Petaluma River Impairment Assessment for Nutrients, Sediment/Siltation, and Pathogens

Part 1: Existing Information and TMDL Comparison

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1. Introduction

1.1. *Purpose*

The Aquatic Science Center has been hired by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) to investigate the possibility of water quality impairment in the Petaluma River by three pollutants: sediment/siltation, pathogens, and nutrients. The project goal is to determine if the River is impaired, and if so, to what degree. This project will be completed in 4 parts:

Part 1: Summarize existing data and make comparisons between what is available for Petaluma and what was used for development of TMDLs for similar types of watersheds

Part 2: Build upon lessons learned in other watersheds to determine which specific datasets are essential for determining impairment

Part 3: Collect additional data

Part 4: Provide scientific analysis of impairment using the following framework:

- **No impairment:** The available data demonstrate no negative effect on beneficial uses of the freshwater portions of the River, and there is sufficient information to make the finding.
- **Impairment unlikely:** The data indicate that nutrients, sediment, and pathogens cause no impairment to the River. However, there is some uncertainty, due to lack of sufficient information or disagreement about how to interpret the data.
- **Possible impairment:** There is some suggestion of impairment, but the uncertainties preclude making a definitive judgment.
- **Definite impairment:** The data clearly demonstrate a negative effect on the beneficial uses of the freshwater portions of the River.
- **Unable to determine impairment:** There is insufficient information to make any determination.

This report summarizes the results of Part 1, and includes the following tasks:

- Describe the beneficial uses for the Petaluma River,
- Compile relevant water quality guidelines and targets for reference,
- Establish and qualify connections between water quality guidelines and beneficial uses,
- Compile the readily available data (not older than last 10 years) to evaluate whether water quality objectives protective of beneficial uses in the waterbody are being attained,
- Compare the data used to develop TMDLs in similar watersheds against what is available for Petaluma.

1.2. ***Impairment listing***

The Petaluma River was first designated as a "water quality limited" segment of the Region 2 basin in 1975 due to low dissolved oxygen concentrations. In 1982, RWQCB staff observed "dissolved oxygen and nutrient problems…producing seasonal fish kills" and documented concerns regarding elevated fecal coliform levels (SFBRWQCB 1982). Subsequently, the City of Petaluma updated their wastewater treatment plant and ceased to discharge effluent between May and October when freshwater inputs from tributaries do not provide enough flow to flush out potential pollutants (SSCRCD 1999). Though the river is no longer considered to be impaired by dissolved oxygen, it remains on the 303(d) list for Impaired Water Bodies for diazinon, nutrients, pathogens, sediment/siltation (SWRCB 2006), and trash (SFBRWQCB 2009).

1.3. ***Physical scope***

Due to the nature of tidal mixing in San Pablo Bay, the mouth of the Petaluma River acts as a sink for some sediment and associated pollutants, and thus, the mouth is considered a separate waterbody from the rest of the watershed and has separate 303(d) listings. This report will focus on the rest of the watershed, which is defined as the mainstem Petaluma River upstream of the crossing at Highway 37 through to the headwaters at the confluence of Liberty, Willow Brook, and Weigand's Creeks (highlighted in red in Figure 1). In the case of impairment by sediment, we will expand the scope to include those tributary streams that support steelhead trout (Looker pers. comm.), namely Lichau, Lynch and Adobe Creeks (NOAA Fisheries (2005). For nutrients, and pathogens, the scope is limited to the mainstem unless there is insufficient data, at which point data from tributary streams is considered.

2. Setting

2.1. ***Watershed location and description***

The Petaluma River is located in southern Sonoma County and a small portion of northeastern Marin County and drains into San Pablo Bay (Figure 1). The watershed encompasses approximately 146 square miles (378 km^2), and is the eleventh largest small tributary to San Francisco Bay (McKee et al, 2003).

The River is actually comprised of a fluvial section and a tidal slough section, and has several perennial and intermittent tributaries. Seasonal first-order tributaries from the Sonoma Mountains in the northeast and the slopes of Mount Burdell and Weigand's Hill in the northwest feed Willow Brook, Liberty, and Weigand's Creeks, which merge to form the Petaluma River a little over 3 miles north of the City of Petaluma. The largest tributary, San Antonio Creek, defines the border between Marin and Sonoma Counties and drains the southwestern portion of the watershed (about 20% of the total watershed area). San Antonio Creek historically entered the lower tidal portion of Petaluma River just north of Burdell Island, however in the 1930s it was diverted to Schultz Slough, which enters the River north of Neils Island, 5.2 miles upstream from the former San Antonio Creek confluence (Collins et al. 2000). Other major tributaries include (from north to south along the eastern side of the mainstem): Lichau, Willow Brook, Lynch, Adobe, Washington, and Ellis Creeks. The tidal slough section of the River begins approximately at the confluence with Lynch Creek, and continues through the saline Petaluma River Marsh complex, before discharging into San Pablo Bay. The tidal marshes along the Petaluma River cover approximately 5,000 acres, and it is claimed that "upstream of its [historic] confluence with San Antonio Creek comprise[s] the largest intact ancient saline and brackish marshland on the west coast of North America, outside of Alaska" (Collins et al 1987).

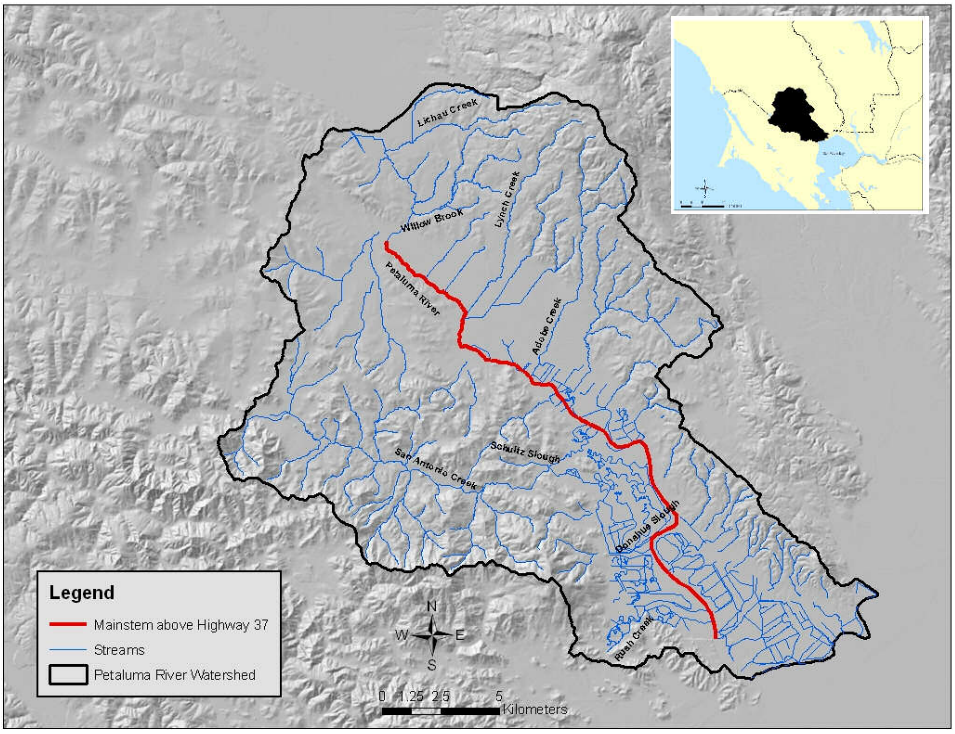

Figure 1. Petaluma River watershed. Red line indicates scope of this report. Inset shows location in Marin and Sonoma counties.

2.1.1. Climate

Like the larger San Francisco Bay Area, the Petaluma River watershed has a Mediterranean climate, with cool, wet winters and warm, dry summers. Over 90% of the annual rainfall occurs during October to April (inclusive), with an average annual precipitation total of 25.2 inches (641 mm) in the watershed (McKee et al., 2003). However, rainfall is highly variable from year to year (40-200% mean annual), and it is this variability that influences sediment production (via processes such as landslides, debris flows, and channel erosion), sediment transport capacity, and water quantity and quality (Pearce et al., 2005). Episodic sediment production from hillslope sources (e.g. landslides) can significantly increase the total load delivered to the channel network. One of the primary drivers of landslides and debris flows is the total amount and intensity of precipitation that the hillslope receives. For example, Wilson (2001) has highlighted the local climate's effect (mainly the drainage rate of rainfall from hillslopes, and its control of pore-water pressures) upon the threshold for debris flow initiation. Therefore, climatic records are an important component in understanding past contributions of sediment from the hillslopes within the watershed, and predicting likely future contributions once precipitation thresholds are crossed.

2.1.2. **Geology/tectonics**

Pliocene and early Miocene sedimentary rocks and Early Cretaceous/Late Jurassic Franciscan Formation metamorphic rocks and mélange are the primary bedrock units underlying the uplands, while the valley bottom is filled with Holocene alluvium and mud deposits (Graymer et al., 2006). The valley is bounded by two mapped Quaternary faults, the Burdell Mountain Fault to the southwest and the Tolay Fault to the northeast (USGS 2009). The larger Rodgers Creek Fault is located in the Sonoma Mountains, which separate the Petaluma River watershed from the Sonoma Creek watershed. Due to its setting along the active San Andreas Fault system, the Bay Area region experiences rapid rates of uplift and locally high rates of sediment production from exposed erodible rock types. The Petaluma River watershed is no exception; the Franciscan Formation on the northwest is known as a highly erodible rock type, and has the potential to generate large volumes of sediment. Inputs of sediment either from episodic landslide or debris flows or from intensive land use on top of erodible rock types are often among the largest components of sediment supply to the channel network in Bay Area watersheds. It is possible that areas underlain by Franciscan Formation rocks are contributing the majority of sediment to the Petaluma River. Although the younger Sonoma Volcanics and marine sedimentary rocks on the east side of the watershed may not be as erodible, some of these rocks contain the mineral apatite (a phosphatic mineral) which can be a source of phosphorus within the watershed when the rocks are weathered and delivered to the channel network. For example, in the adjacent Sonoma and Napa watersheds, certain sub-watersheds underlain by the Sonoma Volcanics (similar to areas in Petaluma) were hypothesized to have elevated levels of phosphorus due to dissolution and leaching via ground water pathways (McKee and Krottje, 2005).

