APPENDIX A: CHARACTERIZATION OF IMPERVIOUSNESS AND CREEK CHANNEL MODIFICATIONS FOR SEVENTEEN WATERSHEDS IN SAN MATEO COUNTY

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ONLY RAIN IN THE STORM DRAIN

San Mateo Countywide Stormwater Pollution Prevention Program

January 1, 2002

TABLE OF CONTENTS

TABLES

FIGURES

APPENDIX A

APPENDIX B

EXECUTIVE SUMMARY

Watershed imperviousness and channel modifications are two of the most important factors impacting the health of creeks in urban and developing areas. Watershed imperviousness is the percentage of watershed area covered by impervious surfaces such as rooftops, parking lots and roads. Channel modifications are typically flood and erosion control measures, such as culverting creeks and protecting creek banks from erosion by building sack concrete walls. The San Mateo Countywide Stormwater Pollution Prevention Program (STOPPP) has characterized watershed imperviousness and creek channel modifications for 17 watersheds in San Mateo County. These watersheds include most of the major urban creek drainages on the Bay side of the county and the watersheds on the coast side facing development pressure. The main objective of this work was to help municipal planners minimize the impacts of future development on creek resources in urban and urbanizing areas.

Watershed imperviousness was estimated using 1995 land use data from the Association of Bay Area Governments (ABAG). Imperviousness coefficients for each ABAG land use within the study watersheds were developed. For selected land uses, impervious or pervious surfaces within sampled areas such as city blocks were digitized on orthorectified digital aerial photograph images. Data from other studies and professional judgement were used to develop coefficients for other land uses. Statistical analyses were performed to assess the variability and error associated with the imperviousness estimates. Creek channel modifications were mainly characterized in the field. Geographical Information System (GIS) software was used throughout the project for data management and mapping.

The level of channel modification and imperviousness in the study watersheds generally increased with urbanization. High-density residential land use made the largest contribution to watershed imperviousness in all but two of the urbanized Bay side study watersheds. Areas with relatively low imperviousness and unmodified channels included the western portion of many of the Bay side study watersheds and most study areas on the coast side.

Municipalities should minimize increases in imperviousness and especially directly connected imperviousness associated with all new and redevelopment projects to the maximum extent practicable. This will help reduce pollutant loads to downstream receiving waters such as the Bay, which is always desirable, regardless of the degree of imperviousness and channel modification in a drainage area. However, using the data provided by this study, municipalities should protect higher quality creeks by giving priority to minimizing increases in imperviousness for projects in areas with relatively low existing imperviousness and unmodified channels.

An amendment to STOPPP's National Pollutant Discharge Elimination System permit with new requirements for new and redevelopment projects is anticipated. These requirements will emphasize the management of increases in peak runoff flow and increased runoff duration, where increased flow and/or volume can cause erosion of creek beds and banks, siltation, or other impacts to beneficial uses. The amendment will require that this management take place through implementation of a Hydrograph Modification Management Plan (HMP). STOPPP's municipalities should use the data developed in this study to help develop a HMP. Imperviousness data may be useful for broadly characterizing runoff flows and durations by land use, and channel modification data will help establish which areas are exempt from requirements to limit increases in runoff flows and volumes.

**CHARACTERIZATION OF
IMPERVIOUSNESS AND CREEK CHANNEL
MODIFICATIONS FOR
SEVENTEEN WATERSHEDS IN SAN MATEO COUNTY**

1.0 INTRODUCTION

Impervious surfaces such as rooftops, parking lots and roads prevent rainwater from infiltrating into the ground. Watershed imperviousness is defined as the percentage of a watershed's area that is covered by such surfaces. Since watershed imperviousness increases with urban development, it is commonly used as an indicator of urbanization.

Increased watershed imperviousness in urban areas results in decreased infiltration of stormwater and dramatic increases in surface runoff during storm events. This leads to many impacts on urban creeks, including increased frequency and magnitude of bankfull and sub-bankfull floods, larger sediment loads, bank erosion, enlargement of channels and other changes in channel morphology. All of these factors lead to loss of instream habitat and aquatic diversity (CWP 1998) and impact the beneficial uses[1] of urban creeks.

Another common consequence of increased watershed imperviousness and the associated increased flows is the modification of urban creek channels for flood and erosion control. Examples of modifications include culverting a creek, constructing a concrete-lined channel and protecting creek banks from erosion by building sack concrete walls. Another type of modification related to urbanization occurs when creek banks are filled to extend adjacent properties. All of these changes to creek channels generally result in further loss of habitat for aquatic life. Channel modifications are a direct indicator of a creek's potential to support a healthy aquatic ecosystem. For example, a culvert or concrete-lined channel generally provides very poor aquatic habitat relative to an unmodified channel.

Watershed imperviousness and channel modifications are two of the most important factors impacting creeks in urban and developing areas.[2] These relatively easily assessed indicators of creek health are useful for community-level watershed planning aimed at protecting aquatic habitat in urban creeks. The San Mateo Countywide Stormwater Pollution Prevention Program (STOPPP) previously characterized watershed imperviousness and creek channel modifications in 17 watersheds in San Mateo County (EOA 1997, 1998a, 1998b, 1999a, 1999b and 2000). These watersheds include most of the major urban creek drainages on the Bay side of the county and the watersheds on the coast side facing development pressure.

This report summarizes and analyzes the watershed imperviousness and creek channel modifications data from the 17 watersheds. The main objective was to help municipal planners minimize the impacts of future development on creek resources in urban and urbanizing areas.

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[1] The California Regional Water Quality Control Board, San Francisco Bay Region designates beneficial uses for several San Mateo Creeks in its Water Quality Control Plan (usually referred to as the Basin Plan) (CRWQCB, 1995). Many of these beneficial uses relate to aquatic life habitat.
[2] Other major factors stressing urban creeks include dams, diversions and loss of riparian habitat.

2.0 METHODS

Figure 1 shows the location of the 17 study watersheds. The following sections present the methods used to delineate the study creeks and watersheds, characterize creek channel modifications, and estimate watershed imperviousness and imperviousness gradients. Geographical Information System (GIS) software (ArcView™, developed by Environmental Systems Research Institute, Inc. of Redlands, California) was used throughout the project.

2.1 Creek and Watershed Delineation

Creeks and their tributaries (Figures 2 - 7) were generally mapped by digitizing blue lines shown on United States Geological Survey (USGS) 7.5-minute series topographic maps (USGS 1993, 1995 and 1997a - e). Some sections of creek in the San Bruno and Pulgas Creek watersheds were mapped using hard copy municipal storm drain maps. These sections connect discontinuous sections of the creeks shown on the USGS maps. In addition, the culverted North Fork of San Pedro Creek, which is not shown on the USGS maps, was mapped using data provided by the San Pedro Creek Watershed Coalition (http://www.pedrocreek.org).

Watersheds boundaries were delineated using data from many sources, including drainage studies, municipal storm drain system maps, municipal master plans and elevation contours on USGS 7.5-minute series quadrangle topographic maps (Appendix A, Table 1). Watersheds boundaries (Figures 2 - 7) were digitized on-screen using the GIS.

2.2 Creek Channel Modifications

Creek channel modifications in the 17 study watersheds were primarily characterized in the field (EOA 1997, 1998b,1999b and 2000). Creeks were surveyed at most publicly accessible areas, such as road crossings and parks (obtaining access to private property was not within the scope of the field surveys). When a stretch of creek was accessible, such as in a park, that stretch was generally walked. Survey locations and channel modification data were recorded on field data sheets and photographs were taken at many locations to further document the field observations.

The following general categories for creek channel modification were developed for San Mateo County creeks, in order of decreasing level of channel modification:

- Culvert
- Concrete-lined Channel
- Earth Channel
- Modified but not Channelized
- Unmodified Channel

Appendix A, Table 2 provides the general characteristics for each of the above categories and Appendix B contains example photographs. Each section of a creek was placed in the category that best fit that section; in general, all or most attributes of the category applied. Interpolation between field observation points and professional judgement for some inaccessible areas were used. Examples of inaccessible areas where professional judgement was applied included:

- Creeks channels in natural-appearing riparian corridors that could only be viewed from a distance (e.g., riparian corridors in a canyon that was physically inaccessible or located on private property) were often designated unmodified.

- Creeks channels in the inaccessible eastern parts of the coastal watersheds that appeared relatively undeveloped on USGS 7.5-minute series topographic maps were designated unmodified. Parts of these areas could be viewed from a distance in the field and appeared relatively undeveloped.

The following creek sections designated not surveyed in previous studies (EOA 1998b, 1999b and 2000) were classified for this report based on discussions with municipal staff:

- The westernmost section of the northern branch of San Bruno Creek was classified unmodified (Heald 2001).

- The southern section of Sanchez Creek was classified unmodified (Francis 2001).

- A tributary to Colma Creek was classified a concrete-lined channel (Frame 2001).

2.3 Imperviousness Estimates

The following sections describe how watershed imperviousness was estimated using land use data from the Association of Bay Area Governments (ABAG).[3]

2.3.1 Imperviousness Coefficients for ABAG Land Uses

Imperviousness coefficients were developed for each ABAG (1996) land use within the 17 study watersheds. These coefficients represent the estimated fraction of a land use that is covered by impervious surfaces. The coefficients were developed using data from previous studies (Bredehorst 1981 and EOA 1997, 1998a,1999a and 2000) and the current study (Appendix A, Table 3). Land use designations in Bredehorst did not always exactly match those used by ABAG; interpretation was required when applying Bredehorst's imperviousness coefficients to ABAG land use classes. Some coefficients were based on best professional judgement.[4]

For selected land uses, imperviousness coefficients were developed by digitizing impervious or pervious surfaces within sampled areas such as city blocks. These land uses (e.g., high density residential) generally comprised a relatively large percentage of the total land use in the study watersheds. Impervious areas were digitized for the selected land uses using high-resolution (0.5 or 1-foot pixel resolution) orthorectified 1995 or 1997 aerial photograph images (AeroTopia®, developed by GeoExplorer of Walnut Creek, California). The images were displayed in the GIS and impervious surfaces were digitized within city blocks or other sampled areas for each land use. The surrounding roads and sidewalk area were included for city blocks (the boundary of a city block was defined as the road centerline).

[3] The resolution of the ABAG land use data is low (2.5 acres), but is adequate for the planning-level purposes of this project. Currently the ABAG data is the only land use coverage available for all of San Mateo County.
[4] Imperviousness coefficients estimated using professional judgement were based on interpretation of one or more of the following data sources: (1) aerial photographs; (2) USGS 7.5-minute series quadrangle topographic maps; and (3) the name and description of the land use (ABAG, 1996).

Infiltration capacity may be reduced when soil is compacted by development activities, rendering even landscaped, presumably pervious areas, somewhat impervious (Booth and Jackson 1997). During digitizing, however, it was assumed that all surfaces were completely impervious or pervious. Impervious surfaces in the sampled areas included roads, parking lots, sidewalks and rooftops; pervious surfaces were mainly landscaping.

The imperviousness values calculated for each sampled area were averaged to define the imperviousness coefficient for each selected land use. EOA (2000) describes statistical analyses performed to assess the variability and error associated with this procedure.

2.3.2 Watershed Imperviousness Estimates

The imperviousness coefficients were entered into a database table and linked to the land use GIS coverage. The impervious areas contributed by the ABAG land uses were estimated by multiplying land use areas by imperviousness coefficients. The ABAG land use types were reclassified into groups of similar land uses (Appendix A, Table 3) to facilitate presentation of the results. For example, schools, government buildings and other public land uses were reclassified into a single “public, quasi-public” land use category. The impervious area contributed by the reclassified land uses and the total watershed imperviousness were then calculated (Appendix A, Table 4) by intersecting the land use coverage with each study watershed in the GIS.

2.3.3 Watershed Imperviousness Gradients

Drainage areas with cumulative imperviousness from 10% to 40% were identified in 10% increments to the extent possible within the study watersheds. These “imperviousness gradients” were defined by delineating areas draining to a point on a creek at estimated significant changes in imperviousness (based on land use) using elevation contours from digital USGS topographic maps. The drainage areas were then intersected with the ABAG land use coverage (containing the coefficients of imperviousness) in a GIS and adjusted iteratively until the desired cumulative imperviousness was obtained (10, 20, 30 or 40%). The gradients are based on interpretation of topographic contour lines on USGS topographic maps and are approximate.

3.0 RESULTS

The following sections present the creek channel modification and imperviousness data developed for the study watersheds.

3.1 Creek Channel Modifications

Figures 8 -19 show the results of the creek surveys. Table 1 summarizes the percent unmodified creek channels in each study watershed. Creek channels were generally unmodified in the five relatively undeveloped coastal study watersheds. The San Pedro Creek watershed is more urbanized than the other five coastal watersheds. The South and Middle Forks of San Pedro Creek generally have unmodified channels, whereas the North Fork has been culverted and much of the main stem is in an earth channel. Creek channels exhibited varying degrees of modification in the 11 urban Bay side study watersheds. Creek channels were generally less modified in the western headwater parts of these watersheds relative to the downstream eastern parts.

