Appendix E – Lake Hodges Study Plan

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Final Hodges Reservoir Nutrient Source Study Plan

Submitted to:

The City of SAN DIEGO

COUNTY OF SAN DIEGO

ESCONDIDO
City of Choice

CITY OF POWAY
Incorporated 1980

November 2017

Prepared by:

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With:

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Executive Summary

Nutrient impairment in the Hodges Reservoir (also known as Lake Hodges colloquially and in some regulatory documentation, and referred to as the Reservoir in this plan) is, "significantly impacting the use of reservoir waters for municipal water supply, restricting water supply blending opportunities, and increasing treatment costs for downstream water supply agencies" (San Diego Regional Water Quality Control Board [Regional Board], 2016). Algal blooms, which are most often related to excess phosphorus in fresh surface water, can impair the functionality of a drinking water reservoir by causing taste and odor issues, filter clogging, and disinfection byproduct precursors.

The 2012 Clean Water Act Section 303(d) list of water quality limited segments (303(d) list) identifies nitrogen, phosphorus, color, pH, manganese, mercury, and turbidity impairments within the Reservoir. The 2012 303(d) list states the single largest contributing source of nitrogen was determined to be commercial crop fertilizer use (56 percent [%] of the San Pasqual Basin total), followed by in-basin manure applications (21%), and landscape fertilizer use (14%), and more nutrients are currently entering the Reservoir than are being removed.

This evaluation includes development of a conceptual model of nutrient sources to and within the Reservoir. The conceptual model highlights data gaps in existing and ongoing monitoring efforts within the Reservoir and the various input pathways throughout the San Dieguito River Above Lake Hodges Subwatershed[1] (Subwatershed). The City of San Diego Public Utilities Department (Public Utilities) has current and future projects focusing on within-Reservoir modeling and monitoring; therefore, this Study Plan primarily focuses on the monitoring recommendations to develop a model for the Subwatershed, which would link with the independently developed Reservoir model. The objectives of this Study Plan are as follows:

- Summarize the previous and ongoing studies and management efforts to characterize nutrients in the Reservoir and its contributing drainage area;
- Develop a conceptual model that fully characterizes nutrient sources and pathways to and within the Reservoir;
- Use the conceptual model and previous and ongoing monitoring efforts to identify data gaps in the characterization of nutrient sources; and
- Provide recommendations for future monitoring and activities to fill these data gaps and data needed to refine existing and future Subwatershed models.

The compilation of previous and ongoing studies and monitoring efforts in the Reservoir and Subwatershed, which are discussed in Section 2, was used to develop a conceptual model that describes the nutrient sources and pathways (Section 3, with more detail in Appendix A). Investigations of the land use and hydrology of the Reservoir and

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[1] The Hodges Reservoir catchment is denoted as "San Dieguito River Above Lake Hodges" in the San Dieguito River Water Quality Improvement Plan.

Subwatershed revealed that the connectedness of the upstream watershed to the Reservoir was important. The upstream watershed area is much larger than the direct tributary watershed area and includes a variety of land uses that have the ability to contribute nutrient loads, which may be significant compared with direct tributary contributions. However, during the extended “low Reservoir condition,” when the upstream watershed is disconnected (at least surficially) from the Reservoir, these upstream loads would likely be greatly reduced. As a result, a two-condition conceptual model is being proposed for the Subwatershed with regard to nutrient loading: a high-flow/high Reservoir water level condition (high Reservoir condition) when the upstream tributaries are directly connected to the Reservoir, and a low-flow/low Reservoir water level condition (low Reservoir condition) when a wetland system is in place between the upstream tributaries and the Reservoir. There is a transition period between these two conditions that would not necessarily be significant or lasting, but may affect the dynamics of the system.

Santa Ysabel Creek and Kit Carson Creek are the main tributaries that flow either into the wetland during low Reservoir conditions or directly into the Reservoir during high Reservoir conditions. When the wetland is exposed, it can affect the fate and transport of nutrients within flows from these tributaries. The wetland can receive loads from the upstream watershed intermittently (small storms) and during the high Reservoir condition. These nutrients continue to be processed and might move through the wetland ecosystem during the low Reservoir condition (e.g., during the decline in flows from high to low Reservoir conditions when shallow flows are still intact). Although most studies find stable wetlands to be a sink for nutrients (Kadlec and Wallace, 2008), there is potential for the wetland to export nutrients to the Reservoir.