2.1.3. **Land Use**

The Petaluma River watershed is a largely agricultural landscape dominated by grassland and pasture for grazing cattle and sheep (Figure 2). As of 2005 there were 29 dairies in the watershed including two goat operations, and one registered confined animal feeding operation (RWQCB unpublished data), though the total number of livestock is unknown. The City of Petaluma was incorporated in 1858, and today its rapidly expanding urban area (population 54,496 in 2007) occupies the central portion of the watershed. Population increase has averaged 130% each decade for the period 1970-2000 and is akin to other rapidly advancing cities in the Bay Area, for example the tricity Livermore Valley (134%) and greater than the average of the Bay area as a whole (114%). The unincorporated community of Penngrove (population 3,845 in 2007) is located just to the north. The remainder of the land use in the watershed is salt marsh and wetlands along the river channel in the south, vineyards scattered around Penngrove and the Petaluma urban boundary, and some forested areas in the hills along the southwestern and northeastern portions. About 7,000 acres of reclaimed wetlands adjacent to the marshlands are used for cultivating hay, are transitioning to vineyards, or are preserved as open space (SSCRCD 1999). Land uses such as grazing, urban/suburban areas, and viticulture typically contribute to elevated levels of sediment within the channel network because they alter runoff rates and routes, soil structure, and vegetation patterns. For example, heavily grazed hillslopes are prone to shallow landsliding and channel bank collapse, and can provide large amounts of fine sediment directly into the channel network because the compacted soils and low amounts of residual vegetation cause reduced infiltration and increased runoff. Additionally, viticulture on very steep slopes can cause direct soil loss during runoff events, or can contribute to hillslope instability. Sonoma County has regulations (Ordinance no. 5819, Chap. 11) which prohibits work on vineyards and orchards in the wet season, establishes setbacks from wetlands and streams, and limits development to slopes less than 50 percent.

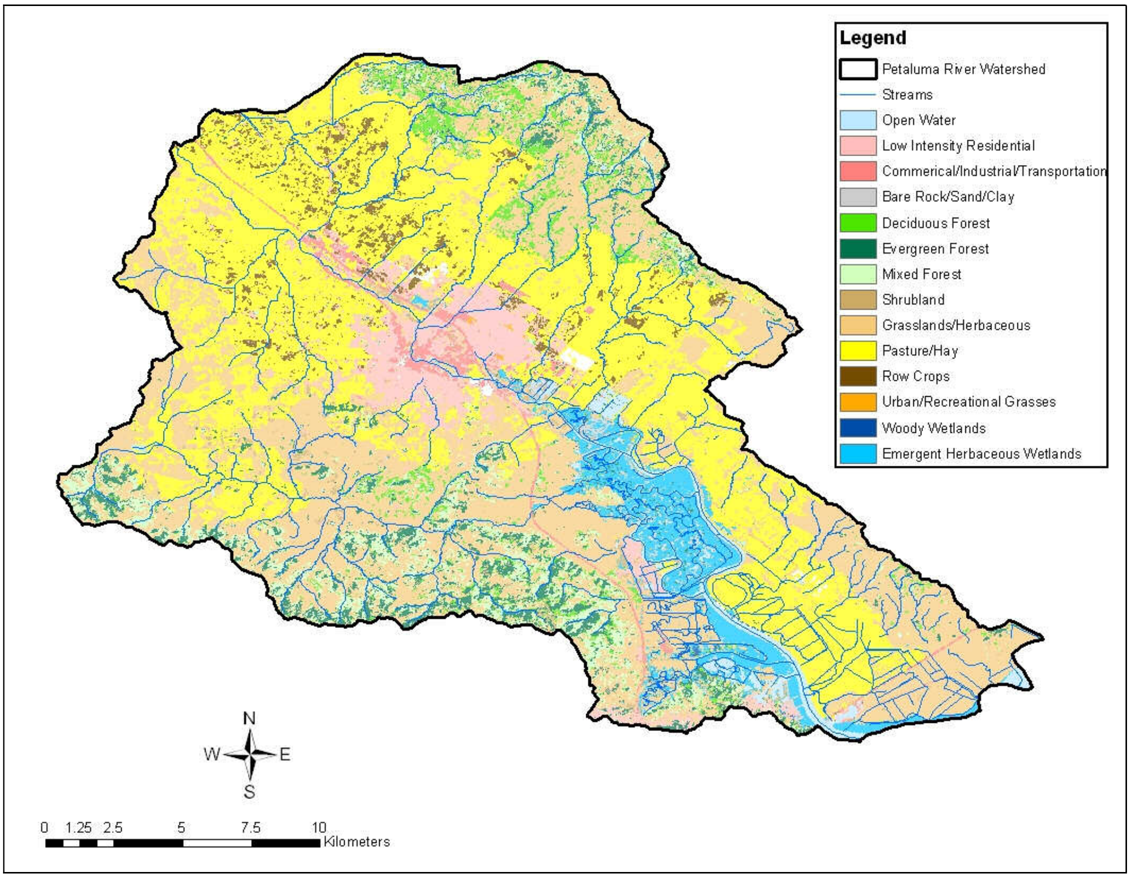

Figure 2. Landcover of the Petaluma River Watershed.

2.2. ***Beneficial Uses***

Beneficial uses "define the resources, services, and qualities of…aquatic systems that are the ultimate goals of protecting and achieving high water quality" (SFBRWQCB 2007a, Chapter 2). Ideally, beneficial uses should be protected from human activities and other outside influences. Thus, water quality guidelines are designed to protect beneficial uses, which are often impacted in impaired waterbodies. The assigned beneficial uses for the Petaluma River are:

- **Cold freshwater habitat:** including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
- **Fish migration:** habitats necessary for migration, acclimatization between fresh water and salt water, and protection of aquatic organisms that are temporary inhabitants of waters within the region.
- **Preservation of rare and endangered species:** habitats necessary for the survival and successful maintenance of plant or animal species established under state and/or federal law as rare, threatened, or endangered.
- **Fish spawning:** high quality aquatic habitats suitable for reproduction and early development of fish.
- **Warm freshwater habitat:** including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
- **Water contact recreation:** recreational activities involving body contact with water where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, whitewater activities, fishing, and uses of natural hot springs.
- **Non-water contact recreation:** recreational activities involving proximity to water, but not normally involving contact with water where water ingestion is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tide pool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.
- **Estuarine habitat:** including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds), and the propagation, sustenance, and migration of estuarine organisms.
- **Navigation:** shipping, travel, or other transportation by private, military, or commercial vessels.
- **Wildlife habitat:** including, but not limited to, the preservation and enhancement of vegetation and prey species used by wildlife, such as waterfowl.

(SWRCB 2007a)

2.3. ***Water Quality guidelines***

In order to assess impairment and the 303(d) listings for the River in the context of beneficial uses, it is important to examine the available water quality guidelines. The San Francisco Bay RWQCB's Basin Plan includes relevant numeric guidelines for unionized ammonia, fecal coliform, dissolved oxygen; as well as narrative guidelines for suspended sediment, other suspended/settleable material, and biostimulatory substances (SFBRWQCB 2007A). In addition, guidelines commonly used to assess aquatic conditions were compiled from EPA documents and the scientific literature. The guidelines will be discussed in further detail in the relevant sections below.

3. Sediment

3.1. ***Beneficial use impairment***

Erosion is a natural process that is an important component of landscape and channel evolution. Geomorphic processes source sediment from the hillslopes and deliver it to alluvial channels, where that sediment is then transported downstream to the marshes and receiving waterbodies (in this case, San Pablo Bay). However, urban development and agricultural land management within a watershed typically exacerbate natural erosional processes. The increased erosion creates excessive volumes of sediment which when delivered to the Petaluma River, can degrade the water quality and can impact beneficial uses.

Here the term "sediment" is inclusive of all inorganic material that is being delivered to the channel network. Sediment ranges from clay (very small grain sizes, less than 0.004 mm in diameter), up to boulders (larger than 25 cm). For the purpose of this beneficial use assessment, we will divide sediment into two sizes: fine sediment (fine sands, silts, and clays smaller than 0.25 mm) that is transported in suspension and coarse sediment (coarse sand, gravel and cobble ranging between 0.25 and 128 mm) that is transported as bed load. These two sizes are usually sourced by very different processes and from very different locations in the landscape. For example, deep seated landslides (often naturally occurring) tend to supply predominantly coarse sediment while land use-related sediment erosion (grazing, urbanization, and viticulture) and channel erosion tend to supply fine sediment. The size of sediment has a large influence on the potential for impairment because fine and coarse grain sizes have very different effects upon the channel form and function. Sediment-related impairment is most commonly identified due to impacts resulting from excessive amounts of anthropogenically-enhanced fine sediment deposited in the streambed and in some reaches on the floodplains. However, coarse sediment can also have deleterious effects such as excess aggradation that reduces flood conveyance capacity. All the beneficial uses (listed above in section 2.2) are to some degree affected by production and transport of excess fine and/or coarse sediment but these effects can be greater or lesser and positive or negative depending on the particular use (Table 1).

Table 1. Impacts (positive and negative) of coarse and fine sediment upon beneficial uses in the Petaluma River. Negative impacts are indicated by italics.