3.2 Watershed Imperviousness Estimates

Watershed imperviousness estimates ranged from 2% to 58% for the 17 study watersheds (Table 1). Estimates ranged from 21% to 58% for the 11 relatively urban study watersheds that drain to San Francisco Bay. Watershed imperviousness was lower (2% to 15%) for the less developed coastal watersheds. The relative contributions of the reclassified land uses to the percentage of watershed imperviousness are presented in the Appendix A, Table 4. High-density residential land use (nine and over dwelling units per hectare) made the largest contribution to watershed imperviousness in all but two of the urbanized Bay side study watersheds, accounting for as much as 43% of watershed imperviousness (Mills Creek watershed). Moderate-density residential land use (two to eight dwelling units per hectare) contributed the most imperviousness in the Sanchez Creek watershed (18%) and the San Francisquito Creek watershed (10%). Other land uses contributing substantial imperviousness in the Bay side watersheds included commercial, industrial, and public/quasi-public.

3.3 Watershed Imperviousness Gradients

Figures 8 -19 present approximate percent imperviousness gradients for the study watersheds. Each area in the watersheds is identified by a range of *cumulative* imperviousness; thus the influence of any upstream drainage areas are taken into account. Cumulative imperviousness was less than 10% for the coastal watersheds, with the exception of the San Pedro Creek watershed. For the San Pedro Creek watershed and most of the Bay side study watersheds, a low percentage of imperviousness typically occurred in the headwater regions, with percent imperviousness increasing in the downstream direction.

4.0 DISCUSSION

The development pattern for most of the Bay side study watersheds is typified by the western portions having steeper slopes and less development compared to the eastern portions near the Bay, which are relatively urbanized. The coastal areas in San Mateo are generally much less urbanized than the Bay side watersheds. In general, the level of channel modification and imperviousness in the study watersheds increased with urbanization. Areas with relatively low imperviousness and unmodified channels in the study watersheds included the western portion of many of the Bay side watersheds and most areas on the coast side (Figures 8 – 19). The expected rough inverse correlation between estimated watershed imperviousness and percent unmodified creek channel was observed (Table 1). Laurel Creek and Mills Creek watersheds were exceptions to this pattern, as each of these watersheds had relatively high imperviousness (greater than 50%) but a relatively high percentage of unmodified channels (65% and 55%, respectively). Most of the unmodified channel in these watersheds is in the headwater areas. These open space areas with steep slopes (Sugarloaf Mountain in the Laurel Creek watershed and Mills Canyon Park in the Mills Creek watershed) are not large enough to result in a low overall watershed imperviousness.

4.1 Imperviousness and Creek Quality Model

Schueler (1994) has characterized creek potential as follows:

Creek Classification	Watershed Imperviousness
Stressed steams	0 to 10%
Impacted streams	11 to 25%
Degraded streams	26 to 100%

Schueler developed the above model based on many studies from different geographic areas that related imperviousness to changes in hydrology, habitat structure, water quality and biodiversity of aquatic systems. The model provides some useful context for the imperviousness data developed in this study. However, directly applying such thresholds to watersheds in San Mateo County is not appropriate at this time, for reasons that include the following:

- The research that the model is based on was performed mainly in the mid-Atlantic and Puget Sound regions. Little research has been performed in regions with semi-arid climates such as the Bay area. Further research is needed to determine whether the model applies in such regions (CWP 1998).

- The methods used for estimating imperviousness have not been standardized and the accuracy of the estimates are dependent on the accuracy of the data (e.g., land use) used to derive them. For example, a recent study in the Santa Clara Basin compared imperviousness estimates derived using two different land use data sets: the 1995 ABAG data set used in this study and a second higher resolution compilation based primarily on 1999 County Assessor data. Imperviousness estimates were 5% to 39% higher for urban areas based on the ABAG data set (Buchan and Randall 2000).

- The model suggests that imperviousness thresholds exist above which certain levels of creek degradation are found. However, degradation of creek quality with increasing urbanization occurs in a continuous rather than threshold fashion (May et al. 1997a).

In a study of creeks in the Puget Sound area in Washington State, creeks with 30% to 35% impervious cover were classified as “fair” with respect to riparian and biotic integrity. Factors such as wide riparian corridors appeared to temper the effects of imperviousness to some degree (May et al. 1997a and b). It follows that creeks in watersheds with imperviousness exceeding 25% are not necessarily highly degraded; many other site-specific factors need to be taken into consideration. While elevated imperviousness is a major factor leading to the degradation of urban creeks, it is also an indicator of urbanization and other associated degrading factors, such as dams, diversions, channel modifications and the extent of riparian habitat. For the planning-level purposes of this study, gradients up to 40% cumulative imperviousness were defined. While this number is somewhat arbitrary, in most cases substantial degradation of creeks is likely in areas with cumulative imperviousness exceeding 40%.

4.2 Prioritizing Areas to Minimize Increases in Imperviousness

Some researchers have defined "directly connected imperviousness" or "effective imperviousness" as the percentage of a watershed's area covered by impervious surfaces with direct hydraulic connection to storm drain systems or surface waters (Booth and Jackson 1997). Stormwater runoff that collects pollutants from directly connected impervious surfaces is not filtered by plant materials or infiltration into the soil. This results in greater pollutant loads in conjunction with the increased flows associated with erosion and creek habitat degradation (BASMAA 1999). Municipalities should minimize increases in imperviousness and especially directly connected imperviousness associated with all new and redevelopment projects to the maximum extent practicable. This will help reduce pollutant loads to downstream receiving waters such as the Bay, which is always desirable, regardless of the degree of imperviousness and channel modification in a drainage area. However, municipalities should use the data provided by this study to help protect higher quality creeks. This would be accomplished by giving priority to minimizing increases in imperviousness for projects in areas with relatively low existing imperviousness and unmodified channels.

STOPPP's New Development Subcommittee formed a work group that met several times to discuss using the data from this study in this way. Most of the members of the work group were municipal planners. The work group members agreed that the data developed in this study would be useful during the environmental review process to help develop conditions of approval for discretionary permits. They acknowledged that municipal planners do not have much control over projects that only require a building permit.

Work group members discussed the political feasibility and equity issues of applying different priorities to different parts of a watershed. Municipalities currently face a lot of resistance towards prescriptive planning due to private property rights arguments. With the right policies in place, however, the work group felt that higher priority could be given to areas with relatively low imperviousness and unmodified channels. Other difficulties faced by municipalities are enforcement and a lack of standardization among STOPPP agencies. The work group felt that each municipality would need the political support of their upper level decision-makers and management staff. The work group agreed that municipal general plan goals should recognize the importance of watershed health so that municipal staff can justify protection techniques to project applicants.

4.3 Requirements to Implement a Hydrograph Modification Management Plan

An amendment to the Santa Clara Valley Urban Runoff Pollution Prevention Program's National Pollutant Discharge Elimination System (NPDES) permit was adopted on October 17, 2001. The amendment contains new requirements for new and redevelopment projects. These requirements emphasize the management of increases in peak runoff flow and increased runoff duration associated with new and redevelopment, where increased flow and/or volume can cause erosion of creek beds and banks, siltation, or other impacts to beneficial uses. The amendment requires that this management take place through implementation of a Hydrograph Modification Management Plan (HMP). A similar NPDES permit amendment is anticipated for STOPPP and other Bay area stormwater programs.

Minimizing increases in imperviousness will help STOPPP meet the anticipated requirements. In addition, the data developed by this study should help STOPPP's municipalities develop a HMP. Data on imperviousness may be useful for broadly characterizing runoff flows and durations by land use. Channel modification data will help establish areas where the potential for erosion, or other impacts to beneficial uses, is minimal. Management of increases in runoff flow and volume may not be required in such areas.

5.0 RECOMMENDATIONS

During plan review, inspection and enforcement activities for new and redevelopment projects, STOPPP's municipalities should:

- Minimize increases in imperviousness and especially directly connected imperviousness associated with all new and redevelopment projects to the maximum extent practicable.

- Give priority to minimizing increases in imperviousness for projects in areas with relatively low existing imperviousness and unmodified channels.

The data in this report are intended for use as a simple planning-level tool for planners to use along with the many other types of project-specific data. Planners should consider both imperviousness and channel modifications when making informed decisions regarding conditions of approval. For example, municipalities may not wish to give high priority to protecting a section of creek in an area with relatively low imperviousness, if the creek channel is highly modified (e.g., a concrete channel or culvert), unless restoration of the creek is a possibility. It should be noted that because of high land values and population densities in the Bay area, it may be difficult for many new developments to attain less than 30% imperviousness (BASMAA 1999). Therefore open space, parks and other land uses with low imperviousness will usually be an important component of drainage areas with low overall imperviousness in the Bay area.

STOPPP's New Development Subcommittee should continue developing planning strategies necessary to help municipalities accomplish the above goals. Guidance for developing and implementing planning strategies to minimize imperviousness are found in documents prepared by the Bay Area Stormwater Management Agencies Association (BASMAA 1999), the United States EPA (USEPA 1996), Schueler (1987 and 1995) and the Center for Watershed Protection (1998). STOPPP's New Development Subcommittee has also prepared a technical memorandum on imperviousness reduction at new and redevelopment sites (EOA 1999c). More site-specific guidance may become available in the future if more comprehensive watershed assessment and planning are performed for the study watersheds.

STOPPP's municipalities should also use the data developed in this study to help develop a HMP. The imperviousness data may be useful for broadly characterizing runoff flows and durations by land use, and the channel modification data will help establish which areas are exempt from requirements to limit increases in runoff flows and volumes.

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Table 1. Watershed imperviousness and percent unmodified creek channels.

Watershed	Area (square miles)	Estimated Percent Imperviousness	Percent Unmodified Creek Channels in Watershed
Denniston Creek	3.7	2	100
Frenchmans Creek	4.3	2	100
Arroyo de en Medio	1.0	4	97
Pilarcitos Creek	28.7	4	100
Dean/Montara/San Vicente Creeks	3.9	7	100
San Pedro Creek	8.0	15	64
San Francisquito Creek	42.8	21	82
Cordilleras Creek	3.3	35	60
Sanchez Creek	1.0	35	66
San Mateo Creek (below Crystal Springs dam)	4.5	38	51
Belmont Creek	3.0	42	26
Colma Creek	16.1	50	0
San Bruno Creek	3.9	51	26
Laurel Creek	4.6	53	65
Pulgas Creek	3.5	54	10
Redwood Creek	9.8	55	31
Mills Creek	1.2	58	55

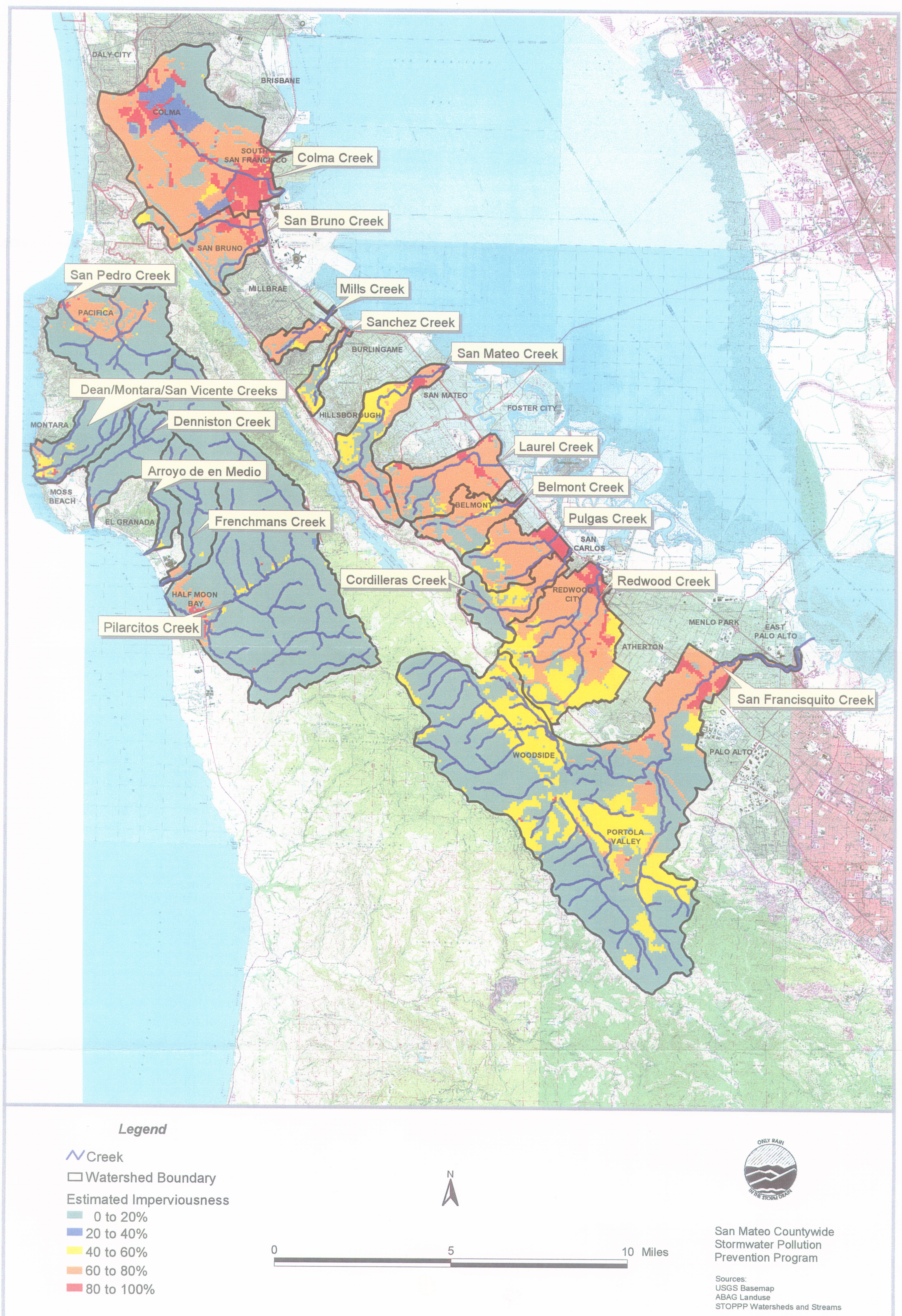

Figure 1. Estimated Percent Imperviousness for Seventeen Watersheds in San Mateo County.

