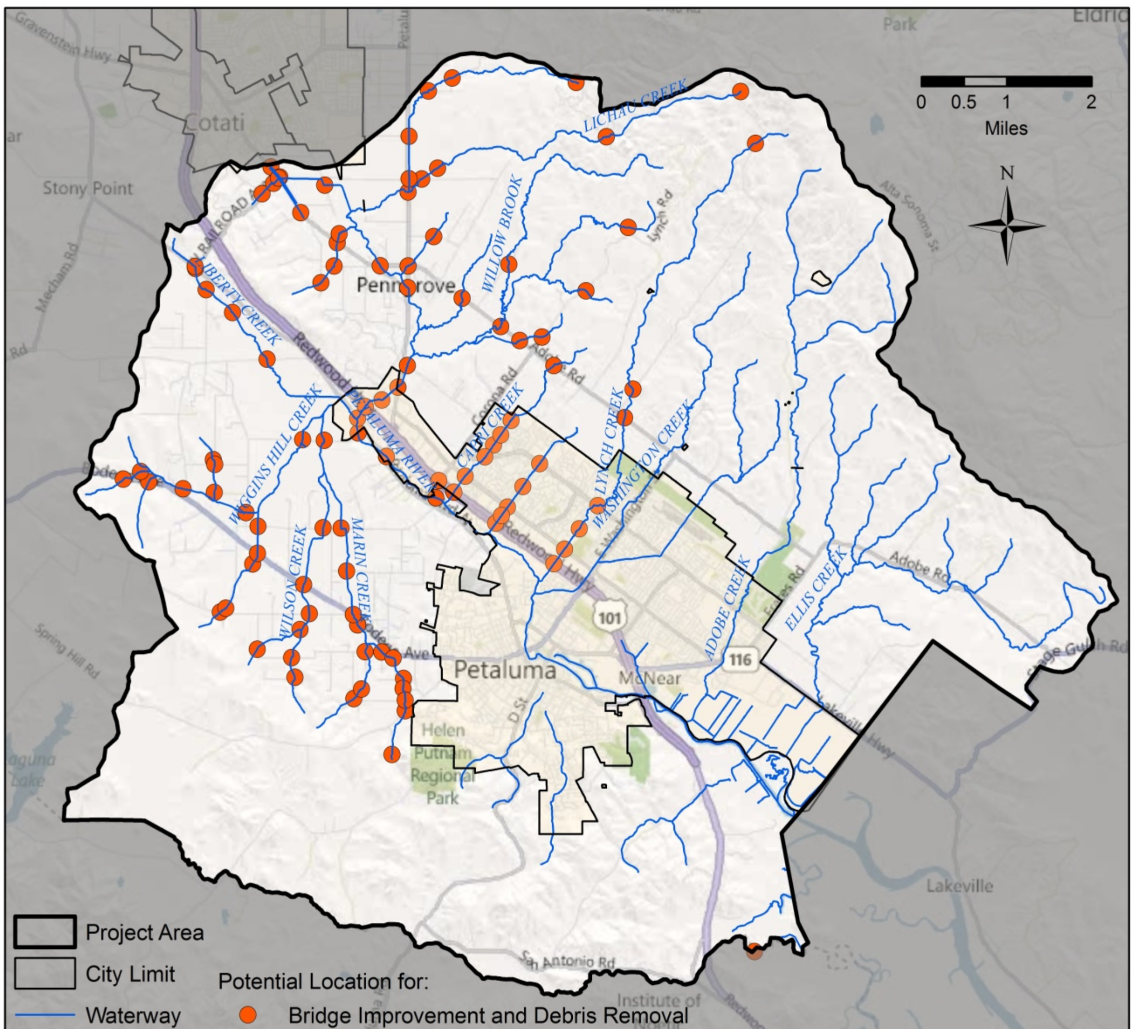
Concept Elements and Alternatives

Bridges sometimes collect debris (e.g. sediment, vegetation, trash) which can limit their hydraulic capacity so much that flooding is induced. Where this occurs, the problem can be addressed either through more regular maintenance or reforming the bridge approach, adding upstream debris collectors, or changing the shape and design of the bridge piers. This concept assumes that existing maintenance is not adequate to address the flooding issues.