Beneficial Use	Coarse sediment (sand, gravel and cobble)	Fine sediment (fine sand, silt, and clay)
Cold freshwater habitat	Positive impact- provides habitat complexity	*Negative impact- reduces habitat complexity*
Fish migration	Positive impact- provides habitat complexity. *Negative impact- can reduce channel capacity and decrease summer/fall surface flow*	*Negative impact- can cause pool infilling reducing resting locations, can reduce summer/fall surface flow*
Preservation of rare and endangered species	Positive impact- provides habitat complexity	*Negative impact- reduces habitat complexity*
Fish spawning	Positive impact- provides appropriate spawning material	*Negative impact- increases embeddedness and gravel scour, reduces permeability*
Warm freshwater habitat	Positive impact- provides habitat complexity	*Negative impact- reduces habitat complexity and, if suspended, can impair eggs and larvae of fish, and reduce access to food*
Water contact recreation	Positive impact- provides appropriate substrate for activities	*Negative impact- increased transport/concentration of pollutants*
Non-water contact recreation	Positive impact- aesthetically pleasing	*Negative impact- stream appears cloudy, may contribute to vegetative choking of waterway*
Estuarine habitat	Positive impact- provides sediment needed by marshes to keep up with sea level rise	Positive impact- provides sediment needed by marshes to keep up with sea level rise. *Negative impact- increased transport of sediment-bound pollutants*
Navigation	*Negative impact- deposition in channel reduces water depth*	*Negative impact- deposition in channel reduces water depth*
Wildlife habitat	Positive impact- provides habitat complexity	*Negative impacts – reduced migration, habitat complexity and access to food*

3.1.1. Physical effects

Excessive sediment delivery to creeks can have many effects upon the physical channel, causing changes in its geometry, habitat, planform, and water and sediment transport capabilities. Here we briefly outline some of the most common changes. Increased sediment supply to the channel will first have an impact upon in-channel features, and generally decreases channel complexity. Any deposition that occurs can cause pool in-filling, creation of larger or a greater number of bars, or aggradation of the entire channel bed causing an increase in overall channel width. As a channel aggrades, the banks are then exposed to faster and deeper water during high flow events, potentially causing instability and erosion. This change may undercut established riparian vegetation, and ultimately may reduce the quality of the riparian corridor. An aggraded wider channel also may have greater access to its floodplain, causing increased deposition of sand splays and fine sediment across the floodplain. Deposition may also be evident in the longitudinal profile, as sediment deposits near the channel mouth, affecting the overall channel gradient and surface flow regime. And in extreme cases, significantly greater sediment load may even cause a channel to change form, for example, from meandering to braided. Increased sediment supply to the channel will also likely have an effect upon the channel bed grain size distributions and sediment transport capabilities. If predominantly coarse sediment is delivered to the channel, it will likely aggrade and coarsen the bed if the channel does not have enough power to transport the sediment downstream. However, if predominantly fine sediment is supplied, the channel bed grain size will fine from deposition of fines on the falling limb of the hydrograph. Also, increased fines in the channel bed increases mobility of the coarse armor layer of clasts, increasing the depth of scour on any given flow event. And because fine sediment is transported in suspension, smaller flows are required to transport it downstream.

3.1.2. Effects on Fish Communities

Similarly to the effects on the physical channel network, excess sediment can also have deleterious effects upon fish communities. Here we will focus on the life cycle of steelhead trout, because they are a federally threatened species present in this watershed, and protecting their populations will ensure protection of other, less sensitive species. The effects are felt in each life stage; for example, spawning, emergence, rearing, and migration of steelhead can all be negatively affected by excessive fine and/or coarse sediment. Some of the most important sediment related impacts result from changes in sediment transport processes that determine the shape, complexity, and hydrology of stream habitats. First, a high proportion of fines degrades potential spawning gravels by increasing embeddedness, making it difficult for the fish to prepare a redd. Also, the high proportion of fines in the transported sediment increases the mobility of the coarse fraction. This process promotes higher bed scour rates, due to lack of the protective armored layer on the bed, and simplification of channels form. Of the redds that are not in danger from scour, high levels of fine sediment then affect the survival of the eggs within the gravel. Fine sediment deposits on stream beds covers gravel interstices reducing sediment hydraulic properties and thus hyporheic exchange between river and sediment (Packman et al., 2004). These conditions result in low gravel permeability, which can cause poor incubation for fish eggs and high mortality prior to emergence. For instance, a 30% fraction of sediment finer than 6.4mm reduces the chance of another salmonid species, Chinook salmon (*Oncorhynchus tshawytscha*) fry emergence from sediment by about 40% (Bjornn and Reiser, 1991). After emergence, juveniles require appropriate habitat to oversummer. Pool riffle morphology is eliminated by the filling of pools and erosion of riffles. If deep pool habitat, where fish rest and feed, is reduced, predation rates increase and the population decreases. Excess fine sediment has a negative effect upon benthic macroinvertebrate populations, the food supply for salmonids like steelhead. Also, juveniles require low velocity shelters during high flow events; channel aggradation typically decreases channel complexity and thus, velocity shelters. And finally, already low springtime surface flows may be decreased by an aggraded channel bed, limiting the ability of fish to outmigrate. These examples illustrate that excess sediment can impact fish populations in all life stages.

3.1.3 Benthic effects

Benthic species are also strongly affected by the presence of excessive fine sediment (Resh and Jackson, 1993). The simplification of channel habitat reduces the number, the size and the quality of pools and riffles. A finer bed grain size distribution decreases the amount of appropriate substrate for a healthy benthic population to thrive. For example, because many benthic macroinvertebrates are not very mobile, they depend upon a diverse substrate particle size distribution, available interstitial spaces, and a complex habitat to survive (Brady et al., 2003). Increased fines will decrease gravel permeability and may reduce their contact with the oxygen-rich water. Greater contributions of fine sediment may cause turbidity to be elevated for longer time periods, affecting access to food, habitat functionality, and reproductive processes. And a change from predominantly coarse sediment to fine sediment may change to overall population assemblage (richness, composition, tolerance/intolerance, functional feeding groups).

3.2 Summary of existing sediment data

Data on sediment and related information collected in the Petaluma River Watershed for the period 1999-2009 was gathered from a variety of sources, compiled, and compared to relevant water quality objectives (Table 2). These data, to the best of our knowledge, make up the available data relevant to determine sediment impairment.

Table 2. Relevant sediment water quality guidelines.

Constituent	Water Quality Objective	Source
Sediment (qualitative for suspended sediments)	"The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses."	SFBRWQCB 2007a
Suspended/settleable material	"Waters shall not contain suspended [or settleable] material in concentrations that cause nuisance or adversely affect beneficial uses."	SFBRWQCB 2007a

Compared to data sets in existence from other Bay Area watersheds, Petaluma is generally lacking sediment and other related data sets (Table 3). In most cases, data simply has not been collected. For the data sets that do exist, we assessed the data and using professional judgment, qualified its quality as either good, adequate or poor. Because the data sets are highly variable in type and purpose, it is difficult to clearly outline the criteria for placement into the three quality categories. However, "good" refers to data sets that are spatially and temporally complete and accurate, and/or are collected using appropriate methods. The term "adequate" refers to data sets that are less temporally and spatially complete and accurate, are estimates, are less detailed, or are only qualitative. The term "poor" refers to data sets that are not temporally and spatially complete and accurate, or are collected using inferior methodologies.

As an example, in the geomorphic channel network assessment category, a single data set has been collected in the San Antonio Creek tributary. This data is very detailed, complete, and accurate, and was collected using appropriate geomorphic methods by a professional scientist. However, due to the narrow scope of geography to one subwatershed, it is classified as adequate. In the discharge record category, the data collected by the USGS is classified as adequate. While the data is very accurate and follows established methodologies, the data is temporally limited and collected in two different locations, ultimately limiting the usefulness of the data set. And as another example, in the turbidity/SSC measurement category, the existing data is classified as poor quality. Although the data was collected as a part of the SWAMP program and follows established methodologies, the extreme low number of samples and lack of corresponding discharge data almost completely negates its usefulness. If samples were taken during high flow events, or over the course of a single high flow event, and the samples corresponded with stage or discharge measurements, the data would become much more useful for impairment assessment.

Table 3. List of data availability and data quality (good, adequate, poor) for the Petaluma River watershed.

Data Set	Exists in Petaluma	Partially exists in Petaluma	Data quality
General documented evidence of erosion (e.g. studies identifying sediment yields from tributary watersheds)	x		Adequate
Geomorphic channel network assessment (e.g. field study of erosion/deposition, etc)		x	Adequate, geographically limited
Measure or estimate of sediment yield from the watershed or tributary watersheds	x		Adequate, only estimated
Precipitation	x		Good
Discharge record		x	Adequate, discontinuous
Turbidity/SSC measurements		x	Poor, very limited measures
Landslide and gully mapping (not including causative mechanisms)		x	Adequate, only large landslides mapped
PSIAC model to determine sediment yield	x		Adequate, results not very meaningful
Current land use	x		Good
Map of on-channel ponds/reservoirs		x	Adequate, needs some development
Sediment basin cleaning records		x	Adequate
Dredging records	x		Good
Fish population (current and historic)		x	Adequate, not quantitative
Habitat quantity and quality		x	Adequate, limited spatially
BMI assessment	x		Good, only one sampling event
Channel rapid assessment		x	Adequate, limited spatially

3.3 Comparison to other TMDLs

After compiling the existing data for the Petaluma River, we then reviewed other Bay Area sediment TMDL documents, including the staff reports for the Napa River TMDL (Napolitano et al., 2007) and Sonoma Creek (Lowe and Napolitano, 2008), and the Existing Conditions report for San Francisquito Creek (Northwest Hydraulics Consultants, 2004). The purpose for our review was four-fold: 1) identify the datasets that were utilized for impairment determination; 2) identify the scientific principles and assumptions that were used to develop the TMDLs; 3) identify the assumptions regarding sediment sources, production, transport, storage, and relation to beneficial uses; and 4) identify any potential data gaps within these studies. The intent of this review is to acknowledge and build upon the previous work, so that in Part 2 of this project (forthcoming) we can recommend appropriate datasets required to inform impairment assessment and eventually TMDL development.