Figure 2. Watershed Boundaries and Creeks in Colma and San Bruno Creek Watersheds.

Legend

Watershed Boundary
Creek

N

0 1 2 Miles

San Mateo Countywide
Stormwater Pollution
Prevention Program

Sources:
USGS Basemap
STOPPP Watersheds and Streams

Figure 3. Watershed Boundaries and Creeks in Mills, Sanchez and San Mateo Creek Watersheds.

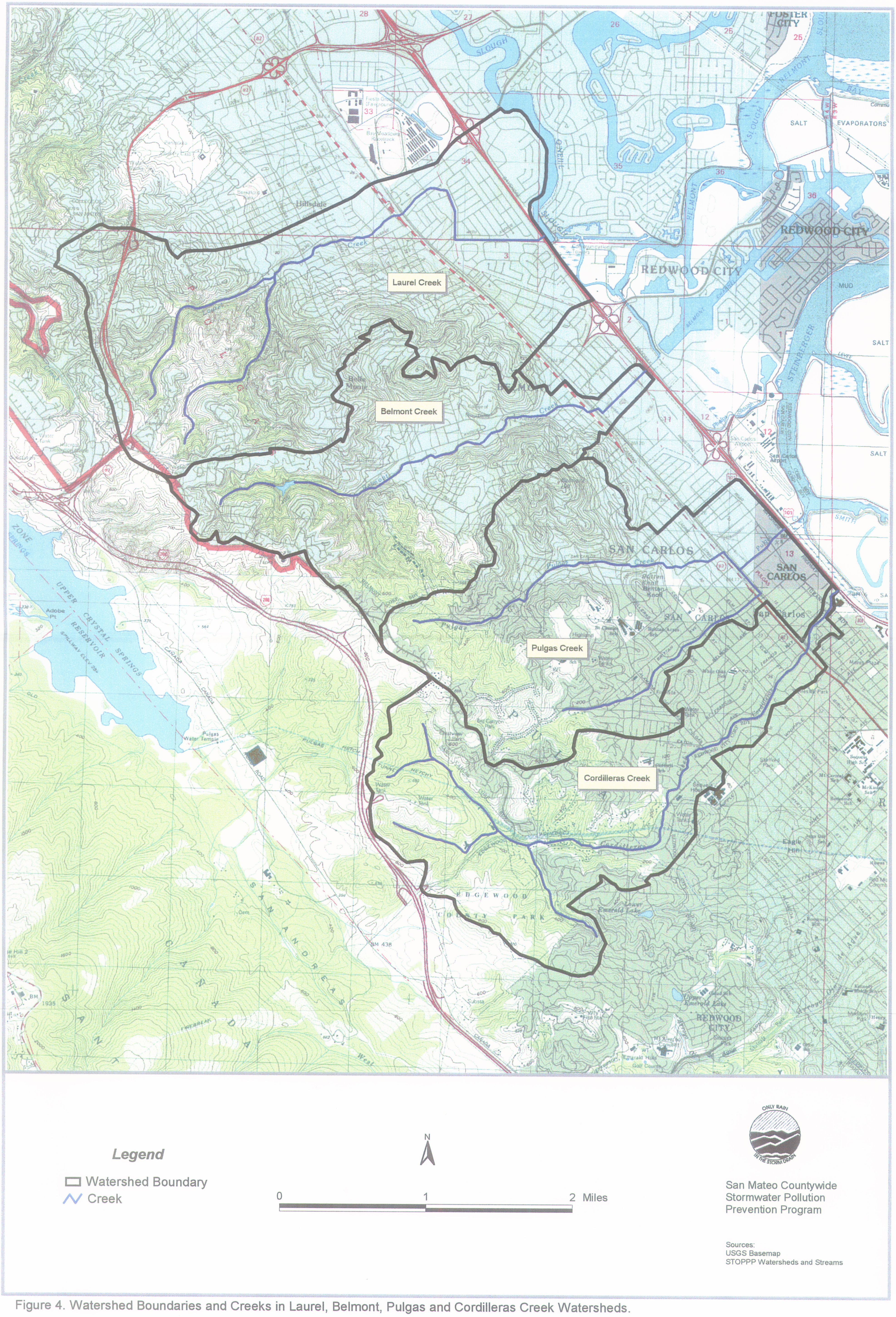

Figure 4. Watershed Boundaries and Creeks in Laurel, Belmont, Pulgas and Cordilleras Creek Watersheds.

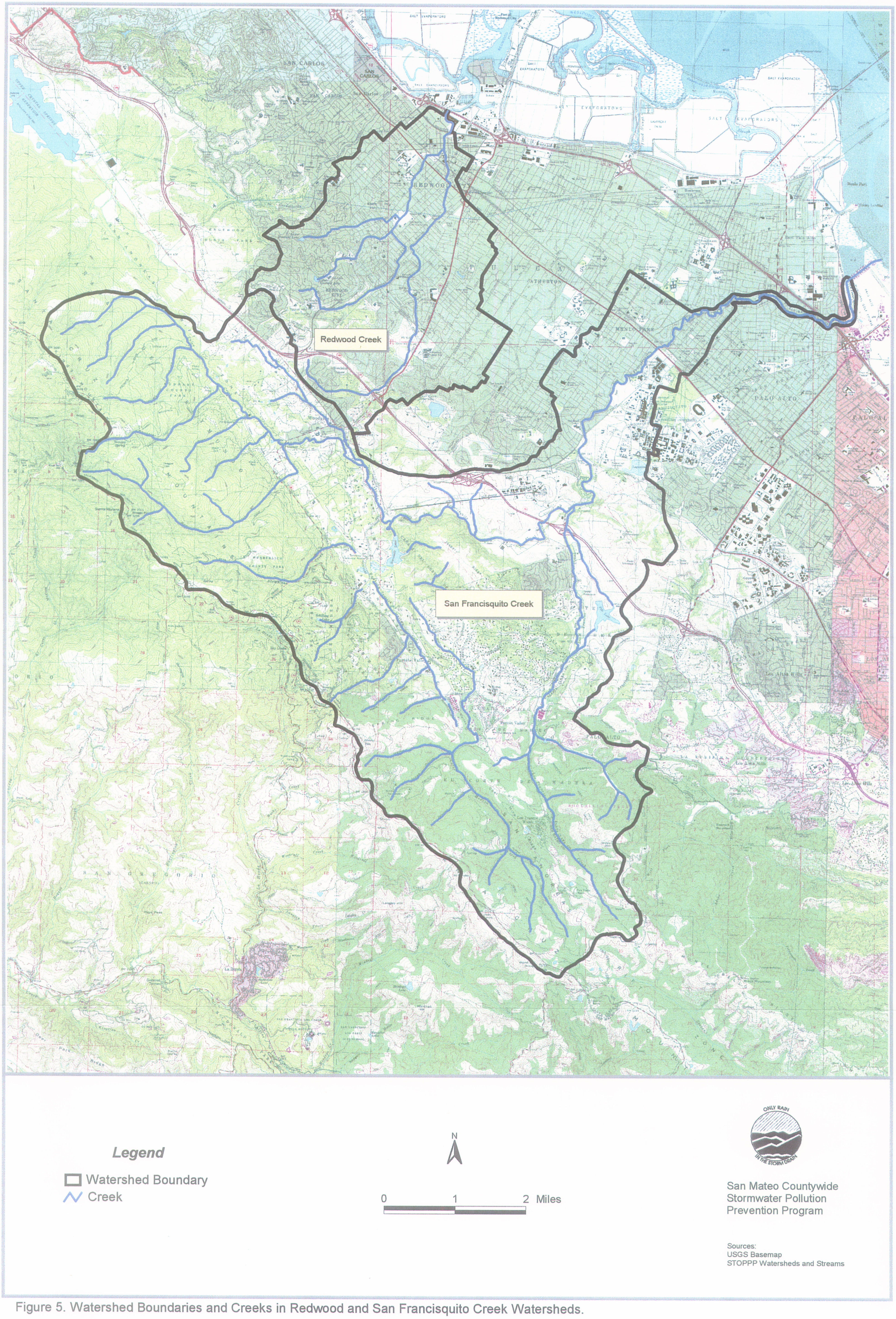

Figure 5. Watershed Boundaries and Creeks in Redwood and San Francisquito Creek Watersheds.

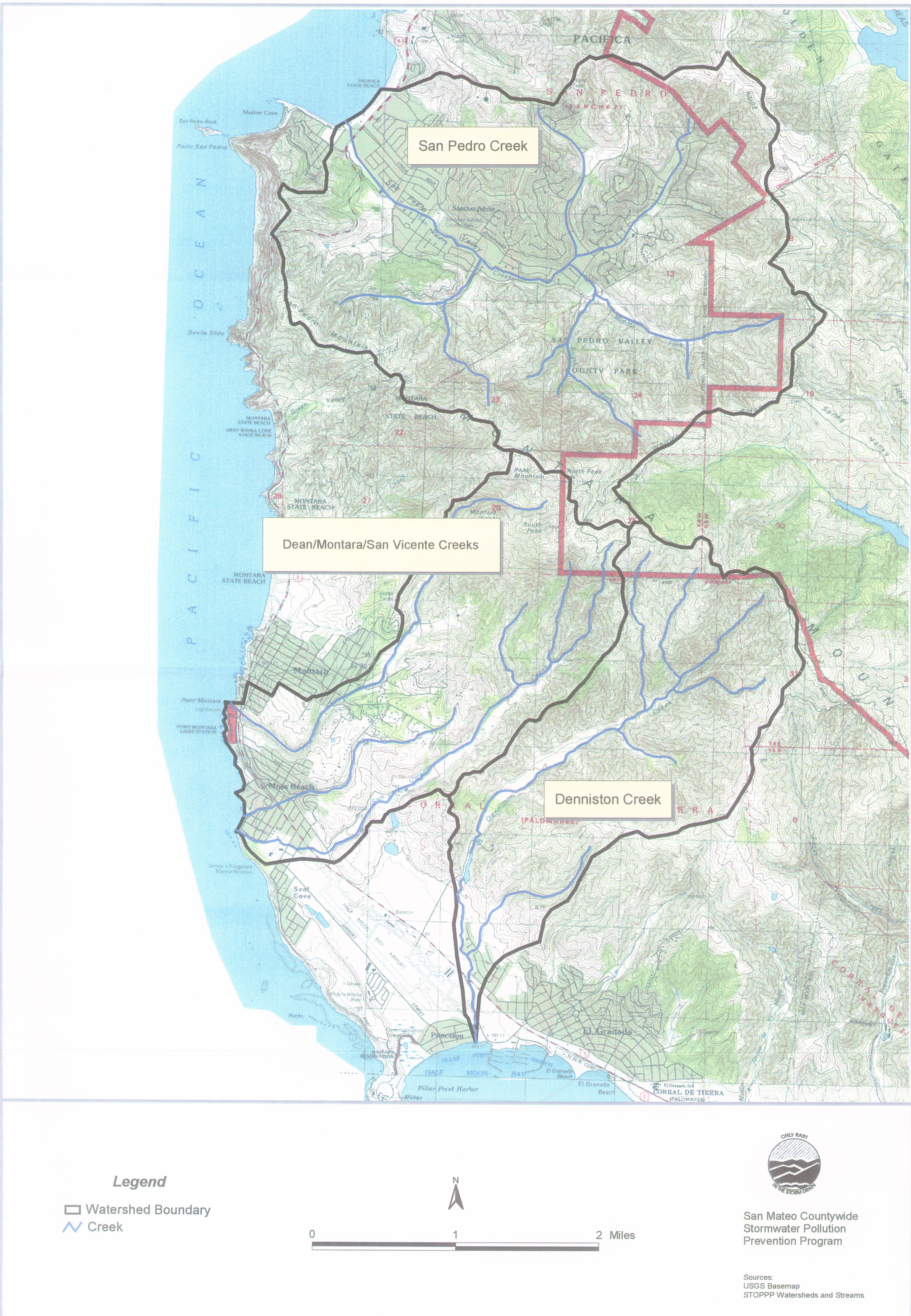

Figure 6. Watershed Boundaries and Creeks in San Pedro, Dean, Montara, San Vicente and Denniston Creek Watersheds.