Implementation of the concept would involve inspection and review of bridges within the Project area for evidence of recent flooding due to debris build-up. Review would include the collection and analysis of anecdotal data, identification of high water marks, and maintenance records in addition to hydraulic modeling to predict how the bridge would function without debris. Where there was evidence of flooding due to debris build-up, the bridge and upstream channel would be examined to identify potential solutions to reduce the build-up of debris. Potential solutions include addition of pier noses (shown in **Figure 22**), redistribution of piers, channel straightening, or construction of barriers to large debris. **Figure 23** shows the location of crossings over creeks in the watershed upstream of the Lynch Creek and Petaluma River confluence.

Figure 22: Pier Noses

Figure 23: Potential Locations for Bridge Improvement and Debris Removal



Source: Sonoma County, CASIL

Concept Objective Analysis

Table 16 summarizes how bridge improvement and debris removal achieves or could achieve the core and supporting objectives identified for this Project.

Table 16: Bridge Improvement and Debris Removal Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Yes	Local flooding due to debris build-up would be addressed. However, while achieving the flood hazard reduction objective (for a specific area), this concept also need to be evaluated for the potential to result in flood impacts outside of the concept area.
Groundwater Recharge	No	The concept does not provide additional infiltration surface, improve surface characteristics for recharge, or detain water for additional percolation time.
Water Quality	No	This concept is not envisioned to significantly change either the surface water quality or groundwater quality.
Water Supply	No	Enhancement of water supply reliability is not envisioned to be a part of this concept.
System Sustainability	Yes	This concept could lead to easier passage of sediment, restoring a more natural geomorphological balance. This concept could also lead to less intensive maintenance activities.
Ecosystem	No	This concept does not improve ecosystem function.
Agricultural Land	Yes	This concept would require little, if any, agricultural land. If it did require the use of any agricultural land it would likely be for the benefit of the upstream agricultural land.
Undeveloped Land	Yes	It is not envisioned that this concept would be required at undeveloped land and would therefore not require any open space land.
Community Benefits	Yes	This concept could improve aesthetics at bridges where unsightly trash and debris impact peoples' appreciation of the stream.

Comparison Construction Cost Estimate

The estimated construction cost for this concept assumes that all bridge improvements will occur within the public right-of-way, and therefore there will be no associated land acquisition costs or easements necessary. Although the benefits associated with debris removal are local only, the cost for such activities relative to increased flood protection is relatively low. Recharge benefits are not expected with this concept. .

Additional Benefits and Constraints

Table 17 summarizes additional considerations when evaluating the bridge improvement and debris removal concept. The description of these considerations is based on the level of detail developed at this conceptual stage.

Table 17: Additional Concept Considerations for Bridge Improvement and Debris Removal

Area	Description
Environmental Considerations	Channel straightening and installation of debris collectors upstream of bridges could have significant environmental impacts.
Permitting	Permitting would vary depending on the recommended solutions, but in most cases a permit would be required from California Department of Fish and Game, Regional Water Quality Control Board, National Marine Fisheries Service, U.S. Fish and Wildlife Service and U.S. Army Corps of Engineers. Where there are modifications to bridge structures or within crossing easements, additional permits would be required from the bridge owner, such as Caltrans, the County, or the City.
Right-of-way	Right-of-way would be necessary for any in-stream feature and for the channel itself for maintenance. Right-of-way would be necessary for realignment of the channel. Changes to the bridge structure would require only temporary construction right-of-way, except where the bridge footprint was increased.
Construction	Construction will vary based on the recommended solution. Concrete work and excavation would likely be necessary for the bridge modifications and upstream debris collectors. Channel straightening would require large earth moving and grading equipment. This work would likely be done primarily in a wet environment.
Operations & Maintenance	Operations and maintenance responsibilities would need to be established on a case-by-case basis and clarified at the inception of this concept. The Water Agency would need to decide whether it is willing to assume responsibility for debris removal from the bridges. This concept does not change the amount of debris in the system but it does change the location of the collected debris. For the debris collectors, O&M would likely increase slightly since it would not be possible to remove debris directly from the bridge piers and some additional transport would be necessary. Debris passed through the bridge would likely be caught elsewhere in the system but potentially in a location that does not require it to be removed, at least in the short term.
Funding	Bridge owners are a potential source of funding for this concept.
Regulatory	This concept would generally involve significant regulatory agency participation.
Willing Land Owner	A willing land owner would be necessary for any channel work. Any bridge work would require the cooperation of and partnership with the bridge owner.
Integration with Other Concepts	Implementation should not induce flooding elsewhere. If it is shown to do so, due to the reduction of attenuation, the concept could be paired with an attenuation-type project to offset the impacts.