During our review, we compiled a comprehensive list of the datasets[1] that were utilized and organized them by general topic (Table 4). In contrast to the Petaluma River watershed, the Napa, Sonoma and San Francisquito watersheds are all well studied and have a vast array of data available as evidenced by the length of Table 4. We specifically focused upon understanding the scientific principles and assumptions that were used, and the assumptions regarding sediment sources, production, transport, storage, and relation to beneficial uses. From this understanding we are able to assess the decisions as to what types of data were included in the previous assessments. We learned that these TMDLs were not developed based upon a preexisting explicit list of datasets that are necessary for impairment assessment, but rather based on data availability, budget for further data collection, expertise of consultants hired, and priority issue at the time (e.g. salmonid populations). Thus, the data types and quality that are actually used varies from watershed to watershed. This strategy could perhaps lead to overlooking certain datasets that are better suited for determining impairment. In addition, we learned that a single beneficial use typically drives each TMDL, determining what data sets are favored for additional data collection. For example, in the Napa River watershed salmonid populations were the driver, causing many of the data sets and numeric targets to be salmonid-oriented.

The driving beneficial use for the Petaluma River watershed is also salmonids spawning habitat (Mike Napolitano, *pers. comm.*). Datasets typically used to assess impairment to salmonids spawning, based on TMDLs for the Sonoma Creek and Napa River watersheds include streambed permeability (for spawning gravels), fine sediment deposition in pools, substrate composition, baseflow during the dry season, number/impact of fish passage barriers, and summer water temperature. Some, but not all of these are available for the Petaluma River (Table 4).

[1] This list does not include any of the developed numeric targets.

Table 4. Data used in the Napa River and Sonoma Creek Sediment TMDLs.

Number	Data Set	Used in Napa	Used in Sonoma	Used in San Francisquito
	GENERAL			
1	Documented evidence of erosion	x	x	x
2	Documented evidence of fish population declines (e.g. numbers of migrating adults, YOY surveys, redd mapping)	x	X	x
	PHYSICAL			
3	Documented planform channel pattern change	x		x
4	Documented channel incision history	x	x	x
5	Maps of drainage network change (e.g. tributary connectivity, ditches, urban stormdrains)	x	x	x
6	Geomorphic channel network assessment		x	x
7	Channel cross sections/ as built drawings	x		x
8	Longitudinal profiles	x		x
9	Channel bed grain size distributions	x	x	x
10	Calculations/models of stream power	x		x
11	Measures/models of bed scour depth	x		x
12	Measure or estimate of sediment yield from the watershed	x	x	x
13	Estimate of natural sediment production rate	x	x	
14	Precipitation			x
15	Discharge record	x	x	x
16	Suspended sediment record	x	x	x
17	Bedload record			x
18	Turbidity/SSC measurements	x	x	x
19	Analysis of underlying geology and soils	x	x	x
20	Landslide and gully mapping	x		x
21	Watershed sediment budget	x	x	x
22	Identification of sediment sources	x	x	x
23	Measured rates of sediment production from sources	x		
24	Estimate of sediment delivery from sources to channel network	x		
25	USLE model to determine soil erosion rates	x		
26	PSIAC model to determine sediment yield			
27	Grain size distributions of sediment sources	x		x
28	Historical Ecology report (e.g. focus on channel network change and sediment supply since European contact)	x		
29	Current land use	x	x	x
30	Historic land use and analysis of change	x	x	x
31	Road erosion survey	x	x	
32	Reservoir sedimentation rates	x		x
33	Map of on-channel ponds/reservoirs	x		

Number	Data Set	Used in Napa	Used in Sonoma	Used in San Francisquito
34	Estimate of urban stormwater sediment supply	x	x	
35	Sediment basin cleaning records			
36	Dredging records			
	BIOLOGICAL			
37	Fish population (current and historic)	x	x	X
38	Habitat quantity and quality	x		
39	Salmonid limiting factors analysis	x		X
40	Redd mapping	x		
41	Gravel permeability measures	x	x	
42	Pool in-filling measures		x	
43	BMI assessment			
44	Channel rapid assessment			

4. **Nutrients**

4.1. ***Beneficial Use Impairment***

Nutrients which cycle in the biosphere are essential for maintaining life. In the case of plants, nitrogen and phosphorous are key nutrients that support cell processes and structure and are deemed “life limiting”. Although these nutrients occur naturally in the environment (the largest pools being the atmosphere in the case of nitrogen and the lithosphere in the case of phosphorus), anthropogenic modification of the global and local nutrient cycle, either through purposeful application of fertilizer to enhance plant production or incidental discard of refuge, has lead to blooms of aquatic macrophytes and algae, low dissolved oxygen (DO), loss of habitat, changes in aquatic community structure (including fish kills), and loss of recreation and commercial opportunities in receiving waters.

There are two general types of nutrient impacts on aquatic resources: toxic effects and eutrophication (Krottje and Whyte 2003). Toxicity usually results from high concentrations of either un-ionized ammonia (NH_3) or nitrate (NO_3). Since un-ionized ammonia is rarely measured as a separate parameter, its concentration is calculated based on concentrations of total ammonia, a combination of un-ionized and ionized ammonia (NH_4^+) that change predictively in relation to pH and temperature. Due mainly to the influence of temperature of solubility, NH_3 is of particular concern in the summer months. Total ammonia concentrations as low as 2 mg-N/L can have enough NH_3 to be toxic to salmonids (USEPA 1999). Ammonia can also be toxic to other aquatic life and humans. The Basin Plan for San Francisco Bay indicates that the water quality objective for un-ionized ammonia is an annual median of 0.025 mg-N//L (SFBRWQCB 2007a at 3.3.20; Table 5).

In addition to ammonia, toxic effects resulting from nutrients is most often linked to elevated levels of nitrate (NO_3) that can impact both humans and aquatic life. Nitrate is a highly soluble, stable form of inorganic nitrogen and an essential nutrient for plants. High nitrate levels in drinking water reduce the oxygen carrying capacity of blood in infants, causing what is known as “blue baby syndrome” (Carpenter et al. 1998). Consequently, the current nitrate standard is based on drinking water quality for humans, and set at 10 mg-N/L, which is also the Basin Plan objective for the San Francisco Bay (SFBRWQCB 2007a). Much lower levels of nitrate, at 1.1 mg-N/L, have also been shown to be toxic to fish and amphibian eggs, however more research is needed to fully understand the toxic impacts of nitrate (Kincheloe et al., 1979; Crunkilton, 2000).

Eutrophication is the more visible impact of excessive nutrient loading, and results in an explosive growth of algae or other aquatic plants. When nutrient loading is excessive beyond the assimilative capacity of the water body, algal growth becomes too much for grazing invertebrates to control and it can overwhelm an aquatic system in many ways. Some common consequences include shading out submerged aquatic vegetation, reduced concentrations of dissolved oxygen for fish and plant uptake, release of algal toxins that can make shellfish inedible, and reduced diversity of macroinvertebrates (Bricker et al. 2007; Cloern 2001). In the San Francisco Bay region, the three most common types of plants that are capable of rapid nutrient uptake are suspended algae (phytoplankton), most common in estuaries, lakes, or slow-flowing rivers; attached algae and their related algal mats (periphyton); and rooted, floating plants (macrophytes). Phytoplankton tends to be the most common indicator of nutrient impairment in tidally-influenced portions of Bay Area streams (Krottje and Whyte 2003). However, toxic algal blooms are only common in larger river systems in the summer when temperatures are warm and flow turbulence that can tear multi-cellular blue green algae apart is reduced.

Table 5. Relevant water quality objectives for nutrients.

Constituent	Water Quality Objective	Source
Ammonia, unionized	Annual median 0.025mg/L	SFBRWQCB 2007a
Nitrate as N	0.16 mg/L	USEPA, 2000
Total N	Maximum 500 μg/L	USEPA, 2000
Total P	Maximum 30 μg/L	USEPA, 2000
Dissolved Oxygen	Warmwater min. 5.0 mg/L	SFBRWQCB 2007a
Dissolved Oxygen	Coldwater min. 7.0 mg/L	SFBRWQCB 2007a
Temperature	Maximum 22° C in salmonid habitat	Zabinsky, 2005
Biostimulatory substances	"Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses."	SFBRWQCB 2007a

4.2. *Current Data*

There are two known sources of data for nutrients in the watershed: 1) the SWAMP Year 3 report (SFBRWQCB 2007b) and 2) a report produced by the Department of Fish and Game (DFG) in Marin and Sonoma counties related to the influence of agricultural runoff on streams (Rugg 2002). Though this report is supposed to focus on the mainstem Petaluma River, there is very limited data available for nutrients from either report, so data from these sources for sites in tributary streams in addition to the mainstem are considered.

The SWAMP report examined data collected at 15 locations along the mainstem and 6 tributary streams (Figure 3). The collection was a one-time effort aimed at characterizing water quality in a variety of Bay Area watersheds. Water samples were collected on three occasions during 2003 (Wet season-January, Spring-April, and Early summer-June) at seven sites (except one site on San Antonio Creek which was dry in the early summer and so a sample was not collected). The samples were collecting using a grab sampling technique and placed into clean glass jars. They were then analyzed in a lab for the following parameters to characterize nutrients: orthophosphate, total phosphorous, nitrate, nitrite, total ammonia, and total Kjedhal nitrogen (TKN). In addition, continuous monitoring devices were deployed at five sites in the watershed for two week intervals in four seasons of 2003-4 (Spring-April 2003, Summer-July 2003, Fall-September 2003, and Winter-December 2003 through January 2004). Dissolved oxygen concentration and percent saturation, temperature, pH, specific conductivity, and depth were recorded during these eight weeks at 15 minute intervals (SFBRWQCB 2007b).

California DFG staff engaged in a program in conjunction with the Marin-Sonoma Animal Waste Committee, and other operators of livestock businesses, and reported yearly results of monitoring efforts aimed at characterizing the level of pollutants originating from agricultural runoff including un-ionized ammonia, total ammonia, as well as the ancillary parameters dissolved oxygen and conductivity (e.g. Rugg 2002). Water samples were collected between 1991 and 2001 at twenty sites in Sonoma County (the other target receiving water body was Tomales Bay) including sites on San Antonio Creek (11), Petaluma River (5) and Ellis Creek (2). Sampling frequency for the San Antonio Creek sites was approximately twice per month for the months of February through June between 1991 and 2001 for most sites. The Ellis Creek sites were added, at about the same frequency for 1998-2002. The Petaluma River mainstem sites were only monitored on two dates: late June and mid-July, 2000. Samples were collected at road crossings using a bucket and rope, then sub-sampled using a clean, glass jar. Physical water quality parameters were measured in the field, while ammonia and turbidity were analyzed in the DFG lab in Yountville.