Figure 7. Watershed Boundaries and Creeks in Arroyo de en Medio and Frenchmans and Pilarcitos Creek Watersheds.

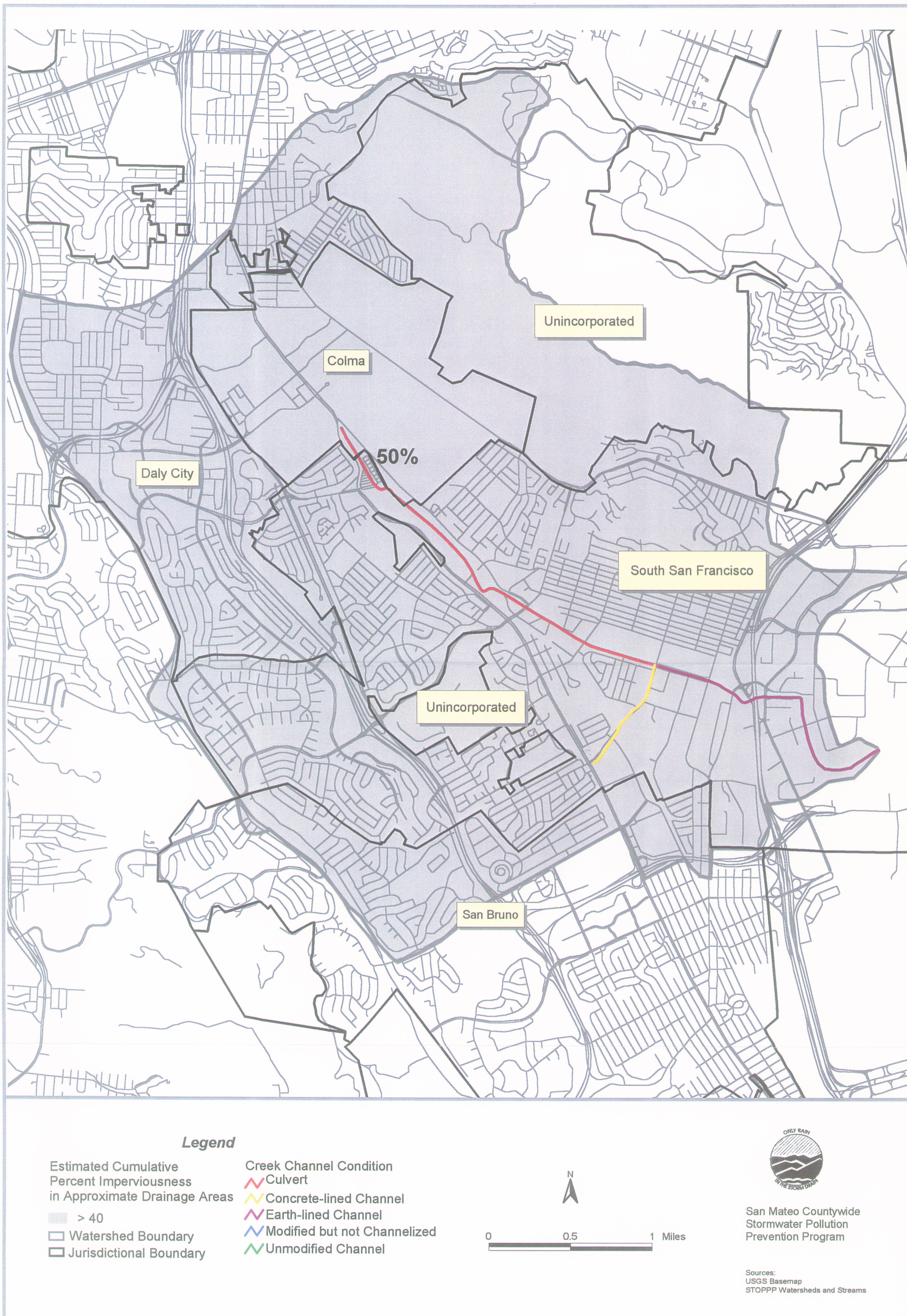

Figure 8. Imperviousness Estimates and Channel Modifications for Colma Creek Watershed.

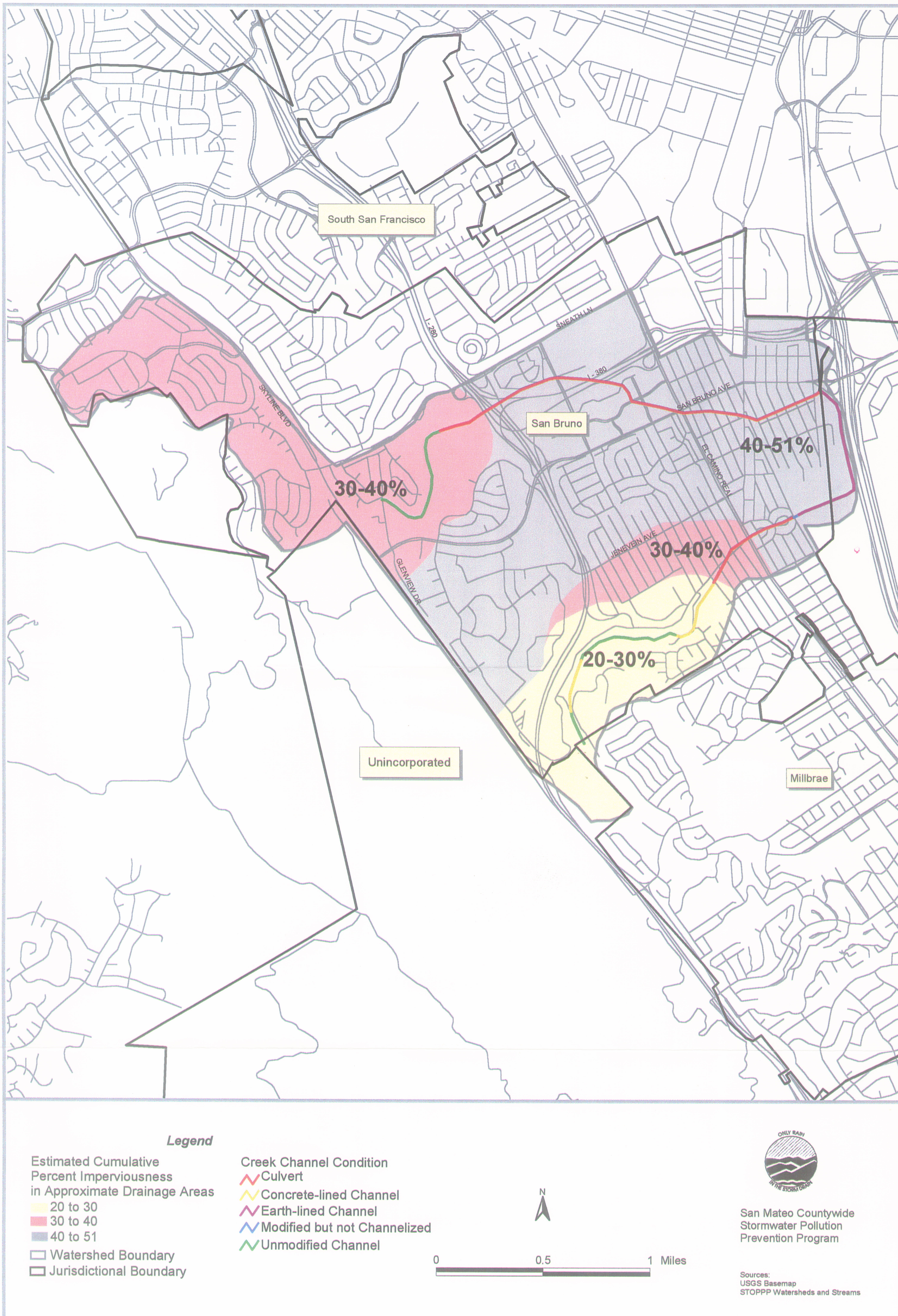

Figure 9. Imperviousness Estimates and Channel Modifications for San Bruno Creek Watershed.

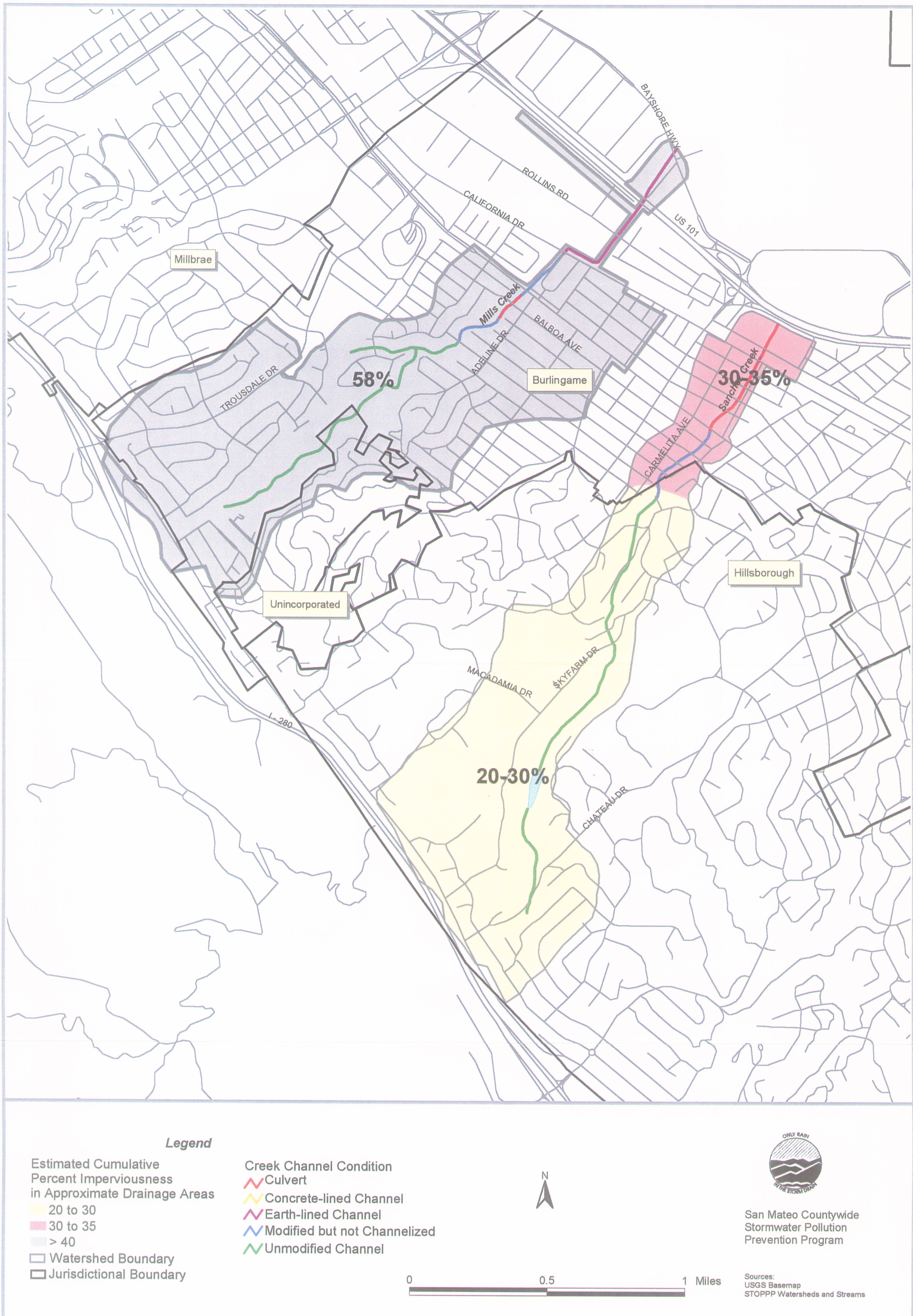

Figure 10. Imperviousness Estimates and Channel Modifications for Mills and Sanchez Creek Watersheds.