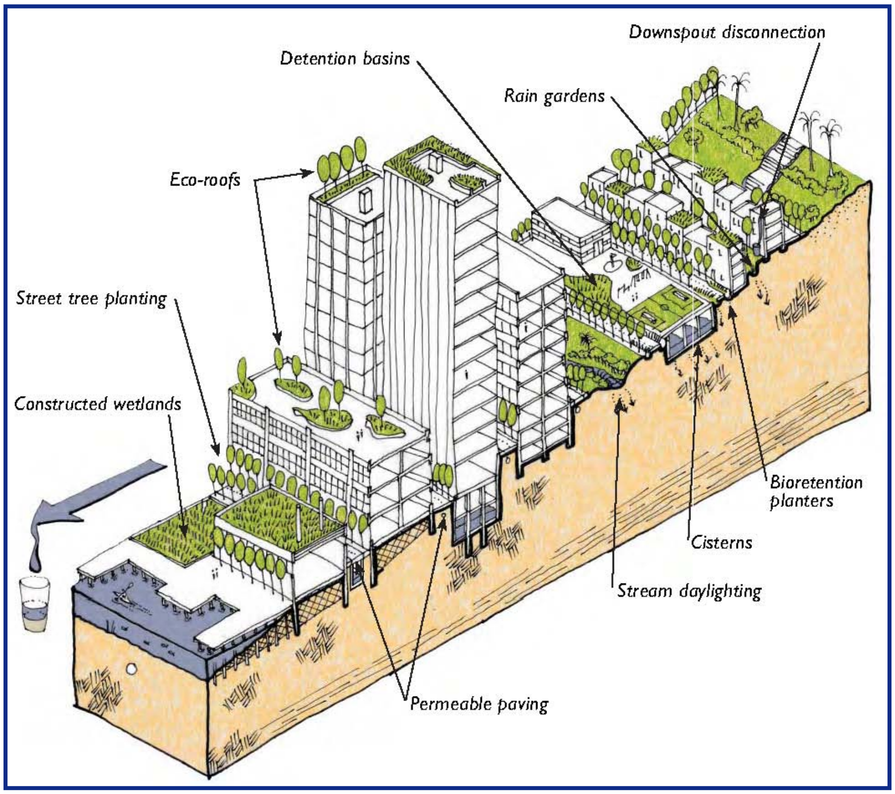
Area	Description
Additional Studies	Geomorphological studies are required to assess sediment transport characteristics of the system with this concept. Biological surveys will also be required where construction is recommended to determine the potential extent of aquatic and riparian.

4.9 Low-Impact Development

Concept Elements and Alternatives

Low impact development (LID) is the term used to describe a land planning and engineering design approach to sustainably manage stormwater runoff. LID emphasizes conservation and use of onsite natural features to protect water quality and encourage stormwater reuse by replicating or restoring natural watershed functions and/or addressing targeted watershed goals and objectives. LID's goal is to mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source. Techniques are based on the premise that stormwater management should not be seen as stormwater disposal. Instead of conveying and managing/treating stormwater in large, costly end-of-pipe facilities located at the bottom of drainage areas, LID addresses stormwater through small, cost-effective landscape features located at the parcel level. These landscape features, known as Integrated Management Practices (IMPs) are the building blocks of LID. Many components of the urban environment have the potential to serve as an IMP, including designated open spaces, rooftops, streetscapes, parking lots, sidewalks and medians. Examples of IMPs include the use of porous pavement, bioretention facilities, grass swales and filter strips. **Figure 24** shows some examples of IMPs.