Although data have been collected in the Subwatershed and within the Reservoir to meet goals of various programs, data required to develop an accurate and robust site-specific nutrient budget model are limited. The primary data gap identified for monitoring purposes was the lack of synchronization of tributary, municipal separate storm sewer system (MS4), and Reservoir monitoring events. Because historical sampling has not occurred during the same monitoring events (wet weather) or timeframe (dry weather), it is difficult to ascertain or apportion the Subwatershed load to different land uses or the MS4. Therefore, additional wet and dry weather sampling of water quality and associated flow volumes in the MS4 that coincides with the sampling occurring in the tributary and Reservoir is recommended. Other critical data gaps and recommended activities to fill them are discussed in Section 4:

- **Tributaries.** Continuous flow monitoring, monthly dry weather water quality sampling, and targeting of both small and large storm events for wet weather water quality sampling are recommended for the tributaries to the Reservoir for approximately three years (final duration and frequency for monitoring will be determined upon program implementation). Most of the wet and dry weather monitoring conducted in the upstream areas will likely be (and has been) during the low Reservoir condition. The high Reservoir condition is observed less often in these areas; therefore, monitoring will be opportunistic to the extent possible, and less reliant on a schedule of number of storms per year, as is typical with many storm monitoring programs. It is recommended that the sampling frequency be increased during this time so that high-water nutrient loading can be adequately characterized. Spatially, most of the existing tributary sampling locations are concentrated in the western part of the Subwatershed, with most located at the confluence of direct tributaries with the Reservoir. Therefore, additional monitoring locations are recommended for the eastern and central portions of the Subwatershed to ascertain nutrient loading from different sources and land uses, which primarily encompass the upstream tributaries to the Reservoir. The direct tributaries, which contribute flows not affected by the wetland, will most likely have similar hydrologic responses and nutrient loadings during both low and high Reservoir conditions. Although monitoring the direct tributaries is not dependent on the Reservoir condition as with other tributaries, monitoring will occur only when the desired conditions exist for the whole program to maintain concurrent sampling throughout the project area.

- ❖ **MS4.** It is recommended to continuously monitor dry and wet weather flows and increase dry weather water quality sampling frequency for the MS4 to monthly for approximately three years (final duration and frequency for monitoring will be determined upon program implementation). Additionally, both small and large storm events should be targeted for wet weather water quality sampling. Additional MS4 wet and dry weather sampling locations are recommended to characterize nutrient loading from different land uses and geologic conditions. Coordinated sampling in the MS4 areas associated with the upstream tributaries to the Reservoir may need to be conducted opportunistically to adequately characterize the MS4-tributary system during the high Reservoir condition (see tributary bullet, above).
- ❖ **Wetland.** To understand the connection of the upstream portion of the Subwatershed to the Reservoir, it is important to study the kinetics of the wetland ecosystem. Knowledge of the water and nutrient budgets during both Reservoir conditions would allow modeling and management decisions to be made and would require an understanding of the nutrient and sediment loading to the wetland and the extent of nutrient transformations and groundwater interactions within this system. Surface water monitoring locations are recommended at the far upstream and downstream extents, where site conditions allow. These surface water stations will help to estimate the nutrient budget of this system. This surface water sampling within the wetland will be opportunistic because, historically, this area is typically not inundated or receives very little flow.
- ❖ **Reservoir.** Public Utilities has considered best management practices (BMPs) to improve water quality in the Reservoir and to reduce nutrient loading (e.g., treatment wetlands, Reservoir hypolimnetic oxygen system, and mid-lake vigorous epilimnetic mixing). These BMPs will all have effectiveness monitoring plans in place for the time period after implementation. Furthermore, a three-dimensional modeling effort for the Reservoir is currently underway by Public Utilities to