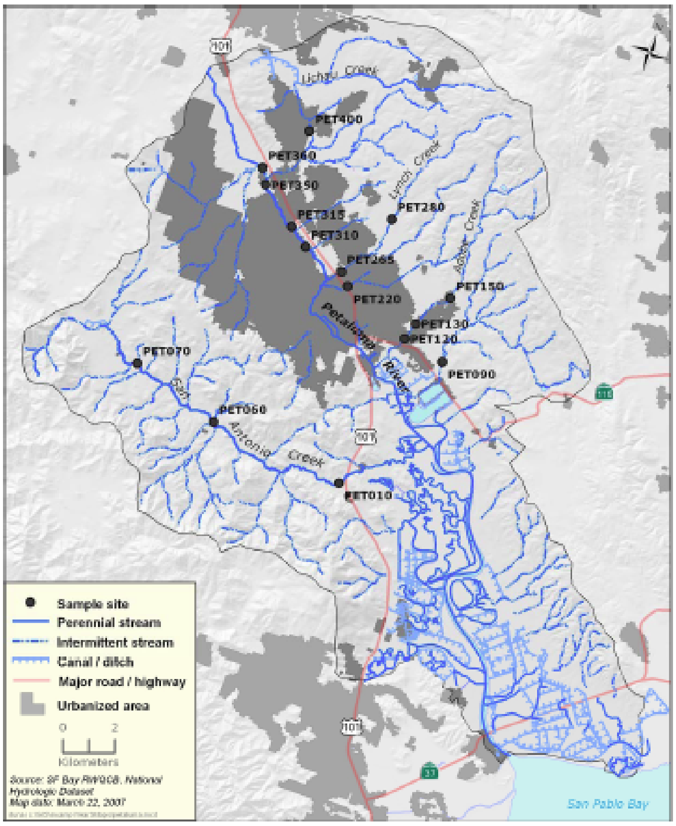

Figure 3. SWAMP monitoring sites for year 3 report in the Petaluma River. Source: SFBRWQCB 2007.

Water quality objectives (Table 5) provide guidance on acceptable concentrations for unionized ammonia in the Basin Plan (SFBRWQCB 2007a), as well as for total phosphorous, total nitrogen, and nitrate as N from the EPA (2000) based on the protection of aquatic life. Results indicate that the EPA guideline for both total phosphorous (30 µg/L) and nitrate (0.16 mg/L) were exceeded in all three seasons

(Tables 6-8) and the concentration at which fish can suffer from nitrate toxicity (1.1 mg/L) was exceeded in both the spring and wet season. The results for total phosphorous are especially significant since concentrations were up to 68 times the EPA guidelines for protection of aquatic life. Nitrate concentrations were also high, up to 15 times the EPA guidelines. EPA also has a guideline for total nitrogen (500 µg/L), which was exceeded at all sites in the wet season, and at most sites for both the dry and spring seasons. Though there is a target concentration for total ammonia for the protection of salmonids based on the literature (2.0 mg/L, USEPA 1999), none of the samples collected on the mainstem exceeded this level, and the highest recorded concentration for the entire watershed was only 0.3 mg/L (on San Antonio Creek).

Considering the spatial location of each site in order to interpret the results for nutrients reveals some important observations. First, even though most sites exceed EPA targets for Total P and N, it doesn't necessarily mean that the site is degraded, or that beneficial uses are impacted (ANZECC 2000; Dodds and Welch 2000). Thus, it is important to compare "pristine" streams to suspected impacted streams to consider what might be "natural" nutrient concentrations. Unfortunately none of the sites monitored are located in "pristine" locations, such as open space in the headwater reaches. The Lichau Creek site, which is highest overall in the watershed and is located in a semi-urban park, and the upper sites in Lynch and Adobe Creeks are actually mid-lower reaches which drain grazing and residential areas. Data from sites in the true headwaters of any tributary would be helpful in assessing the natural level of nutrients.

In general, total nitrogen in the wet season increases in a downstream direction, suggesting an accumulative affect. The lowest concentration was recorded at site PET400 on Lichau Creek (at the top of the watershed) and an accumulative affect occurred in the total nitrogen concentrations for those creeks with two sites (Lynch and Adobe). The highest concentration was from a site on lower Adobe Creek, which is considered to have the most steelhead habitat. However, this site is directly downstream from a large golf course, which could potentially be a source of nitrogen-based fertilizer. The pattern of increasing Total N concentrations was the same for the spring season. In the dry season, however, the site downstream of the golf course on Adobe Creek had a lower concentration than the upstream site; both of which were only slightly higher than the EPA guideline. This suggests that runoff in the wet season plays an important role in delivering nutrients to the channels.

Total phosphorous concentrations did not necessarily follow the increasing downstream pattern. The second highest wet season concentration was at the top of the watershed at PET400 on Lichau Creek, which would be expected to be lower than mainstem sites downstream. The lower site on Lynch Creek (PET265) had a lower concentration than the site above (PET280) in all three seasons sampled. There is a difference in land use between these two sites: the upper site is in grazing land, whereas the lower site is in heavy residential and downstream from a park. In the dry season, the sites on Adobe Creek followed this decreasing downstream pattern as well. The extent and intensity of agriculture has been shown to correlate with nitrogen and phosphorous concentrations in waterbodies (e.g. Bolstad and Swank 1997; Spahr and Wynn 1997).

Nitrate concentrations followed the expected pattern for the dry season, however in the wet season, the unexpected pattern of lower downstream conditions occurred in both Adobe and Lynch Creeks. These unexpected patterns may be in part due to unknown near-field sources to the sampling locations or artifacts of the sampling design. At this time no full interpretation is possible.

Following Emerson, et al. (1975) we were able to estimate un-ionized ammonia by using data for total ammonia (as N), pH, and temperature for a few sites, even though it was not directly measured. For the dry and spring seasons, the only detectable concentrations for total ammonia were at site PET310, though the un-ionized ammonia concentration was well below the water quality objective. Moreover, with only one data point it is not possible to calculate an annual median, which is the basis for the objective. Since pH was not measured in the wet season, it was not possible to estimate un-ionized ammonia concentrations, though total ammonia concentrations were in the same range as the other seasons. Thus it is likely that the un-ionized ammonia concentrations would also be very low.

Table 6. Dry season nutrient concentrations. Sites are arranged in upstream to downstream order. Samples that exceed water quality objectives (in parentheses of column headers) are indicated by bold text.

Station Number	Location	Temp-erature (22°C)	Nitrate as N (0.16 mg/L)	Nitrite as N (mg/L)	Nitrogen, Total Kjeldahl (mg/L)	Total N (0.5 mg/L)	Ortho – Phos-phate as P (mg/L)	Total P (0.03 mg/L)	Un-ionized Ammonia (0.025 mg/L)
PET400	Lichau Ck	19.7	0.114		1.32	**1.44**	0.373	**0.608**	0
PET310	Mainstem	21.4	**0.262**	0.007	1.58	**1.03**	0.845	**2.04**	0.001
PET280	Lynch Ck	20	0.06		0.554	**1.36**	0.429	**0.371**	0
PET265	Lynch Ck	20.6	**0.925**		0.734	0.289	0.25	**0.25**	0
PET150	Adobe Ck	**28.3**	0.046		0.368	**0.805**	0.196	**0.17**	0
PET130	Adobe Ck	**23.8**	0.066		0.43	**0.700**	0.202	**0.164**	0

Table 7. Wet season nutrient concentrations. Sites are arranged in upstream to downstream order. Samples that exceed water quality objectives (in parentheses of column headers) are indicated by bold text.

Station Number	Location	Temp-erature (22°C)	Nitrate as N (0.16 mg/L)	Nitrite as N (mg/L)	Nitrogen, Total Kjeldahl (mg/L)	Total N (0.5 mg/L)	Ortho - Phosphate as P (mg/L)	Total P (0.03 mg/L)
PET400	Lichau Ck	9.4	**0.894**	0.015	1.02	**2.57**	0.502	**0.484**
PET310	Mainstem	9.8	**2.4**	0.038	2.27	**3.76**	1.26	**1.39**
PET280	Lynch Ck	10.3	**1.74**	0.015	0.676	**3.11**	0.381	**0.382**
PET265	Lynch Ck	10.2	**1.58**	0.007	0.563	**3.26**	0.379	**0.35**
PET150	Adobe Ck	8.3	**1.51**	0.006	0.53	**2.88**	0.19	**0.187**
PET130	Adobe Ck	8.6	**1.3**	0.007	0.43	**3.14**	0.198	**0.256**
PET010	San Antonio Ck	9.7	**1.71**	0.054	1.32	**2.31**	0.51	**0.612**

Table 8. Spring season nutrient concentrations. Sites are arranged in upstream to downstream order. Samples that exceed water quality objectives (in parentheses of column headers) are indicated by bold text.