Figure 24: Concept Sketch for Low Impact Development



Source: *Low Impact Design Toolkit*, San Francisco Public Utilities Commission, 2007.

LID has numerous benefits and advantages over conventional stormwater management approaches. It uses environmentally sound technology and is designed to enhance the local environment, protect public health and improve community livability. However, LID is intended to use decentralized site-based source controls to manage more frequent or micro-storms that occur on a regular basis and does not typically control 10- and 100-year storms unless paired with more traditional flow control management techniques. LID's primary strategy of restoring the built area's natural rainfall-runoff relationship is more suitable to the more frequent events. Where there are known flooding problems, a hybrid approach is typically recommended (combining LID BMPs with traditional flow control management techniques) to reduce liability and provide a sense of safety. In fact, the LID national design manual recommends hybrid systems if site constraints warrant it and additional detention is necessary.

While LID techniques, by their nature, are intended to promote infiltration, LID is incorporated into developed areas (through retrofits) or to-be-developed areas (as part of the development process). For this concept, these are areas that typically overlie the younger alluvium at the floor of the valley, and as such, implementation of this concept would limit groundwater augmentation to this formation.

Concept Objective Analysis

Table 18 summarizes how Low Impact Developments achieve or could achieve the core and supporting objectives identified for this Project.

Table 18: Low Impact Development Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Limited	If broadly implemented, LID has the potential to reduce flood hazards, but may need to be combined with traditional flood hazard reduction techniques (a hybrid approach), if necessary, to address larger flows. The effects of this concept should be evaluated for the potential to result in flood impacts outside of the concept area.
Groundwater Recharge	Yes	Location and scale dependent. While groundwater recharge is achievable through LID, it will be limited to the younger alluvium underlying the valley floor, unless implemented with new development in areas overlying outcroppings of other formations.
Water Quality	Yes	LID BMPs will provide physical, biological and chemical treatment processes that filter pollutants and reduce the loading of some contaminants to downstream flood waters.
Water Supply	Yes	Reuse of stormwater locally will offset potable and groundwater demands, increasing reliability of other water supplies. Additionally, enhanced infiltration resulting from LID implementation may augment the local groundwater supply, though the degree to which this is achieved is scale and location dependent.
System Sustainability	Yes	LID is a sustainable approach to stormwater runoff management.
Ecosystem	Maybe	Use of LID can improve ecosystem habitats under the right circumstances.
Agricultural Land	Yes	Agricultural land use would be preserved with this concept, particularly as the identified concept area is more urban settings.
Undeveloped Land	Yes	Undeveloped land would be preserved with this concept, particularly as the identified concept area is more urban settings.
Community Benefits	Maybe	Feature and land owner preference dependent.

Comparison Construction Cost Estimate

LID IMPs are typically comparable to traditional stormwater management infrastructure in cost, but saves in long-term operations and maintenance costs. The cost of this concept relative to increased flood protection is medium, and the cost of this concept relative to increased recharge is low.

This concept has high value relative to many of the supporting objectives but relatively low value for the primary objectives, particularly flood hazard reduction. Construction costs associated with this concept are anticipated to be offset or paid for by developers during construction. They can also be included in other municipal projects for relatively low cost..

Additional Benefits and Constraints

Table 19 summarizes additional considerations when evaluating the LID concept. This information is based on the level of detail developed at this conceptual stage.