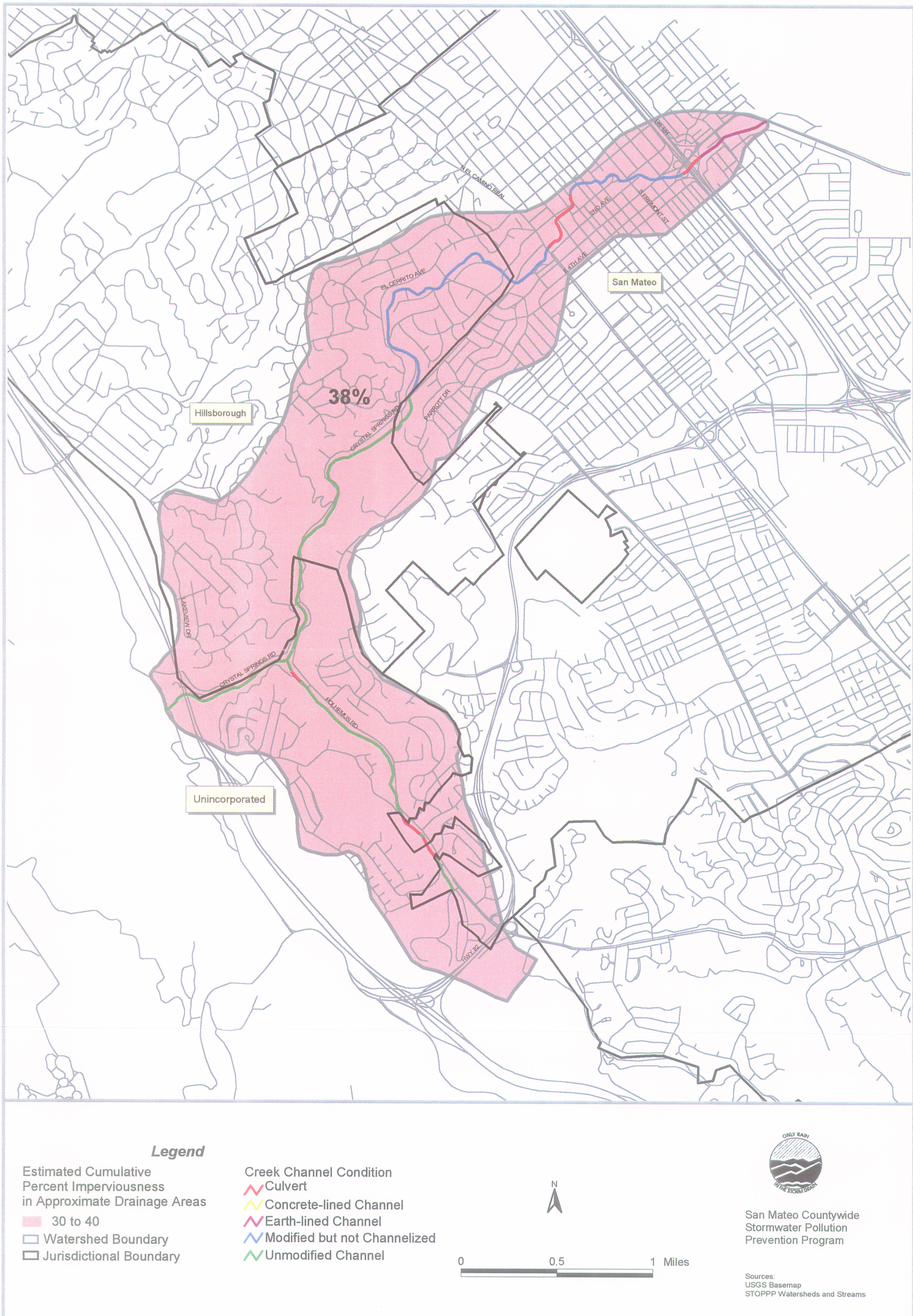

Figure 11. Imperviousness Estimates and Channel Modifications for San Mateo Creek Watershed.

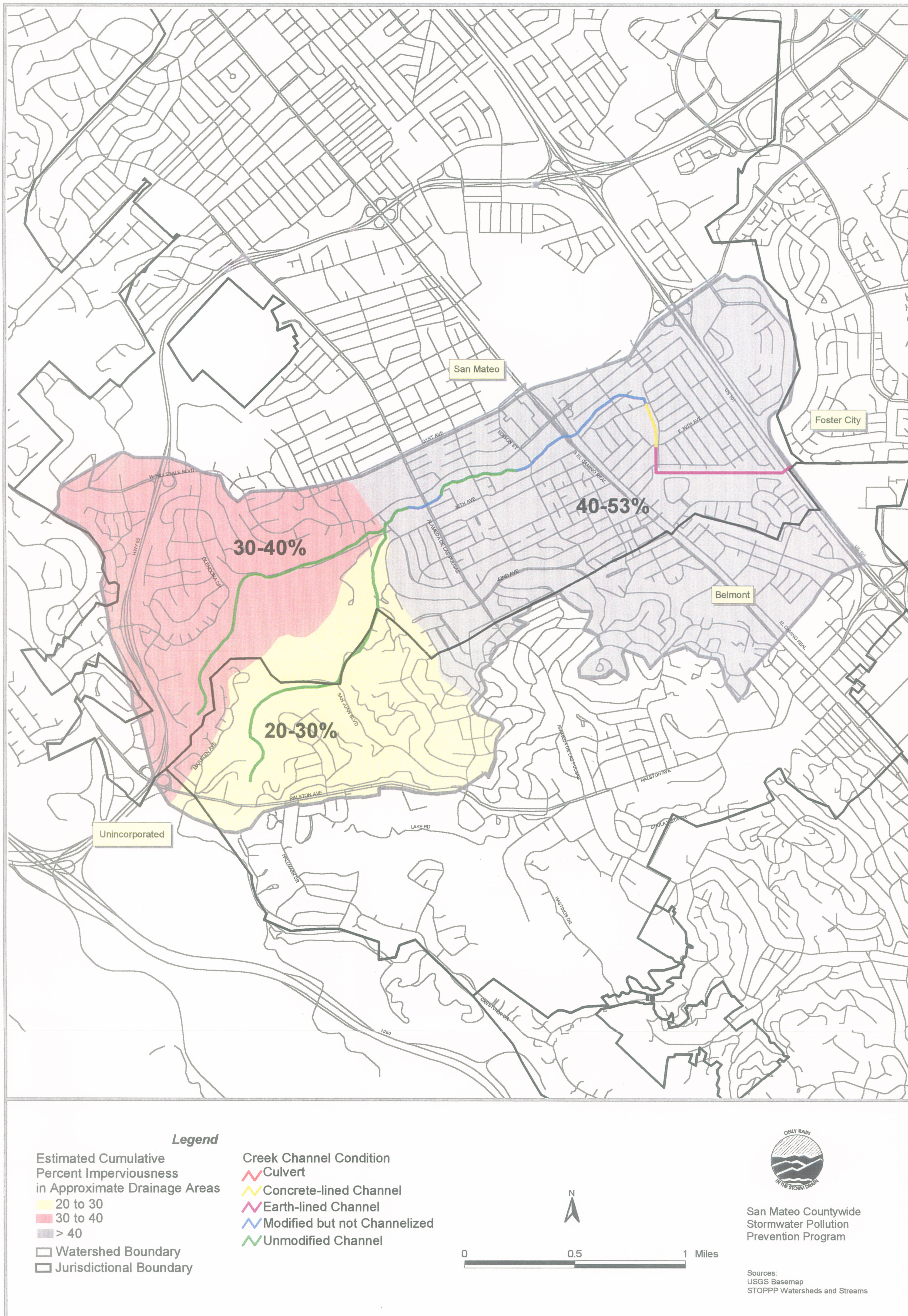

Figure 12. Imperviousness Estimates and Channel Modifications for Laurel Creek Watershed.

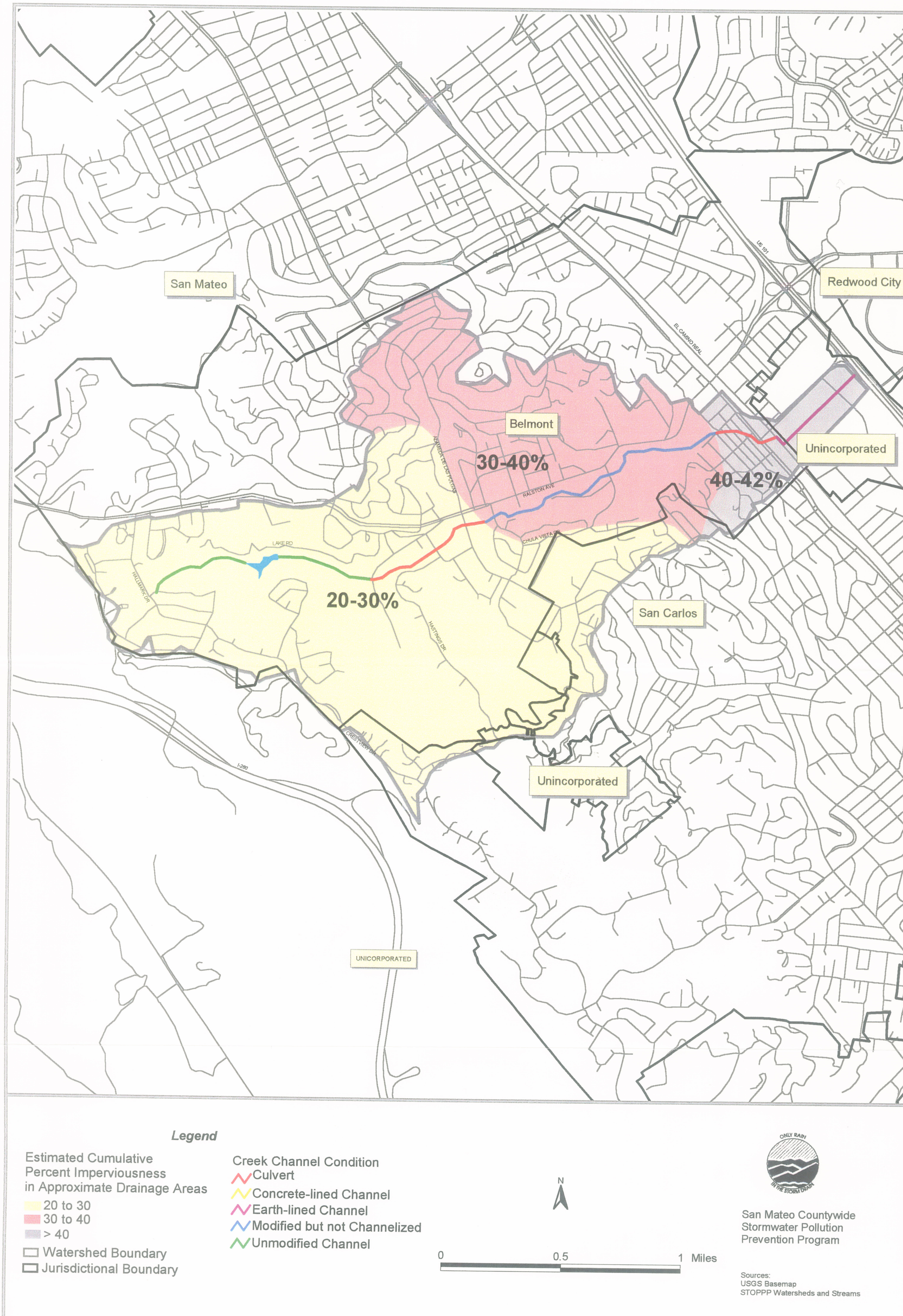

Figure 13. Imperviousness Estimates and Channel Modifications for Belmont Creek Watershed.

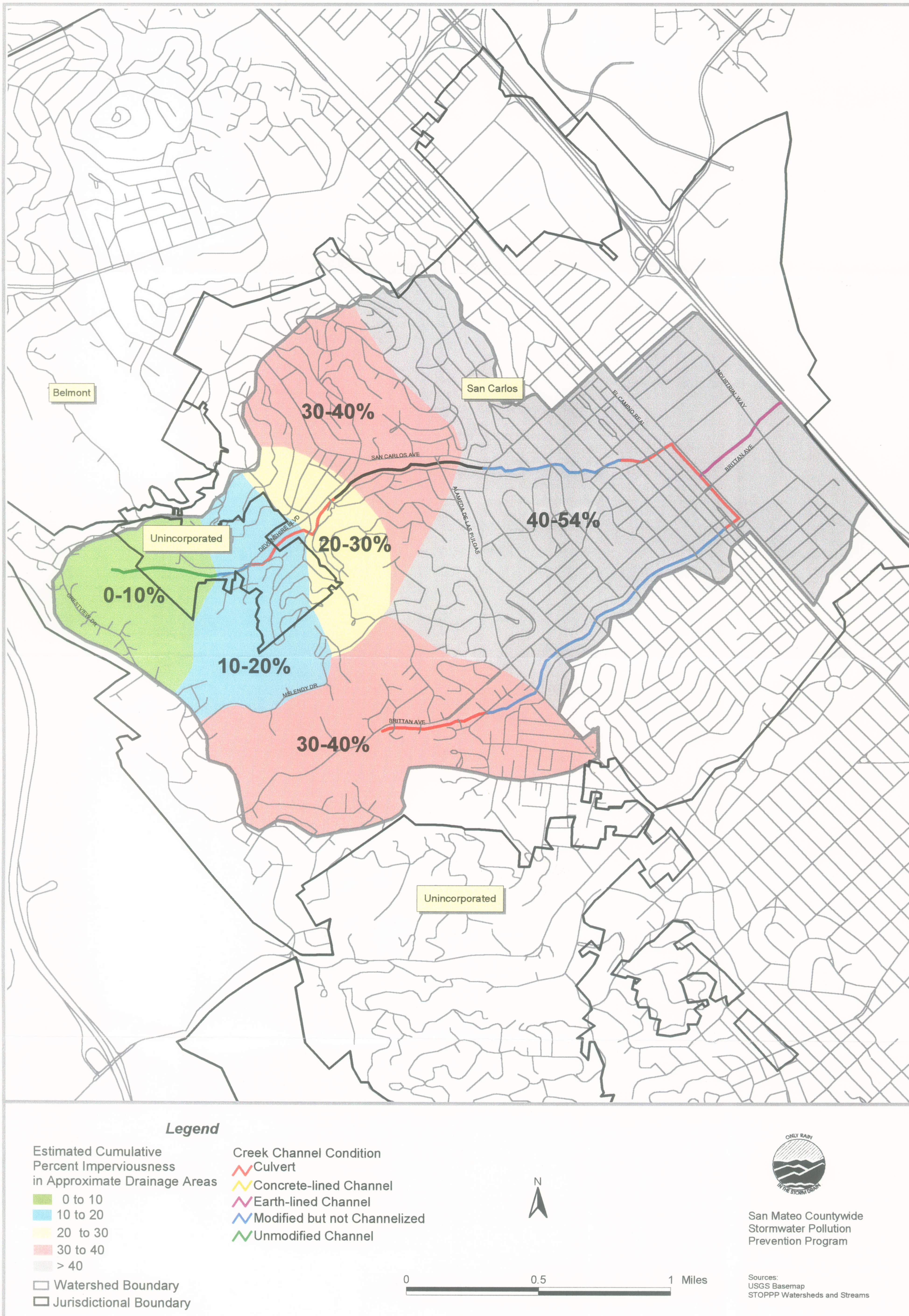

Figure 14. Imperviousness Estimates and Channel Modifications for Pulgas Creek Watershed.