Station Number	Location	Temp-erature (22°C)	Nitrate as N (0.16 mg/L)	Nitrite as N (mg/L)	Nitrogen, Total Kjeldahl (mg/L)	Total N (0.5 mg/L)	Ortho – Phos-phate as P (mg/L)	Total P (0.03 mg/L)	Un-ionized Ammonia (0.025 mg/L)
PET400	Lichau Ck	15.3	**1.13**	0.007	0.63	0.433	0.296	**0.988**	0
PET310	Mainstem	15.6	**0.01**	0.023	1.48	**0.633**	0.904	**0.35**	0.003
PET280	Lynch Ck	11.6	**1.27**		0.594	**1.60**	0.338	**0.205**	0
PET265	Lynch Ck	8.8	0.063	0.012	0.315	**0.834**	0.226	**0.132**	0
PET150	Adobe Ck	10.6	0.066		0.279	**1.91**	0.142	**0.167**	0
PET130	Adobe Ck	12.2	**0.565**		0.229	**0.838**	0.184	**0.437**	0

Using CDFG data from 1991-2001, we were able to estimate an annual median un-ionized ammonia concentration. Since sites sampled varied by year, we lumped all sites to calculate an annual median for the watershed, instead of several medians for each site for each year. The Basin Plan guideline for un-ionized ammonia (0.025 mg-N/L) was not exceeded in any of the years for which data is available (1991-2001, Table 9, Rugg 2002). Rugg reported that over the last ten years, "mean un-ionized ammonia [concentrations in San Antonio Creek] increased slightly, but the high concentration indicated by the range is clearly acutely toxic, and thus unacceptable." (2002, p. 3, Table 10). The maximum recorded value in Ellis Creek sites (0.108 mg/L) for 2000-2001 increased from the maximum recorded the previous year, and exceeded the Basin Plan Objective (Table 11). However, Rugg interpreted un-ionized ammonia on a per day, or annual mean basis, which does not follow the Basin Plan water quality objective.

Table 9. Annual median un-ionized ammonia, 1991-2001. Median was calculated for all sites in the watershed sampled in a given year. Note that sites varied by year. The water quality objective (0.025 mg/L) was not exceeded in any year.

Annual median, un-ionized ammonia (0.025 mg/L)	Year
0.01	1991
0.018	1992
0.013	1993
0.007	1994
0.004	1995
0.007	1996
0.002	1997
0.012	1998
0.005	1999
0.0001	2000
0.00285	2001
0.00325	2002

Table 10. Summary of data for water years 1999-2000 and 2000-2001 collected by CDFG in the San Antonio Creek Watershed (Rugg 2002). Note that un-ionized ammonia is reported as a mean, not median, as it is measured for the Basin Plan water quality objective.

San Antonio Creek
2000-1 (99-00) Data

	Dissolved Oxygen mg/l	Total Ammonia mg/l	Un-ionized Ammonia mg/l	Conductivity • mhos/cm
Mean *	10.12 (9.28)	0.3665 (0.4212)	0.0063 (0.00494)	527 (568)
Range	2.9-16.0 (1.78 - 22.39)	0.0-2.82 (0.0 - 7.15)	0.0-0.059 (0 - 0.086)	180-1563 (66 - 2092)
Criteria **	> 5.0	-	0.025	(750)
Exceedance	2 (10)	-	5 (14)	13 (43)
Percent Exceedance	2.9(4.88)	-	7.3 (6.83)	19.1 (20.98)

*68 (108) measurements
** SF Bay RWQCB Basin Plan

Table 11. Summary of data for water years 1999-2000 and 2000-2001 collected by CDFG in the Ellis Creek Watershed (Rugg 2002). Note that un-ionized ammonia is reported as a mean, not median, as it is measured for the Basin Plan water quality objective.

Ellis Creek Watershed (>Petaluma River)

2000-1(99-00) Data

	Dissolved Oxygen mg/l	Total Ammonia mg/l	Un-ionized Ammonia mg/l	Conductivity • mhos/cm
Average *	11.19 (9.38)	0.959 (0.1693)	0.01842 (0.003921)	703 (998)
Range	8.9-14.8 (2.98 - 15.8)	0.0098-4.4(0.0 - 0.94)	0.0006-0.108 (0.0 - 0.0262)	472-920 (489 - 1980)
Criteria **	5.0-7.0	-	0.025	(750)
Exceedance	0 (3)	-	1 (1)	4 (24)
Percent Exceedance	0 (10.34)	-	10 (3.5)	40 (79.3)

* 10(29) measurements
** SF Bay RWQCB Basin Plan

Dissolved oxygen (DO) is a useful parameter to accompany nutrient data for interpreting threats to aquatic life, since it can detect when oxygen demanding material, such as animal waste (a nutrient source), is contaminating streams and depriving aquatic life of the necessary amounts of oxygen. The algal blooms that often accompany high nutrient levels are also oxygen demanding material; thus low DO can be correlated to elevated nutrients. In turn, low DO can accelerate existing algal growth, and deplete already low DO levels essential for aquatic life.

Continuous monitoring results (Figure 4) indicate that the coldwater minimum DO concentration specified in the Basin Plan for coldwater fish habitat (7.0 mg/L) was not met for some sites in the spring, and not met for any sites in the summer or fall (though the mainstem site PET310 did not meet quality assurance (QA) requirements). The winter minimum DO was acceptable overall. Summer and fall DO concentrations were particularly low throughout the watershed, as all sites but one in upper Willow Brook Creek remained around 0 mg/L.

One site on San Antonio Creek that was monitored as a part of the DFG study (Rugg 2002) was also continuously monitored for SWAMP (site PET010 in Figure 3 above), and not surprisingly, showed extremely low DO concentrations for three seasons (data collected in the fall was rejected for QA issues), including a negative DO concentration for both the summer and fall periods. These concentrations appear to be lower than the minimum DO concentration noted by Rugg, suggesting that conditions have declined.

The results from Ellis Creek were much better than for San Antonio Creek. Mean DO (9.38 mg/L), and the range (8.9-14.8 mg/L) indicates that the minimum necessary for cold water habitat was reached for all of the 2000-2001 sampling season. This was a great improvement over the 1999-2000 data, which had a much wider range (2.98 - 15.8 mg/L) and some instances of DO concentrations below the minimum target (Table 10).

Data was also available for five sites on the mainstem Petaluma River, though the exact locations are not certain due to a change in DFG personnel and misplacement of files attached to this study. All five locations were sampled twice within a 2 week period in late June-July 2000. Every sample came below the 7.0 mg/L target for coldwater habitat, and four of the ten samples fell below the 5.0 mg/L concentration necessary for warmwater habitat. The approximate locations of only sites P-4 and P-5 are known, and both are in the middle of the urban center of the city of Petaluma (Stevens pers. comm.).

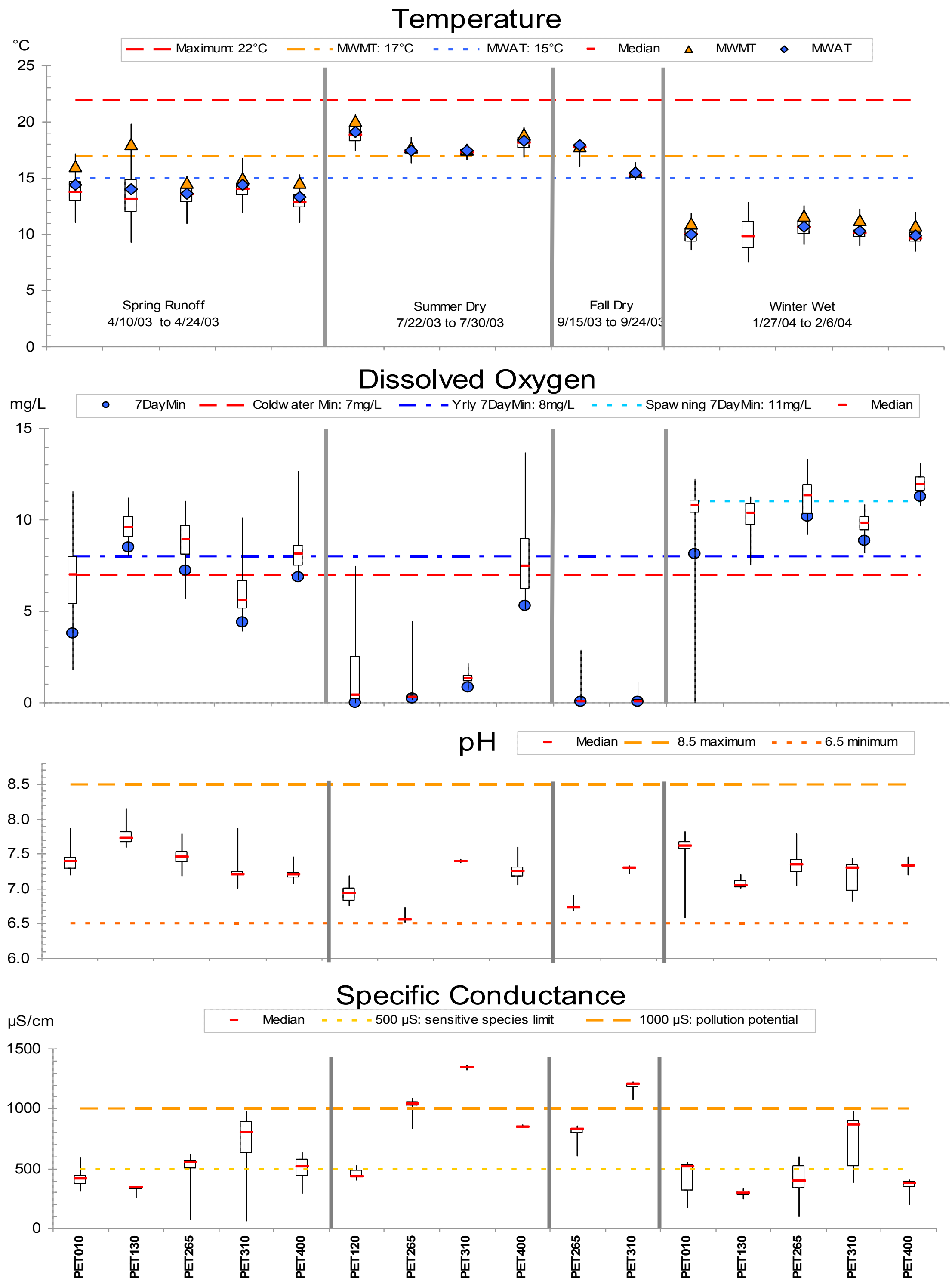

Figure 4. Continuous monitoring results for the Petaluma River watershed. MWMT=Maximum Weekly Maximum Temperature, MWAT=Maximum Weekly Average Temperature Source: SFBRWQCB 2007b, p. 3-20