Table 19: Additional Concept Considerations for Low Impact Development

Area	Description
Environmental Considerations	Environmental impacts resulting from implementation of LID are typically minimal, as the objective of LID is to restore the pre-developed watershed characteristics. Environmental benefits may result from concept implementation.
Permitting	Permitting for concept implementation is likely limited to building and grading permits.
Right-of-way	Right-of-ways are not typically required for LID implementation; however, cooperation of the site owner is required and may include the need for temporary easements or encroachment permits.
Construction	Construction is dependent on the features that are to be included with the concept. Construction would likely be limited to earth grading, replanting and some light construction for concept features.
Operations & Maintenance	LID IMPs have been shown to reduce O&M costs over conventional approaches to stormwater management through reduced infrastructure and site preparation work. Cost estimates and pilot programs show at least a 25% to 30% reduction in costs associated with site development, stormwater fees, and maintenance for residential developments that use LID IMP techniques. These savings are achieved through reductions in clearing, grading, pipes, ponds, inlets, curbs and paving. The IMPs would need to be maintained regularly by the owner however to realize these savings.
Funding	Funding sources are dependent on the final purpose and features of the project. State grants have been available for projects of this type in the past. The multi-benefit opportunities of the concept will increase the number of funding sources.
Regulatory	Regulatory agency involvement is anticipated to be minimal for this concept.
Willing Land Owner	Willing land owners are necessary for this concept to be successful.
Integration with Other Concepts	LID IMPs are intended for smaller, more frequent storm events. A hybrid approach is typically recommended for flood management from infrequent larger storm events (i.e. 100-year flood management).
Other	LID IMP use is limited predominantly to developed sites and those to be developed.

4.10 Policy Review and Development

Concept Elements

This concept would involve the following elements:

- Identify entities that can impact flooding and groundwater recharge;
- Identify policies of those entities that impact flooding and groundwater recharge;
- Review of how those policies are implemented and enforced;
- Consider community input on the policies, implementation, and enforcement;
- Revise existing policies and develop new policies as necessary to reduce flood hazards and protect or improve groundwater recharge; and
- Establish a funding mechanism to support any additional effort to implement policies.

This concept is collaborative in nature as it would involve multiple public entities to maximize its effectiveness. It is assumed that most of the policies relating to flood and recharge have to do with land use and development in general rather than specific projects. Policies in different jurisdictions should be complementary so that land use and development on one side of a political boundary does not offset the efforts on the other side of the political boundary.

This concept could be applied to a larger area than just Zone 2A as the Water Agency and County jurisdictions are county-wide.

Concept Objective Analysis

Table 20 summarizes how policy development achieves or could achieve the core and supporting objectives identified for this Project.

Comparison Cost Estimate

While there are no construction costs associated with this concept, implementation will require legislative and legal analyses and public outreach. The cost of this concept relative to increased flood protection and relative to increased recharge is unknown. The concept is anticipated to have a relatively low cost compared to the construction concepts identified in this memorandum. Benefits associated with the primary objectives are dependent on the findings of the review and any new policies developed as a part of the concept implementation.

Additional Benefits and Constraints

Table 21 summarizes additional considerations when evaluating the policy development concept. The description of these considerations is based on the level of detail developed at this conceptual stage.

Table 20: Policy Review and Development Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	Maybe	Achieving this objective is dependent on the policies reviewed and updated or developed. The project concept would serve to remind staff and the public of existing policies that help to reduce flood hazards even if new policies are not required.
Groundwater Recharge	Maybe	Achieving this objective is dependent on the policies reviewed and updated or developed. The project concept would serve to remind staff and the public of existing policies that help to improve recharge even if new policies are not required.
Water Quality	Maybe	Achieving this objective is dependent on the policies reviewed and updated or developed. It is considered likely that policies affecting water quality could be tied to flood reduction and increased recharge.
Water Supply	Maybe	Achieving this objective is dependent on the policies reviewed and updated or developed. It is considered likely that policies affecting water supply could be tied to flood reduction and increased recharge.
System Sustainability	Maybe	Achieving this objective is dependent on the policies reviewed and updated or developed. It is considered likely that policies affecting system sustainability could be tied to flood reduction and increased recharge.
Ecosystem	Maybe	Achieving this objective is dependent on the policies reviewed and updated or developed. It is considered likely that policies affecting ecosystem function and habitat could be tied to flood reduction and increased recharge.
Agricultural Land	Maybe	It is uncertain how the policies and policy updates will impact agricultural land. It is highly likely though that agricultural land will continue to be a valuable asset to the concept area.
Undeveloped Land	Maybe	It is uncertain how the policies and policy updates will impact undeveloped land. It is highly likely, though, that undeveloped land will continue to be a valuable asset to the concept area and could be designated as permanent open space.
Community Benefits	Maybe	Achieving this objective is dependent on the policies reviewed and updated or developed. It is considered likely that policies affecting community benefits could be tied to flood reduction and increased recharge.