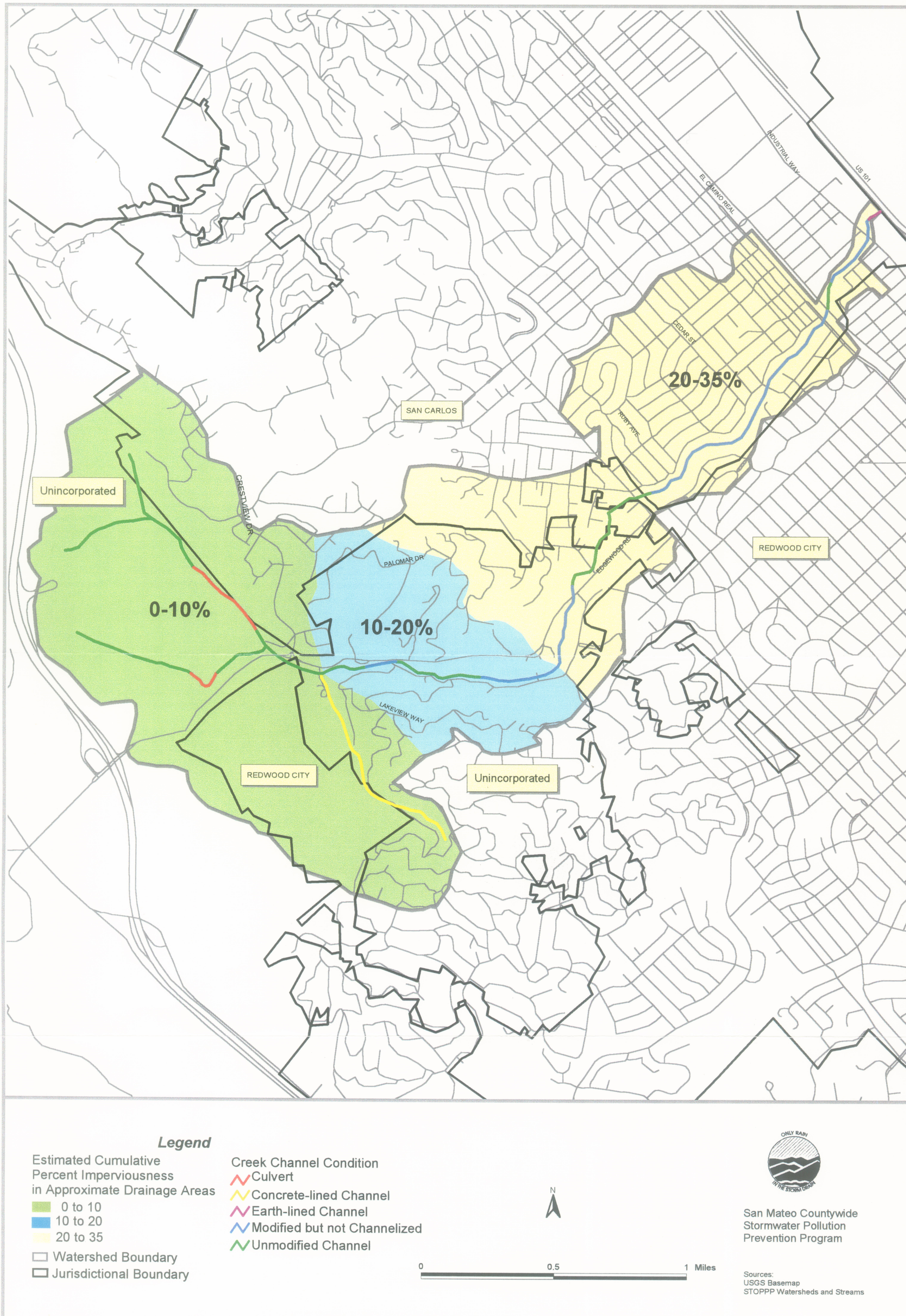

Figure 15. Imperviousness Estimates and Channel Modifications for Cordilleras Creek Watershed.

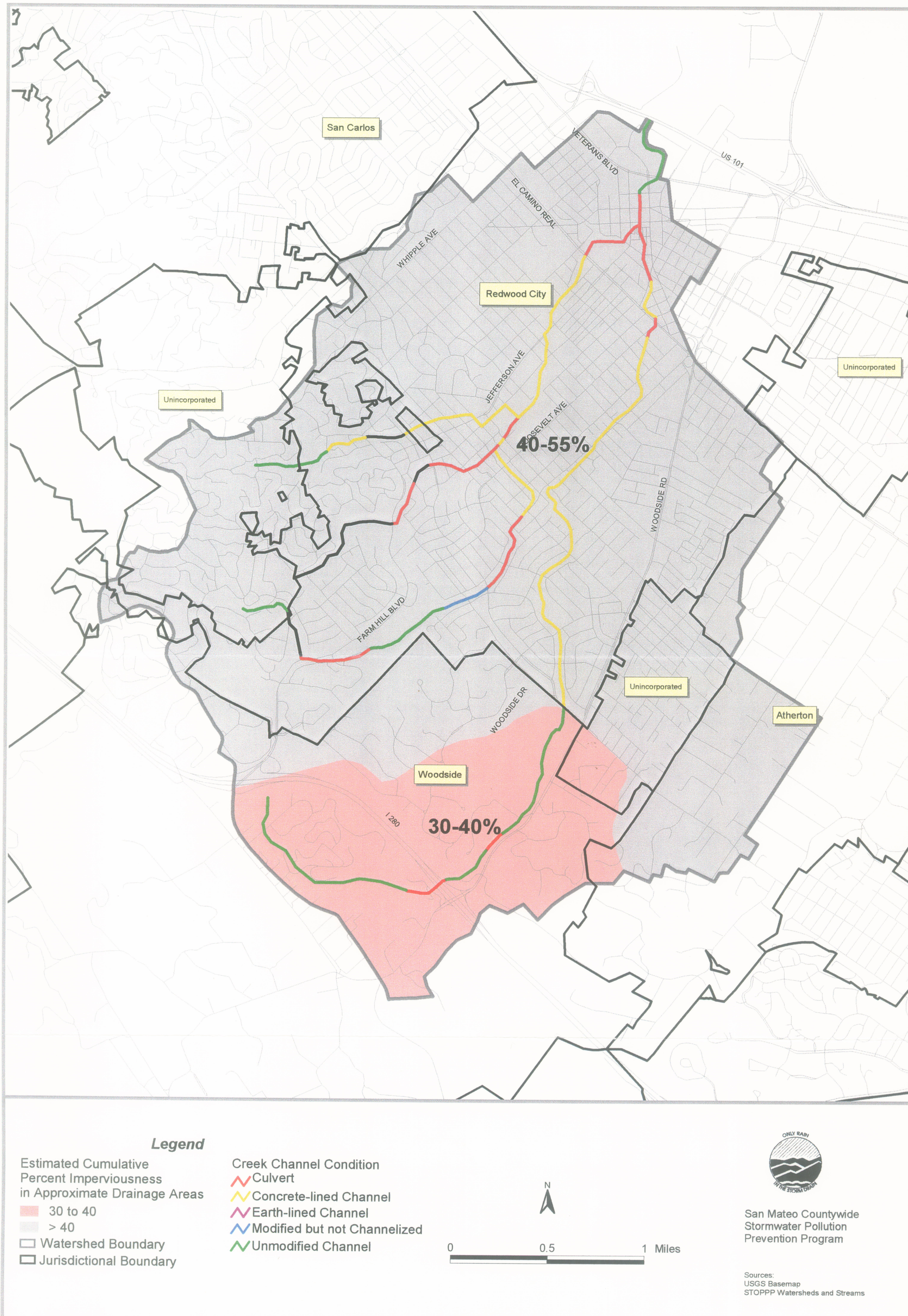

Figure 16. Imperviousness Estimates and Channel Modifications for Redwood Creek Watershed.

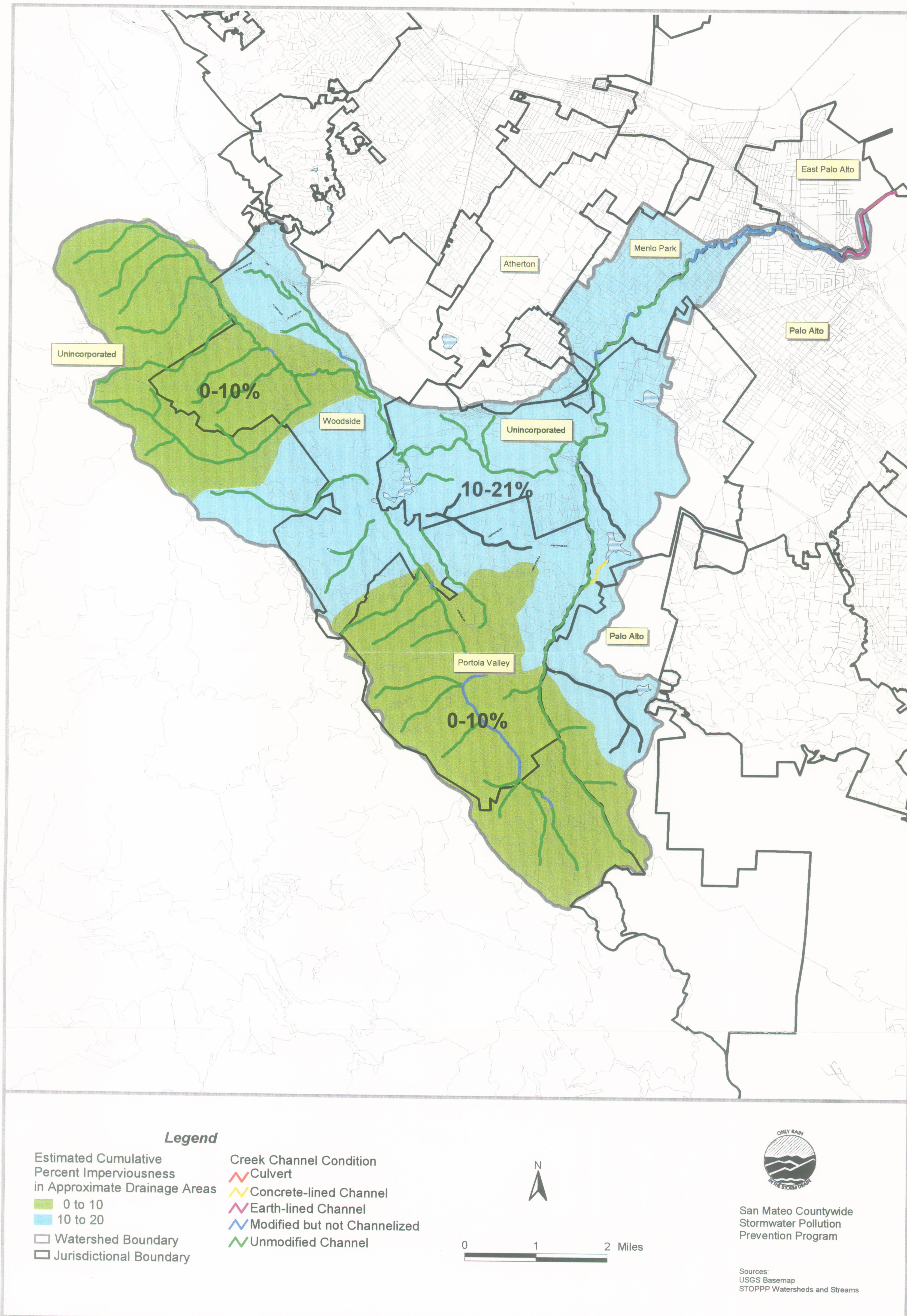

Figure 17. Imperviousness Estimates and Channel Modifications for San Francisquito Creek Watershed.