4.2.1. **Visual Reconnaissance**

Aquatic Science Center staff conducted a visual reconnaissance of the watershed on March 11, 2009 to document any potential impairment. No obvious signs of impairment by nutrients were visible in any of the major tributary streams (Lichau, Lynch, Willow Brook, and Adobe Creeks) although our reconnaissance was limited to publically accessible locations and a one day timeframe. A small urban tributary, Corona Creek, exhibited some algal blooms and filamentous algal growth (Figures 5a, b). This Creek drains a dense residential area and several playing fields that might be sources of nitrogen-based fertilizers. Some algal growth was also seen along the banks of the tidal portion of the mainstem (below the Ellis Creek confluence), and along the substrate of the freshwater portion (between Corona Road and the Lynch Creek confluence; Figure 5c,d). As this reconnaissance was conducted at the mid-late end of the rainy season when temperatures are still cool, it is not representative of the highest potential for algal growth and obvious signs of impairment by nutrients. Late summer and fall, when temperatures are high and freshwater inputs are at a minimum, are the seasons when we would expect algal growth to be at its peak. According to the state protocol for stream algae sampling, the index period for both algal and benthic macroinvertebrate sampling is May-September, due to the lack of storm-related flows that could remove algae and biofilms from streambeds and other surfaces (Fetscher, et. al 2009). Based on this protocol, we recommend additional reconnaissance and implementation of the protocol in the index period throughout the watershed in order to better determine impairment and compare results to other watersheds sampled.

a)

b)

c) d)

Figure 5. a) Algae along substrate of Corona Creek at Wellington Place b) Algae on surface of Corona Creek at Wellington Place c) Algae on surface and d) on substrate of Petaluma River at Outlets.

4.3. *Comparison to other TMDLs*

4.3.1. Bay Area Nutrient TMDLs

There are currently no EPA-approved nutrient TMDLs in the San Francisco Bay region, though projects for Sonoma Creek and the Napa River are in progress. A *Conceptual Approach for Developing Nutrient TMDLs for San Francisco Bay Area Waterbodies* (Krottje and Whyte 2003) was developed in 2003. A summary of the necessary steps towards assessing impairment and establishing water quality targets for nutrients was outlined in this report, and is summarized and compared to the available information from the Petaluma River in Table 9. Assuming this approach is valid for the Bay Area, it is difficult to determine impairment for the Petaluma River. Some pieces of the approach are complete, but key components such as algal biomass, and the more detailed monitoring approach at reference and potentially impacted reaches is still missing.

Table 12. Comparison between *Bay Area Approach to Nutrient TMDLs* and available data for the Petaluma River.

Element	Bay Area Approach	Petaluma River
Initial steps for impairment assessment	Reviewing existing data	Complete; includes SWAMP year 3 report and Rugg 2002
	conducting screening level monitoring studies	6 sites monitored in 3 seasons, 1 additional site was only monitored in 2 seasons
	interviewing stakeholders, and conducting visual reconnaissance	No interviews available; 1 day visual reconnaissance conducted by ASC staff (3/11/09)
More detailed monitoring	"focusing on identified problem reaches, but also including less-impacted reaches in order to provide a basis of comparison and possibly establish reference conditions"	Not available, McKee and Krottje 2005 is an example of how this could be done.

Criteria used for assessing impairment	Water column nutrient concentrations	Nitrate, nitrite, TKN, unionized ammonia, total ammonia, orthophosphate, total phosphorous and total nitrogen data available for 6-7 sites depending on season (SFBRWQCB 2007B)
	Water column dissolved oxygen concentrations	Continuous DO data available at 4-5 stations depending on season; grab samples also available for 2-10 years depending on site (Rugg 2002)
	Algal densities (measured periphyton growth by the amount of algal biomass (either as ash-free dry weight or chlorophyll-a) per unit of stream bottom area, and in a semi-quantitative manner using USEPA's rapid field assessment method)	Chlorophyll a data (concentrations, in ug/L) available for 6-7 sites depending on season; but tentative targets are based on unit per stream bottom area Invertebrate data also available to assess abundance of sensitive species

4.3.2. Other region TMDLs

In the Central Coast region, there are two completed nutrient TMDLs in watersheds with comparable land uses to the Petaluma River; Los Osos Creek (including Warden Creek, and Warden Lake Wetland; CCRWQCB 2004), and Chorro Creek (which is a TMDL for both nutrients and dissolved oxygen; CCRWQCB 2006). Both of these watersheds are in San Luis Obispo County and are smaller agricultural (mostly non-irrigated grazing land) watersheds that drain to the major estuary of the region, Morro Bay. Both of these watersheds also have similar beneficial uses including coldwater fish habitat. One major difference is that they provide drinking water so the nitrate standard for drinking water (10 mg/L) was the major guideline used to assess impairment. The Petaluma River is not a drinking water source, so the nitrate objective to use would likely be a lower priority, and based on what is considered protective of aquatic life (0.16 mg/L NO_3 as N; SFBRWQCB 2007a). A summary of the data collected, criteria, and impairment determination used in the two Central Coast nutrient TMDLs, along with a comparison to what is available for the Petaluma River is summarized in Table 10.

Table 13. Summary of elements used in Chorro and Los Osos Creeks Nutrient TMDLs.

Element	Chorro Creek	Los Osos Creek	Petaluma River
# of samples for nitrate as N (% exceedance[2])	681 (4% in summer)	627 (19%)	20 (65%)
# samples for dissolved oxygen concentration (%	160 (29%)	742 (52% below either warm or coldwater	12[3] (42%)

[2] Due to different beneficial uses of the three watersheds, this row refers to different water quality objectives for nitrate. For Chorro and Los Osos Creeks, exceedances refer to the drinking water quality standar, 10 mg/L. For Petaluma River, the standard that is protective of aquatic life (0.16 mg/L) is more appropriate, and is used for reference here.

exceedance of 7 mg/L)		objective)	
# samples for algal biomass (% exceedance)	21 (57%)	0	0
Criteria used for assessing impairment	Nitrate as N target for municipal drinking water supply (10 mg/L)	Nitrate as N target for municipal drinking water supply (10 mg/L)	
	Dissolved oxygen target for coldwater habitat (7 mg/L)	Dissolved oxygen target for coldwater habitat (7 mg/L) and warmwater habitat (5 mg/L)	
	Biostimulatory substances objective (aerial cover of algae exceeding 40%)		
	Algal biomass greater than 150 mg/m2 presents nuisance conditions in streams (EPA		
Impairment (basis for impairment)	Impaired for "biostimulatory substances" and dissolved oxygen, but not by nitrates (definition of impairment as 10% exceedance of water quality objectives (SWRCB Res. No. 2004-0063))	impaired by nitrates only (exceedance of nitrate WQO at some stations)	

According to California's 303(d) listing policy (SWRCB 2004), a waterbody with sample size less than 30 with at least 5 exceedances of water quality standards is considered impaired (p. 10). Compared to the Los Osos and Chorro Creeks TMDLs, the Petaluma River has less data for nutrients in terms of number of samples. The percentage of samples in which numeric water quality objectives were exceeded is very high; however these results may be biased by sampling design.

5. Pathogens

5.1. *Beneficial Use Impairment*

Pathogens refer to a wide variety of bacteria, protozoa, fungi, and viruses that cause disease and can be harmful to humans and wildlife. Due to the wide range of pathogens found in waters, sampling to determine impairment usually consists of detection of certain indicator bacteria. Water quality standards are written for the protection of human life, which also dictates the type of indicator bacteria tested (Table 11) . Fecal coliform, total coliform, and *Escherichia coli* (*E. coli*) are the most commonly used indicator bacteria. Total coliform measures a group of about 19 genera of bacteria from both fecal and non-fecal origin. Some of these bacteria originate from plants, so fecal coliform, a more specific group of bacteria that mostly originates in warm-blooded animals fecal matter is a more definitive indicator of pathogen contamination that would harm humans. *E. coli* is a species of fecal coliform that constitutes between 80 and 90% of the fecal coliforms in human and animal feces-contaminated water samples (Noble et al 2000). Several indicator bacteria are used because no single definitive indicator of

[3] Dissolved oxygen concentrations were monitored continuously . To summarize the results, 12 samples represent the number of stations where median DO is available (and not rejected during quality assurance review).

fecal contamination and risk to human health exists without source and genetic information. For example, the presence of *E. coli* in water samples does not necessarily indicate a risk to human health because though all *E.coli* strains have fecal origins, they might not be pathogenic. In addition, some strains can remain dormant in sediment and re-emerge in water sample testing after the actual contamination occurred. Many factors can affect the survival and growth of indicator bacteria including nutrients, light, and temperature, absorption to sediment particles, and predation by protozoa. Despite these limitation and complexities, they are the best indicator that we have at this time. The best water quality control mechanisms will address slowing or stopping the growth of coliform bacteria as a means to reduce contamination.

The River supports beneficial uses for both contact (e.g. swimming, wading) and non-contact (e.g. boating, bird-watching, hiking) water recreation (SFBRWQCB 2007a), both of which can be impacted by elevated pathogen concentrations in the water. Symptoms of human exposure to *E. coli* usually involve skin rashes and gastrointestinal problems.

Table 14. Relevant water quality guidelines for pathogens in freshwater creeks where contact recreation is a beneficial use.

Constituent	Water Quality Objective	Source
Fecal coliform	• Geometric mean <200 MPN/100mL • No more than 10% of all samples ≥400 MPN/100 mL	SFBRWQCB 2007a
Total Coliform	• Median 250 MPN/100mL • Maximum 10,000 MPN/100mL	SFBRWQCB 2007a
E. Coli	Maximum < 126 MPN/100 mL	USEPA 1986

5.2. *Current Data*

Water samples were collected weekly for five weeks at four sites in the watershed, including two on the mainstem, during July and August 2006 and analyzed for *E. coli* and fecal coliform according to EPA protocols as a part of the SWAMP program (SFBRWQCB 2007b). Both of the mainstem sites (PET310 and PET 315) as well as a site on Lichau Creek (PET400) exceeded both target values for fecal coliform: the geometric means were greater than 200 MPN/100mL and over 10% of each sites' samples were higher than 400 MPN/100mL (Table 12; SFBRWQCB 2007a). The mainstem sites had particularly high fecal coliform concentrations; with 80-100% of samples exceeding Basin Plan Objectives for The Lynch Creek site (PET265) had the lowest overall concentrations (Table 12).