Table 21: Additional Concept Considerations for Policy Review and Development

Area	Description
Environmental Considerations	Environmental considerations would be one of the primary review elements for the concept.
Permitting	No permitting is necessary for this concept.
Right-of-way	No right-of-way is necessary for this concept.
Construction	No construction is necessary for this concept.
Operations & Maintenance	No operations and maintenance is necessary for this concept.
Funding	Funding for this concept would likely be through existing budgets of the participating agencies.
Regulatory	Coordination with regulatory agencies may be involved to clarify positions on existing and new policies.
Willing Land Owner	No lands are necessary for this concept. It is envisioned that there would be an opportunity for residents within the concept area to participate in the project.
Integration with Other Concepts	This concept does not need to be integrated with other concepts.
Additional Studies	Additional studies may be required to support the development of new policies.

4.11 Direct Recharge Wells

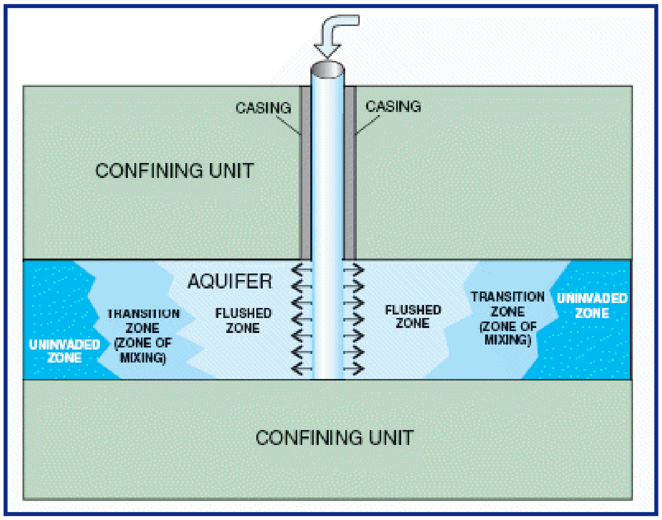
Concept Elements and Alternatives

In brief, direct recharge is where recharge water is put directly into the underground water-bearing formations for storage and subsequent retrieval and reuse, as shown in **Figure 25**. Direct recharge is suitable for areas where the large infiltration/percolations basins are not feasible or where the primary water-bearing formations are not in direct connection to the overlying land.

In the direct recharge concept, recharge wells are used to place stormwater runoff into the underlying basin aquifers. Key to a successful direct recharge project is the quality of the recharge water. In many cases (especially with surface water), the recharge water is treated sufficiently prior to recharge to ensure that the well screens and/or the adjacent aquifer formations do not plug with particulates or organic material and to ensure that the aquifer itself is not contaminated.

A typical recharge well site includes facilities for delivering the recharge water plus the wells and wellhead facilities required for the recharge process itself. Often included at the site are pre-treatment facilities and recovery facilities (in the form of extraction wells and or dual-purpose wells). A settling basin is recommended to improve stormwater quality prior to placement. The basin would also serve as a storage unit to capture the flashy flood flows to increase the amount of volume available for recharge at a steady rate.