determine the nutrient cycling and internal loading of the Reservoir. This modeling effort would coincide with ongoing (San Dieguito Hydrologic Storm Water Management Model [SWMM] Investigation) and future Subwatershed modeling efforts to provide a comprehensive and cohesive picture of the nutrient loads from the Subwatershed to the tributaries that enter and cycle within the Reservoir. To support the independent Reservoir modeling efforts led by Public Utilities (i.e., independent of potential future Subwatershed modeling driven by this Study Plan), spatial mapping of sediment quality and seasonal oxygen content of the water column and short-lived radioisotope sampling after wet weather events are recommended in the Reservoir for estimating the potential nutrient fluxes of in-Reservoir sediments. These modeling efforts could also benefit from incorporation of eutrophication indicators linked to beneficial uses, such as municipal and domestic supply (MUN) (cyanotoxins, trihalomethanes) and noncontact water recreation (REC-2) (turbidity), and aquatic life-related beneficial uses (chlorophyll-a, cyanobacterial abundance, dissolved oxygen, and pH). A data gap analysis quantifying the status of data sets composed of the indicators described previously and biostimulatory conditions (temperature, subsurface photo-actively available radiation, seasonal stratification, etc.) is recommended prior to conducting any Reservoir modeling efforts.

- **Other data gaps:**
  - **Atmospheric inputs**. While potentially minor, atmospheric inputs have not been measured or studied specifically for the Subwatershed. However, several regional dry and wet aerial deposition estimates for nitrogen and phosphorus for the southern California region have been determined through multiple studies and can be used in lieu of direct measurements.
  - **Olivenhain Reservoir.** The water that Olivenhain Reservoir receives from the aqueduct system is exchanged bidirectionally between the Olivenhain and Hodges Reservoirs. The planned three-dimensional modeling effort of Hodges Reservoir, along with endpoint average concentrations and flow volumes, could be used to estimate net transport of nutrients.
  - **Groundwater loads.** It may be possible to use regional groundwater chemistry and water budgets from previous studies to estimate nutrient loads to the Reservoir. If this quantification is not possible, groundwater fluxes into the Reservoir could be estimated seasonally using flux chambers and Radon-222 isotopes. The groundwater contribution is not expected to be large, per previous studies (City of San Diego, 2014a).
  - **Rainfall data**. Rainfall gauges that can adequately represent the entire Subwatershed spatially will be critical for developing model estimates of nutrient loading to the Reservoir and using models as a forecasting or decision-making tool. All publicly available rainfall sources will be used for future modeling efforts.

- **Land use and septic system installations.** The current land use information provided through public venues is relatively coarse, with agriculture being used as a blanket land use value in most of the upper portion of the Subwatershed. Desktop geographic information system (GIS) analyses are recommended to further define some of the “blanket” land uses (i.e., agriculture) so that nutrient loads can be accurately attributed to specific land uses. Septic system installations would also be determined by cross-referencing residential land uses with the existing water, storm water, and sewer infrastructure.

The Cities of San Diego, Escondido, and Poway and the County of San Diego (Copermittees) have identified preliminary approaches in this Study Plan. However, the Copermittees are committed to an open and transparent process that would include all potentially affected stakeholders, the Regional Board, and interested members of the public. The process for developing work plans, model reports, and recommendations for the Reservoir and the Subwatershed will likely include a stakeholder advisory group as well as a technical advisory group with periodic public workshops for public input into the process.

Although this version of the Study Plan is designated as final, it is subject to future revisions based on future water quality or hydrologic information, potential BMP implementation results, regulatory, stakeholder, or public input, or other potential factors that are not available for consideration at the time of this document preparation.

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Acronyms and Abbreviations

Acronym or Abbreviation	Definition
%	percent
3-D	three-dimensional
303(d) list	Clean Water Act Section 303(d) list of water quality impaired segments
AGR	agricultural supply beneficial use
Basin	San Pasqual Valley Groundwater Basin
Basin Plan	Water Quality Control Plan for the San Diego Basin
BMP	best management practice
City	City of San Diego
COLD	cold freshwater habitat beneficial use
COMM	commercial and sport fishing beneficial use
Copermittees	Copermittees in the San Dieguito River WMA (Cities of San Diego, Escondido, and Poway and the County of San Diego)
DOC	dissolved organic carbon
$g/m^2/d$	grams per square meter per day
GIS	geographic information system
HA	Hydrologic Area
HOS	Hypolymnetic Oxygenation System
HSA	Hydrologic Subarea
HU	Hydrologic Unit
IND	industrial process supply beneficial use
IRWM	Integrated Regional Water Management
LSPC	Loading Simulation Program in C++
MDL	method detection limit
mg/L	milligrams per liter
MS4	Municipal Separate Storm Sewer System
MUN	municipal and domestic supply beneficial use
NOAA	National Oceanic and Atmospheric Administration