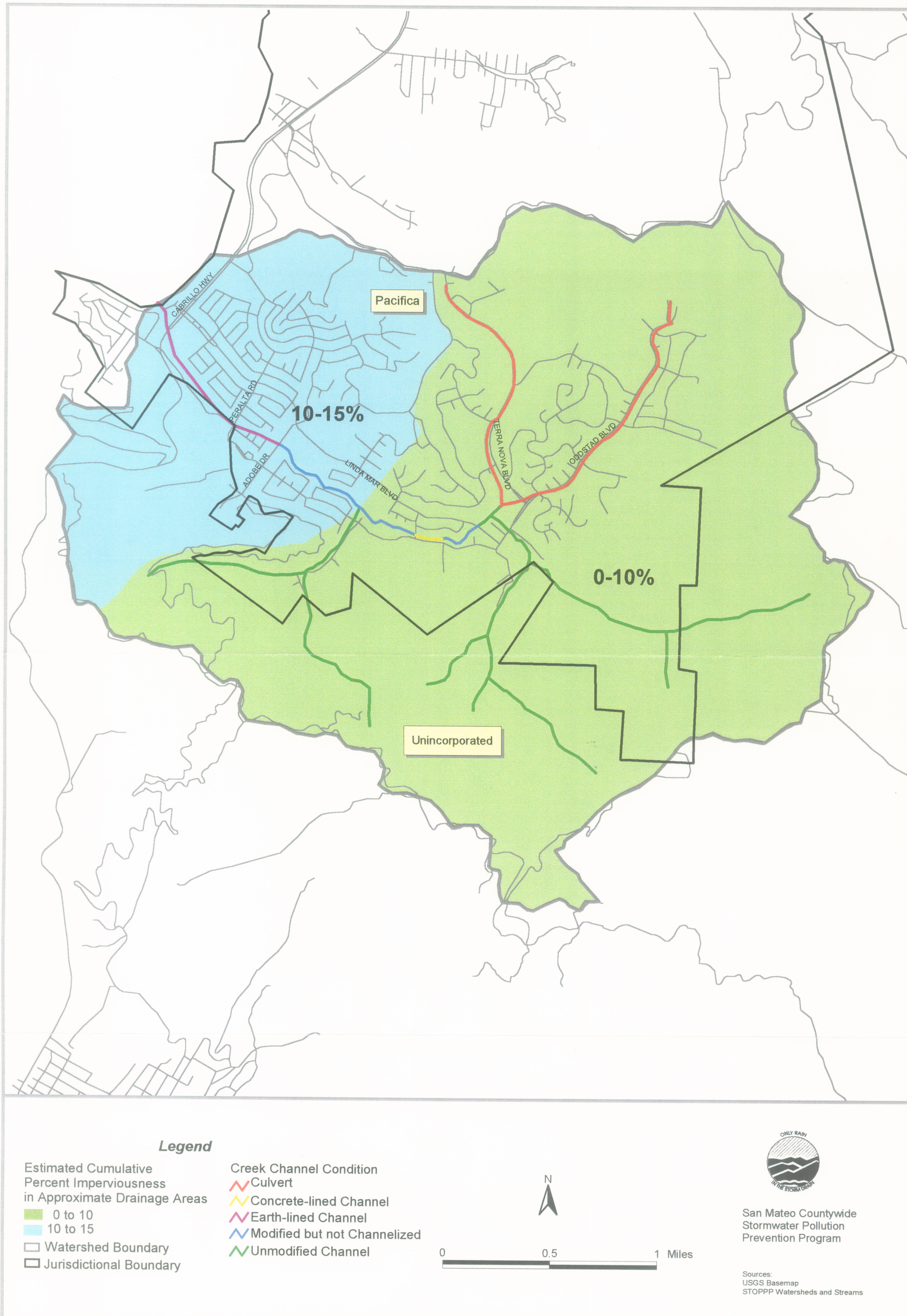

Figure 18. Imperviousness Estimates and Channel Modifications for San Pedro Creek Watershed.

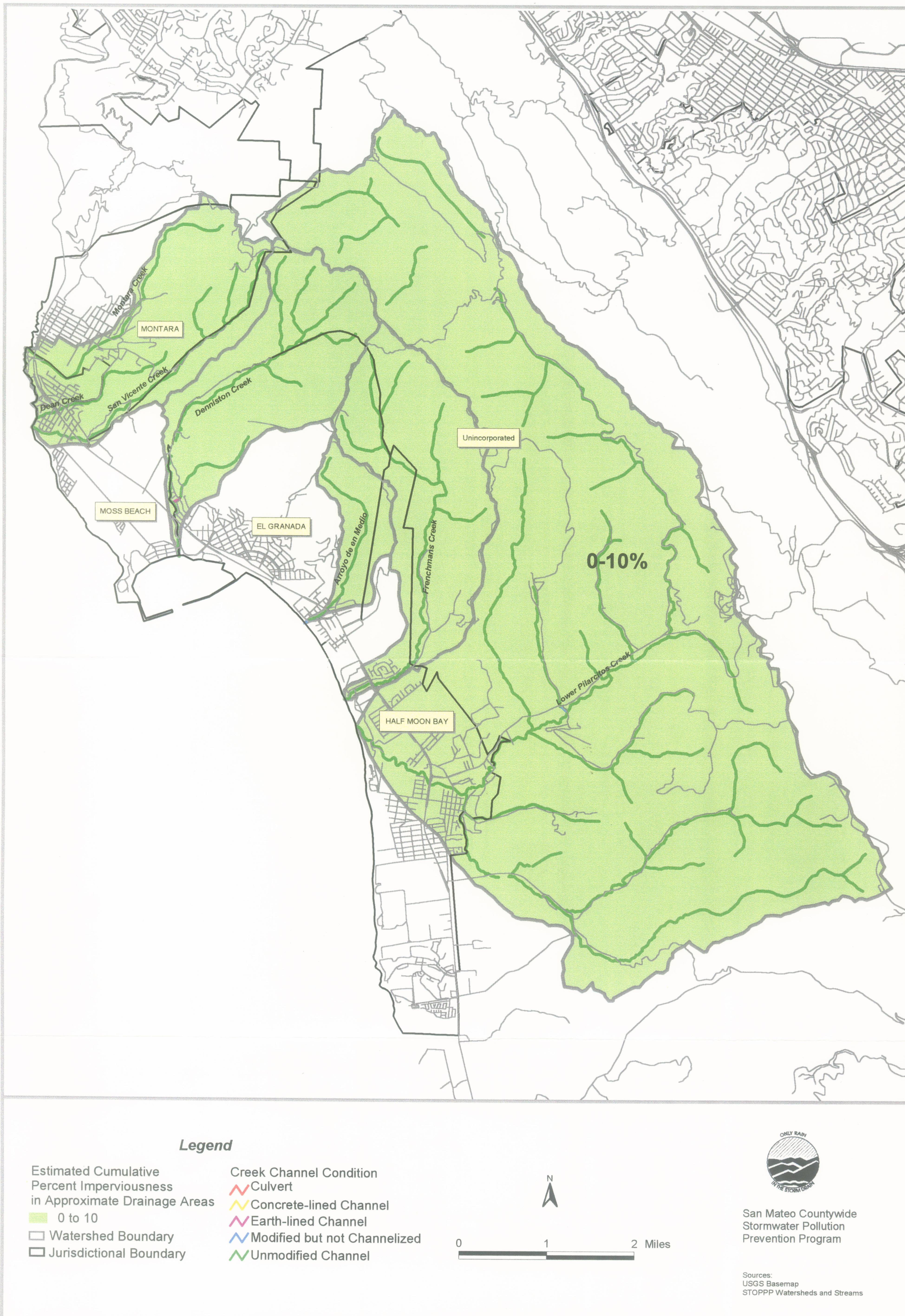

Figure 19. Imperviousness Estimates and Channel Modifications for Arroyo de en Medio and Denniston, Dean/Montara/Vincente, Frenchmans, and Pilarcitos Creek Watersheds.

APPENDIX A

Appendix - Table 1: Data sources used for watershed delineation.

Creek	Data Sources for Watershed Boundary Delineation
Arroyo de en Medio	Topographic maps (USGS, 1997a and 1997c).
Belmont Creek	City of Belmont's Master Plan (Wilsey and Ham, 1980), a map produced by Ken Erickson (a contract engineer for Belmont) and topographic maps (USGS, 1997b and d).
Colma Creek	Flood control study on Colma Creek basin (Army Corps of Engineers, 1970).
Cordilleras Creek	Engineering study on Cordilleras Creek (Boone, Cook and Associates, 1985) and Redwood City's Master Plan (Kennedy/Jenks/Chilton Consulting Engineers, 1986).
Dean/Montara/San Vicente Creeks	Devil's Slide Bypass study (Caltrans, 1983) and a topographic map (USGS, 1997c).
Denniston Creek	USGS topographic map (USGS, 1997c).
Frenchmans Creek	City of Half Moon Bay's Master Plan (City of Half Moon Bay, 1978) and topographic maps (USGS, 1997a and c).
Laurel Creek	Drainage study (City of San Mateo, 1966).
Mills Creek	Storm drain system map (City of Burlingame, 1954) as interpreted by a representative of the City of Burlingame Public Works (Monaghan, 1999) and topographic maps (USGS, 1997c and d).
Pilarcitos Creek	Restoration plan for Pilarcitos Creek creek (Philip Williams & Associates, Ltd., 1996) and topographic maps (USGS, 1997a - d).
Pulgas Creek	Engineering study on the adjacent Cordilleras Creek drainage area (Boone, Cook and Associates, 1985), City of San Carlos storm drain maps (McCandless, Boone and Cook, 1973) and topographic maps (USGS, 1997b and d).
Redwood Creek	Redwood City's Master Plan (Kennedy/Jenks/Chilton Consulting Engineers, 1986), a storm drain system map (City of Redwood City, 1998) and topographic maps (USGS, 1997b and e).
San Bruno Creek	Storm drain study (Bissell and Karn, 1991).
San Francisquito Creek	Watershed map prepared by the Santa Clara Valley Water District.
San Mateo Creek (below dam)	Drainage study (City of San Mateo, 1966).
San Pedro Creek	Creek and wetland restoration project report (Lee & Associates, 1995).
Sanchez Creek	Storm drain system map (City of Burlingame, 1954) as interpreted by a representative of the City of Burlingame Public Works (Monaghan, 1999) and topographic maps (USGS, 1997d).

Appendix - Table 2: Creek channel modification categories.

Culvert:

- Creek runs underground in a culvert for distances greater than approximately 500 feet.

Concrete-lined Channel:

- Creek is generally channelized in a concrete structure.
- Parts of creek may be culverted for distances less than approximately 500 feet (e.g., passing beneath roads).

Earth Channel:

- Creek is generally in an earth channel.
- Parts of creek may be culverted for distances less than approximately 500 feet (e.g., passing beneath roads).

Modified but Not Channelized:

- Creek generally does not appear to be channelized.
- Parts of creek may be culverted for distances less than approximately 500 feet (e.g., passing beneath roads).
- Creek generally has erosion control structures (e.g., gabion, riprap) or treatments (e.g., plastic sheeting) in some areas.
- Creek banks may have been filled in some areas.

Unmodified Channel:

- Creek generally does not appear to be channelized.
- Parts of creek may be culverted for distances less than approximately 500 feet (e.g., passing beneath roads).
- Creek generally does not have erosion control structures or treatments.
- Creek banks generally do not appear to have been filled.

Appendix - Table 3: Coefficients of imperviousness estimated for Association of Bay Area Governments (ABAG) land use data (ABAG, 1996). Included are: (1) descriptions of ABAG land use categories and codes and the associated land use classes as reclassified for the purposes of this study; and (2) imperviousness coefficients derived from the following sources: Bredehorst, 1981 (B); EOA, 1999a and 2000 (E) and the current study (C). Superscripts indicate (1) coefficients were estimated by best professional judgement; (2) coefficients were derived by digitizing impervious or pervious surfaces on aerial orthophotos in a GIS.