Figure 25: Concept Sketch for Direct Recharge



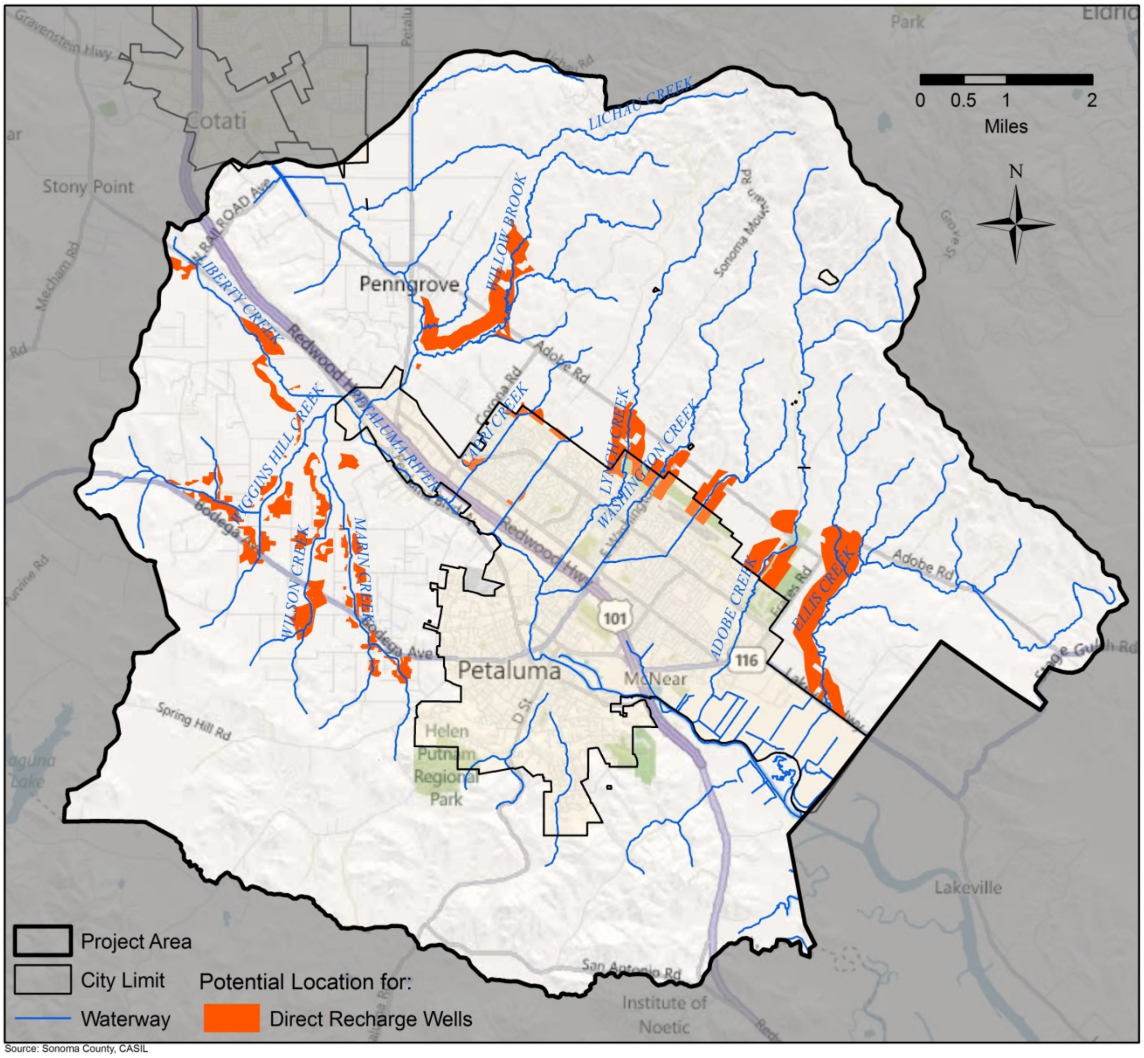
Source: United States Geological Survey as viewed at http://www.netl.doe.gov

Figure 26 shows the potential locations identified for potential direct recharge. These areas are outside of the 100-year floodplain, in relatively flat areas (around 2% slope or less), over the assumed location of the Wilson Grove and Petaluma formations (not limited to their outcroppings) or local alluvium, and within around 1,000 feet of the waterway without impacting existing structures. If an appropriate project site cannot be identified in this defined area, the area will be expanded to include areas with slopes up to 10%.

Concept Objective Analysis

Table 22 summarizes how direct recharge achieves or could achieve the core and supporting objectives identified for this Project.