Acronyms and Abbreviations (continued)

Acronym or Abbreviation	Definition
N:P	nitrogen-to-phosphorus ratio
NTS	Natural Treatment System
NTU	nephelometric turbidity unit
OEHHS	Office of Environmental Health Hazard Assessment
OMWD	Olivenhain Municipal Water District
OWTS	onsite wastewater treatment system
ppb	parts per billion
PROC	industrial process supply beneficial use
Public Utilities	City of San Diego Public Utilities Department
QAPP	Quality Assurance Project Plan
RARE	rare, threatened, or endangered species habitat beneficial use
REC-1	water contact recreation beneficial use
REC-2	noncontact water recreation beneficial use
Regional Board	San Diego Regional Water Quality Control Board
Reservoir	Hodges Reservoir (aka Lake Hodges)
SANDAG	San Diego Association of Governments
SDCWA	San Diego County Water Authority
SHELL	shellfish harvesting beneficial use
SNMP	Salt and Nutrient Management Plan
SOD	sediment oxygen demand
Storm Water	City of San Diego Transportation and Storm Water Department
Subwatershed	San Dieguito River Above Lake Hodges Subwatershed
SWMM	Storm Water Management Model
TDS	total dissolved solids
TN	total nitrogen

Acronyms and Abbreviations (continued)

Acronym or Abbreviation	Definition
TP	total phosphorus
USEPA	United States Environmental Protection Agency
VEM	Vigorous Epilimnetic Mixing
WARM	warm water habitat beneficial use
WILD	wildlife habitat beneficial use
WMA	Watershed Management Area
WOD	water column oxygen demand
WQO	water quality objective
WSS	Watershed Sanitary Survey

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1 Introduction

This Study Plan is part of a joint effort between the City of San Diego (City) Transportation and Storm Water Department (Storm Water) and the City Public Utilities Department (Public Utilities) to evaluate nutrient impairments in the Hodges Reservoir. Hodges Reservoir is also known as Lake Hodges colloquially and in some regulatory documentation; it is referred to as the Reservoir in this Study Plan. This evaluation includes development of a conceptual model of nutrient sources to the Reservoir, as well as identification of data gaps in existing and ongoing monitoring efforts and the various input pathways throughout the San Dieguito River Above Lake Hodges Subwatershed[2] (Subwatershed) in the San Dieguito River Watershed. The objectives of this Study Plan are as follows:

- Summarize the previous and ongoing studies and management efforts to characterize nutrients in the Reservoir and its contributing drainage area;
- Develop a conceptual model that fully characterizes nutrient sources and pathways to and within the Reservoir;
- Use the conceptual model and previous and ongoing monitoring efforts to identify data gaps in the characterization of nutrient sources; and
- Provide recommendations for future monitoring and activities to fill these data gaps and data needed to refine existing and future Subwatershed models.

The goal of the Study Plan and the conceptual model is to provide the necessary steps to ultimately develop a functional model of the complete system from the watershed, including its internal drainage pathways (e.g., tributaries, Municipal Separate Storm Sewer System [MS4], groundwater, etc.) to the Reservoir.

The Cities of San Diego, Escondido, and Poway and the County of San Diego (Copermittees) have identified preliminary approaches in this Study Plan. However, the Copermittees are committed to an open and transparent process, which would include all potentially affected stakeholders, the San Diego Regional Water Control Board (Regional Board), and interested members of the public. The process for developing work plans, model reports, and recommendations for the Reservoir and the Subwatershed will likely include a stakeholder advisory group as well as a technical advisory group with periodic public workshops for public input into the process.

Although this version of the Study Plan is designated as final, it is subject to future revisions based on future water quality or hydrologic information; potential BMP implementation results; regulatory, stakeholder, or public input; or other potential factors that are not available for consideration at the time of preparation of this document.