Reclassified Land Use Category	ABAG Land Use Category	ABAG Land Use Code	Impervious Coefficient	Source
Agriculture	Farmsteads and Other Agriculture	24	0.02	B
	Irrigated Cropland	2111	0.02	B
	Non-irrigated Cropland	2112	0.02	B
	Orchards	221	0.02	C[1]
	Greenhouses and Floriculture	223	0.47	B
	Cropland and Pasture	21	0.02	B
	Pasture	212	0.02	E[1]
Commercial	Commercial and Services	12	0.96	B
	Commercial Outdoor Recreation	122	0.66	B
	Mixed Residential and Commercial Use	16	0.93	E[2]
	Mixed Commercial and Industry	15	0.95	E[1]
	Retail and Wholesale	121	0.96	B
	Offices	128	0.91	B
Forest	Pine	422	0.01	E[1]
	Redwood and Douglas Fir	421	0.01	E[1]
	Evergreen Forest	42	0.01	C[1]
	Evergreen Mix	423	0.01	E[1]
High-Density Residential	Nine and Over DUs per Hectare	113	0.64	E[2]
	Mobile Home Parks	114	0.82	B
Industrial	Heavy Industry	131	0.91	B
	Industry	13	0.91	B
	Light Industry	132	0.91	B
Low-Density Residential	One and Under DUs per Hectare	111	0.10	C[1]
Moderate-Density Residential	Two to Eight DUs per Hectare	112	0.47	E[2]
Other	Other Urban and Built-Up Land	17	0.20	E[1]
	Land on USGS Maps, Not on Topos	64	0.01	C[1]
	Water on USGS Maps, Not on Topos	56	0.01	C[1]
	Beaches	72	0.01	E[1]
	Strip Mines, Quarries and Gravel Pits	75	0.02	B
	Bare Exposed Rock	74	0.95	C[1]
Public/Quasi-Public	Colleges and Universities	1232	0.47	B
	County Government Center	1265	0.75	E[1]
	Education	123	0.67	E[2]
	Elementary/Secondary Schools	1231	0.67	E[2]
	Cemeteries	172	0.28	E[2]
	Jails and Rehabilitation Centers	1267	0.75	E[1]
	Military Installations	125	0.75	E[1]

Reclassified Land Use Category	ABAG Land Use Category	ABAG Land Use Code	Impervious Coefficient	Source
Public/Quasi-Public (Continued)	Other Public Institutions and Facilities	126	0.75	E[1]
	Police Station	1264	0.75	E[1]
	Churches	1262	0.82	B
	Hospital Trauma Center	1241	0.74	B
	Medical Long-Term Facility	1243	0.68	B
	Community Hospital	1242	0.74	B
	Fire Station	1263	0.75	C[1]
	Research Centers	127	0.75	C[1]
	Psychiatric Facility	1249	0.75	C[1]
Rangeland	Chaparral	321	0.01	E[1]
	Coastal Shrub	322	0.01	E[1]
	Herbaceous Rangeland	31	0.01	E[1]
	Mixed Rangeland	33	0.01	E[1]
	Shrub and Brush Rangeland	32	0.01	C[1]
Recreation	Golf Courses	1711	0.03	B
	Extensive Recreation	171	0.20	E[1]
	Parks	173	0.20	E[1]
	Racetracks	1712	0.66	B
Transportation	Highways and Interchanges	1411	0.66	E[2]
	Public Airports	1437	0.66	B
	Rail Passenger Stations	1421	0.95	E[1]
	Rail Yards	1422	0.95	E[1]
Utilities	Electric - Other	1453	0.47	B
	Electric Substation	1452	0.95	E[1]
	Wastewater Treatment Plant	1461	0.75	E[1]
	Wastewater Pumping Station	1462	0.75	E[1]
Vacant, Undeveloped	Open Space - Urban	174	0.02	B
	Other Transitional	762	0.02	E[1]
	Urban Vacant Land	175	0.02	B
	Transitional Areas	76	0.02	E[1]
Water	Reservoirs	53	0.01	E[1]
	Lakes	52	0.00	C[1]
	Streams and Canals	51	0.20	C[1]
	Bays and Estuaries	54	0.00	C[1]
Wetlands	Forested Wetlands	61	0.01	C[1]
	Nonforested Wetlands	62	0.01	E[1]

Appendix - Table 4: Watershed imperviousness estimated from 1995 land use data.

Watershed	Reclassified Land Use Category	Total Impervious Area (Acres)	Percentage of Watershed Imperviousness
Arroyo de en Medio	Moderate-Density Residential	13.32	2.06
	Rangeland	4.98	0.77
	High-Density Residential	2.63	0.41
	Transportation	2.31	0.36
	Commercial	1.69	0.26
	Agriculture	0.92	0.14
	Forest	0.57	0.09
	Low-Density Residential	0.45	0.07
	Other	0.02	< 0.01
	Vacant, Undeveloped	0.02	< 0.01
	Total Watershed Percent Imperviousness:		**4**
Belmont Creek	High-Density Residential	597.78	31.40
	Public, Quasi-Public	88.29	4.64
	Moderate-Density Residential	38.09	2.00
	Commercial	32.48	1.71
	Industrial	31.46	1.65
	Rangeland	3.33	0.17
	Forest	2.89	0.15
	Vacant, Undeveloped	0.92	0.05
	Recreation	0.55	0.03
	Water	0.03	< 0.01
	Total Watershed Percent Imperviousness:		**42**
Colma Creek	High-Density Residential	2529.36	24.53
	Commercial	852.64	8.27
	Industrial	666.94	6.47
	Public, Quasi-Public	642.55	6.23
	Transportation	333.08	3.23
	Moderate-Density Residential	32.54	0.32
	Recreation	30.15	0.29
	Utilities	22.68	0.22
	Rangeland	16.56	0.16
	Other	15.01	0.15
	Vacant, Undeveloped	5.84	0.06
	Agriculture	2.62	0.03
	Forest	0.47	< 0.01
	Water	0.00	< 0.01
	Total Watershed Percent Imperviousness:		**50**
Cordilleras Creek	High-Density Residential	494.10	23.12
	Moderate-Density Residential	163.11	7.63
	Public, Quasi-Public	34.71	1.62
	Transportation	18.60	0.87
	Commercial	14.38	0.67
	Industrial	6.84	0.32
	Forest	5.44	0.25
	Rangeland	3.46	0.16
	Other	0.30	0.01
	Vacant, Undeveloped	0.27	0.01
	Recreation	0.22	0.01
	Total Watershed Percent Imperviousness:		**35**

Dean/Montara/ San Vicente Creek	Moderate-Density Residential	80.07	3.24
	High-Density Residential	25.30	1.02
	Commercial	18.99	0.77
	Rangeland	14.32	0.58
	Transportation	10.25	0.42
	Agriculture	8.96	0.36
	Public, Quasi-Public	8.46	0.34
	Utilities	7.03	0.28
	Industrial	6.94	0.28
	Forest	2.45	0.10
	Other	0.52	0.02
	Low-Density Residential	0.49	0.02
	Vacant, Undeveloped	0.20	0.01
	Water	0.03	< 0.01
	Total Watershed Percent Imperviousness:		**7**
Denniston Creek	Rangeland	22.22	0.93
	High-Density Residential	17.39	0.73
	Transportation	14.73	0.62
	Agriculture	1.70	0.07
	Moderate-Density Residential	0.64	0.03
	Forest	0.20	0.01
	Water	0.07	< 0.01
	Vacant, Undeveloped	0.07	< 0.01
	Commercial	0.04	< 0.01
	Other	0.00	< 0.01
	Total Watershed Percent Imperviousness:		**2**
Frenchmans Creek	Rangeland	23.34	0.86
	High-Density Residential	22.74	0.83
	Agriculture	5.74	0.21
	Commercial	5.41	0.20
	Transportation	3.88	0.14
	Forest	1.97	0.07
	Low-Density Residential	1.48	0.05
	Other	0.07	< 0.01
	Water	0.03	< 0.01
	Total Watershed Percent Imperviousness:		**2**
Laurel Creek	High-Density Residential	1207.83	40.94
	Commercial	182.93	6.20
	Public, Quasi-Public	92.42	3.13
	Transportation	36.80	1.25
	Moderate-Density Residential	29.05	0.98
	Recreation	6.33	0.21
	Forest	2.85	0.10
	Rangeland	2.70	0.09
	Vacant, Undeveloped	0.56	0.02
	Wetlands	0.03	< 0.01
	Total Watershed Percent Imperviousness:		**53**
Mills Creek	High-Density Residential	338.36	42.93
	Public, Quasi-Public	35.40	4.49
	Moderate-Density Residential	30.56	3.88
	Industrial	22.40	2.84
	Transportation	17.03	2.16
	Commercial	11.21	1.42
	Recreation	1.48	0.19
	Vacant, Undeveloped	0.45	0.06
	Rangeland	0.26	0.03

Mills Creek (cont.)	Forest	0.25	0.03
	Total Watershed Percent Imperviousness:		**58**
Pilarcitos Creek	High-Density Residential	218.65	1.19
	Rangeland	122.95	0.67
	Commercial	109.13	0.59
	Public, Quasi-Public	63.01	0.34
	Agriculture	51.72	0.28
	Moderate-Density Residential	48.67	0.27
	Forest	37.54	0.20
	Transportation	18.97	0.10
	Other	3.33	0.02
	Utilities	3.02	0.02
	Low-Density Residential	1.73	0.01
	Water	1.36	0.01
	Recreation	0.99	0.01
	Vacant, Undeveloped	0.18	< 0.01
	Total Watershed Percent Imperviousness:		**4**
Pulgas Creek	High-Density Residential	795.23	35.69
	Industrial	170.98	7.67
	Commercial	88.54	3.97
	Moderate-Density Residential	76.57	3.44
	Public, Quasi-Public	58.31	2.62
	Transportation	7.05	0.32
	Recreation	4.45	0.20
	Rangeland	2.52	0.11
	Forest	1.44	0.06
	Vacant, Undeveloped	0.59	0.03
	Total Watershed Percent Imperviousness:		**54**
Redwood Creek	High-Density Residential	1842.19	29.23
	Moderate-Density Residential	939.55	14.91
	Commercial	413.51	6.56
	Public, Quasi-Public	222.43	3.53
	Transportation	52.13	0.83
	Recreation	17.58	0.28
	Forest	2.15	0.03
	Rangeland	1.32	0.02
	Water	0.05	< 0.01
	Vacant, Undeveloped	0.05	< 0.01
	Total Watershed Percent Imperviousness:		**55**
San Bruno Creek	High-Density Residential	711.46	28.44
	Commercial	248.56	9.94
	Public, Quasi-Public	136.75	5.47
	Transportation	111.39	4.45
	Recreation	30.38	1.21
	Industrial	20.15	0.81
	Utilities	13.29	0.53
	Rangeland	2.68	0.11
	Other	2.47	0.10
	Moderate-Density Residential	2.33	0.09
	Vacant, Undeveloped	1.98	0.08
	Forest	1.61	0.06
	Low-Density Residential	0.25	0.01
	Agriculture	0.12	< 0.01
	Water	0.08	< 0.01
	Total Watershed Percent Imperviousness:		**51**

San Francisquito Creek	Moderate-Density Residential	2854.94	10.41
	High-Density Residential	1548.80	5.65
	Public, Quasi-Public	461.80	1.68
	Commercial	429.51	1.57
	Transportation	154.21	0.56
	Forest	122.86	0.45
	Rangeland	41.24	0.15
	Other	41.06	0.15
	Recreation	18.73	0.07
	Industrial	16.56	0.06
	Agriculture	12.01	0.04
	Vacant, Undeveloped	9.45	0.03
	Water	3.19	0.01
	Low-Density Residential	2.47	0.01
	Utilities	1.16	< 0.01
	Wetlands	1.01	< 0.01
	Total Watershed Percent Imperviousness:		**21**
San Mateo Creek (below Crystal Springs dam)	High-Density Residential	466.69	16.12
	Moderate-Density Residential	413.59	14.28
	Commercial	99.34	3.43
	Public, Quasi-Public	69.22	2.39
	Transportation	38.64	1.33
	Forest	6.01	0.21
	Rangeland	3.49	0.12
	Vacant, Undeveloped	1.58	0.05
	Recreation	0.00	< 0.01
	Total Watershed Percent Imperviousness:		**38**
San Pedro Creek	High-Density Residential	579.54	11.26
	Public, Quasi-Public	69.16	1.34
	Commercial	50.08	0.97
	Rangeland	36.23	0.70
	Moderate-Density Residential	21.48	0.42
	Transportation	11.79	0.23
	Recreation	4.94	0.10
	Forest	3.01	0.06
	Utilities	1.85	0.04
	Vacant, Undeveloped	0.93	0.02
	Agriculture	0.54	0.01
	Low-Density Residential	0.49	0.01
	Other	0.10	< 0.01
	Water	0.05	< 0.01
	Total Watershed Percent Imperviousness:		**15**
Sanchez Creek	Moderate-Density Residential	120.58	18.49
	High-Density Residential	69.50	10.66
	Transportation	21.26	3.26
	Commercial	12.75	1.95
	Public, Quasi-Public	1.94	0.30
	Forest	1.84	0.28
	Recreation	0.85	0.13
	Industrial	0.63	0.10
	Low-Density Residential	0.20	0.03
	Rangeland	0.15	0.02
	Vacant, Undeveloped	0.15	0.02
	Water	0.03	< 0.01
	Total Watershed Percent Imperviousness:		**35**

APPENDIX B

EXAMPLE PHOTOGRAPHS OF CREEK CHANNEL MODIFICATIONS

Entrance to Culvert – Colma Creek

Concrete-lined Channel – Colma Creek

Earth Channel – Colma Creek

Modified but Not Channelized – Belmont Creek

Unmodified Channel – Tributary to San Pedro Creek