Figure 26: Potential Locations for Direct Recharge



Source: Sonoma County, CASIL

Table 22: Direct Recharge Concept Objectives

Objective	Objective Achieved	Notes
Flood Hazard Reduction	No	Direct recharge is for groundwater augmentation; it will have no significant flood hazard reduction effects.
Groundwater Recharge	Yes	Direct recharge allows for the placement of recharge water directly into the water-bearing formations of interest.
Water Quality	Maybe	This concept does have the potential to create water quality impacts. The level of these impacts will be depend on the quality of water used for recharge and the potential for geochemical reactions resulting from the subsurface mixing of recharge waters and ambient groundwater.
Water Supply	Yes	All water captured under this concept would be used for direct recharge and will therefore augment aquifers currently utilized as water supply.
System Sustainability	No	Individual sites for this concept have a high likelihood of fouling due to particulates and organics in the source water. When this happens and maintenance fails to clear the fouling the site would be abandoned. The concept is also not a passive system (as the other concepts are) but solar energy could be explored.
Ecosystem	No	This concept would not improve ecosystem function or habitat.
Agricultural Land	No	The well site and settling basin could require some agricultural land depending on location.
Undeveloped Land	No	The well site and settling basin could require some undeveloped land for implementation, depending on location.
Community Benefits	Maybe	Well site tours could be hosted as a part of water supply education.

Comparison Construction Cost Estimate

Groundwater recharge projects vary considerably based on water quality, depth to the target formation and the relative need for facilities. The cost of this concept relative to increased flood protection is not applicable as this concept does not provide any flood protection benefits. The cost of this concept relative to increased recharge is low as this concept is the most effective at recharging the basin relative to construction cost.

Additional Benefits and Constraints

Table 23 summarizes additional considerations when evaluating the Direct Recharge concept. This information is based on the level of detail developed at this conceptual stage.

Table 23: Additional Concept Considerations for Direct Recharge

Area	Description
Environmental Considerations	Environmental impacts resulting from implementation of direct recharge are primarily related to groundwater quality changes. This can include both the introduction of contaminants into the subsurface as part of the recharge process and/or geochemical processes resulting from the mixing of recharge water with ambient groundwater.
Permitting	Key permits for direct recharge include the Federal Class V Underground Injection Control Permit from the U.S. Environmental Protection Agency, and Waste Discharge Requirements from the Regional Water Quality Control Board. Other permits will include a well construction permit from Sonoma County. Grading and building permits may also be required for wellhead facility construction. Additional permits associated with species and waterways could be necessary based on the diversion location and design.
Right-of-way	Right-of-ways may be required depending on project design. Additionally, right-of-ways may be required for project operation.
Construction	Construction is dependent on the features that are to be included with the concept. Construction would likely be limited to well construction, grading, and building for wellhead facilities plus the associated settling basin/facilities.
Operations & Maintenance	Regular operations and maintenance is required to maintain the performance capabilities of the facilities. O&M activities include maintenance of wellhead facilities, periodic redevelopment of the well, and maintenance/cleaning of the associated settling basin.
Funding	Funding sources are dependent on the final purpose and features of the project. State grants have been available for projects of this in the past.
Regulatory	Regulatory agency involvement for this concept (well development) is primarily with the Regional Water Quality Control Board.
Willing Land Owner	Willing land owners are necessary for this concept to be successful. Typically, the well site is purchased for such a project.
Integration with Other Concepts	There are limited opportunities to integrate this concept with other concepts.
Additional Studies	Hydrogeologic investigations and pilot studies are imperative for the success of this concept. Additional water quality testing is necessary to better understand existing and potential threats to aquifer water quality. Biological surveys will also be required to determine the potential extent impacts resulting from construction of the project.
Other	Stormwater runoff typically contains elevated levels of sediment and organics. This is detrimental to a recharge well, and pre-treatment of stormwater runoff prior to recharge is recommended.

5 Next Steps

The concepts described in this memorandum will undergo a screening and evaluation process to focus on those concepts that best fit the goals and objectives of the Project and are likely to be the most feasible to implement. The initial screening will remove concepts from consideration that are not feasible or not appropriate for this Project. The secondary evaluation will compare the concepts to the goals and objectives of the Project as well as other criteria that impact feasibility.

Based on the results of the screening and evaluation, the preferred concepts will be moved forward to a feasibility level evaluation, where additional project details will be developed as well as packaging of various concepts to provide a defined level of flood hazard reduction and groundwater recharge.

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