The results were very similar for *E. Coli* counts; the mainstem sites exhibited the highest concentrations, followed by significantly lower concentrations at the Lichau, and Lynch Creeks sites (Table 12). Site PET310 had two samples with concentrations four or more times the guideline for infrequently used areas. There is no Basin Plan objective for *E. Coli*, however it does include the EPA-recommended ambient water quality objectives based on the frequency of use of a stream as a supplement to the fecal coliform objectives (Table 11; SWRCB 2007a.).

Table 15. Results of pathogen sampling at four sites. The numbers in bold exceed Basin Plan or EPA water quality objectives (in parentheses in column headers).

Station	Location in Watershed	E. Coli	Fecal coliforms	
		Maximum (126 MPN /100mL)	Geometric Mean (200 MPN/100mL)	% ≥ 400 MPN/100 mL (10%)
PET265	Lynch Creek	**161**	115	0%
PET310	Mainstem	**498**	**705**	**80%**
PET315	Mainstem	**431**	**928**	**100%**
PET400	Lichau Creek	**215**	**346**	**40%**

The spatial locations of the four sampled sites were considered in order to determine whether location offers any explanation for the data for both indicator bacteria (Figures 6, 7). Higher concentrations of fecal coliform and *E. coli* were observed at sites PET310 and PET315, which are all downstream from agricultural (grazing) and rural residential lands. Site PET400 drains similar land uses, but the concentrations were not as high as for the two mainstem sites. Lower concentrations were observed at the Lynch Creek site (PET265), which is located just downstream from a large public park. These results suggest that, within the Petaluma River watershed, grazing of agricultural lands is a larger source of fecal coliform and *E. coli* than public parks, where domestic pets are thought to be the major source. This finding is further supported by comparison of the Lichau Creek and Lynch Creek sites. Like the Lynch Creek site, the site on Lichau Creek (PET400) is located at an urban park, though the density of residential units is much lower. The higher indicator bacteria concentrations at the Lichau Creek site, when compared to Lynch, may be explained by the upstream land use (grazing) in this watershed. It is also possible that the Lynch Creek site has lower concentrations due to dilution.

Lastly, in addition to potential upstream sources, it is important to consider direct proximity to potential sources. While the two mainstem sites drain mostly grazing lands, their proximity to urban land uses (highways, large streets, parking lots) could explain the elevated observed bacteria levels. These sites receive proportionately higher loads of urban stormwater runoff than the other sites. Indicator bacteria have not been quantified in this urban stormwater, though urban stormwater has been shown to carry pathogens at other locations (Hager et al. 2004, Petersen et al 2005, Gannon and Busse 1989). Additionally, Site PET310 at Corona Road is located across the street from a livestock auction yard, which certainly presents a potential source of *E. coli* and fecal coliform (Jamieson et al 2003, Doran and Linn 1979). This, in addition to resuspension/reactivation of dormant *E.Coli*, growth due to low flow (and high temperature) conditions, or sampling bias, could account for PET310 *E. Coli* concentrations being higher than the site upstream, PET315.

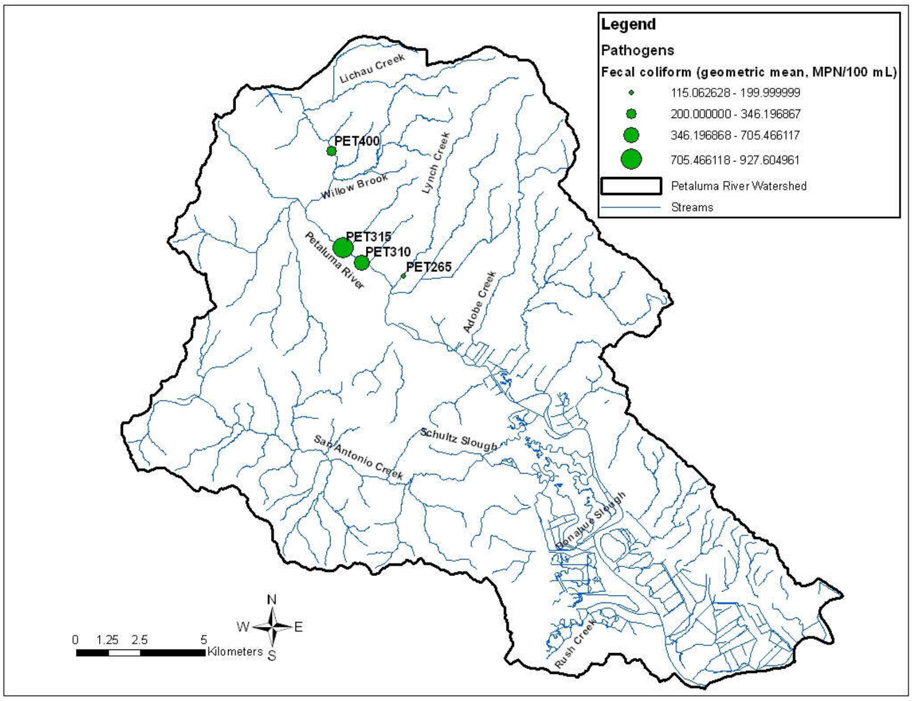

Figure 6. Fecal coliform concentrations (geometric means) at four sites in the Petaluma River watershed. The Basin Plan objective is < 200 MPN/100mL.

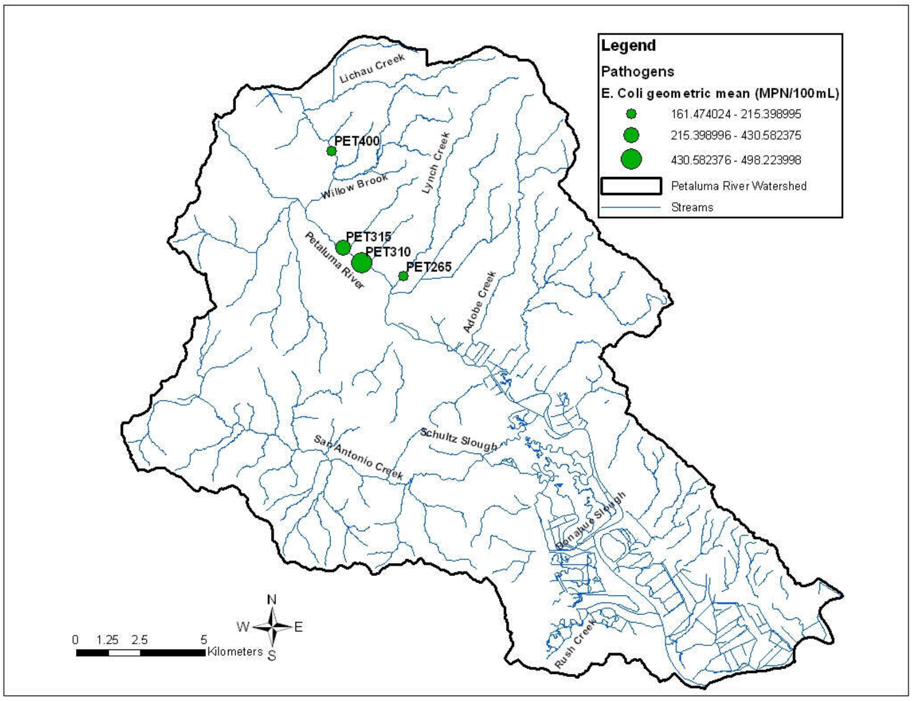

Figure 7. E. Coli concentrations (geometric means reported in MPN/100mL) at four sites in the Petaluma River watershed. All sites exceed the EPA objective of 126 MPN/100mL.

5.3. *Comparison to other Pathogen TMDLs*

The EPA has approved Pathogen TMDLs in the Bay Area for the two watersheds to the east of Petaluma: Sonoma Creek and the Napa River. An extensive sampling effort was employed to determine the spatial extent and degree of impairment using both *E. coli* and fecal coliform indicator bacteria. The elements used to assess impairment and develop TMDLs for these two watersheds, and a comparison to the Petaluma River's available data is summarized in Table 13. This comparison highlights that the Petaluma River suffers from a lack of multiple sampling events and locations over multiple seasons. A more in-depth study comparing reference and impacted sites is warranted to mirror the efforts used in other regional TMDLs and to determine impairment.

Table 16. Information used to develop Pathogen TMDLs for Sonoma Creek and the Napa River, compared to the Petaluma River.

Element	Sonoma Creek	Napa River	Petaluma River
# tributary sites sampled for *E. Coli* (# sampling events[4])	7 (3)	16 (3)	2 (1)
# mainstem sites sampled for *E. Coli* (# sampling events)	9 (3-5)	7 (3)	2 (1)
# tributary sites sampled for *fecal coliform* (# sampling events)	0	0	2 (1)
# mainstem sites sampled for *fecal coliform* (# sampling events)	0	7 (4)	2 (1)
Exceedances of E.coli 90th percentile or geometric mean	4/16 sites exceeded E.coli guidelines in wet season, 6/32 in dry season	5/23 sites exceeded e coli target in wet season; 3/23 in July and 3/23 in Oct	4/4 sites exceeded geo mean for e coli
Exceedances of fecal coliform geometric mean or 90th percentile	N/A	12 sites (of 14 over 2 years) exceeded guidelines in wet season; 5 exceeded guidelines in dry season	¾ sites exceeded both geo mean and 90th percentile for fecal coliform

[4] Sampling events consists of five or more sequential samples within 30 days, according to EPA protocol. Multiple sampling events often take place in the wet and dry seasons in order to characterize seasonal variation in loads.

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