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[2] The Subwatershed is denoted as the San Dieguito River Above Lake Hodges in the San Dieguito River Water Quality Improvement Plan.

1.1 Hodges Reservoir Drainage Area Characterization

Hodges Reservoir was created in 1918 by construction of Hodges Dam on the San Dieguito River. The Reservoir currently provides source water to the Santa Fe Irrigation District, the San Dieguito Water District, and Public Utilities, which together provide potable water to the Cities of Encinitas, Solana Beach, and San Diego, as well as the community of Rancho Santa Fe. In addition to its primary purpose of providing drinking water, the Reservoir also provides water for agricultural and industrial supply, offers multiple recreational opportunities to the residents of San Diego County, and supplies habitat for aquatic and terrestrial species (Regional Board, 2011).

The Reservoir lies within the San Dieguito Hydrologic Unit (HU) (905.00) and captures drainage from the following Hydrologic Areas (HAs): Hodges (905.20), San Pasqual (905.30), Santa Maria Valley (905.40), and a portion of the Santa Ysabel (905.50) HA. This drainage area was collectively designated as the San Dieguito River Above Lake Hodges subwatershed (Subwatershed) in the San Dieguito River Watershed Management Area (WMA) Water Quality Improvement Plan (San Dieguito River WMA Copermittees, 2015). Municipal jurisdictions within the Subwatershed are the Cities of San Diego, Escondido, and Poway as well as the County of San Diego. Table 1-1 provides the Hydrologic Subarea (HSA) names for the HSAs draining to the Reservoir.

Table 1-1. Hodges Reservoir Hydrologic Subareas

Hydrologic Area (HA)	Hydrologic Subarea (HSA)	Jurisdiction			
		City of Escondido	City of Poway	City of San Diego	County of San Diego
Hodges (905.20)	Del Dios (905.21)	X	X[a]	X	X
	Green (905.22)		X	X	
	Felicita (905.23)	X		X[a]	X
	Bear (905.24)	X[a]			X[a]
San Pasqual (905.30)	Highland (905.31)		X[a]	X	X[a]
	Las Lomas Muertas (905.32)	X[a]		X	X
	Reed (905.33)				X[a]
	Hidden (905.34)				X[a]
	Guejito (905.35)				X[a]
	Vineyard (905.36)				X[a]
Santa Maria Valley (905.40)	Ramona (905.41)				X
	Lower Hatfield (905.42)				X[a]
	Wash Hollow (905.43)				X[a]
	Upper Hatfield (905.44)				X[a]
	Ballena (905.45)				X[a]
	East Santa Teresa (905.46)				X[a]
	West Santa Teresa (905.47)				X[a]
Santa Ysabel[b] (905.50)	Boden (905.51)			X[a]	X[a]
	Pamo (905.52)				X[a]

Notes:

a. Jurisdiction does not operate a major MS4 outfall in this HSA.

b. Two additional HSAs within the Santa Ysabel HA, Sutherland HSA (905.53) and Witch Creek HSA (905.54), discharge to Sutherland Reservoir and do not discharge directly to Hodges Reservoir.

The Water Quality Control Plan for the San Diego Basin (Basin Plan) designates the following 10 beneficial uses for the Reservoir (Regional Board, 2011):

- Municipal and Domestic Supply (MUN)
- Agricultural Supply (AGR)

- Industrial Service Supply (IND)
- Industrial Process Supply (PROC)
- Water Contact Recreation (REC-1) (fishing from shore is permitted but all other REC-1 uses are prohibited)
- Noncontact Water Recreation (REC-2)
- Warm Freshwater Habitat (WARM)
- Cold Freshwater Habitat (COLD)
- Wildlife Habitat (WILD)
- Rare, Threatened, or Endangered Species Habitat (RARE)

Figure 1-1 displays the land uses within the Subwatershed. Predominant land uses are Vacant/Undeveloped (28 percent [%]), Residential (19%), Federal- or State-Owned Land and Indian Reservations (18%), and Open Space/Parks (17%). The areas designated as Federal- or State-Owned Land and Indian Reservations, which are located predominantly in HSAs 905.51 and 905.52 within the boundaries of the County of San Diego, are outside the jurisdictional control of the Subwatershed Copermittees.

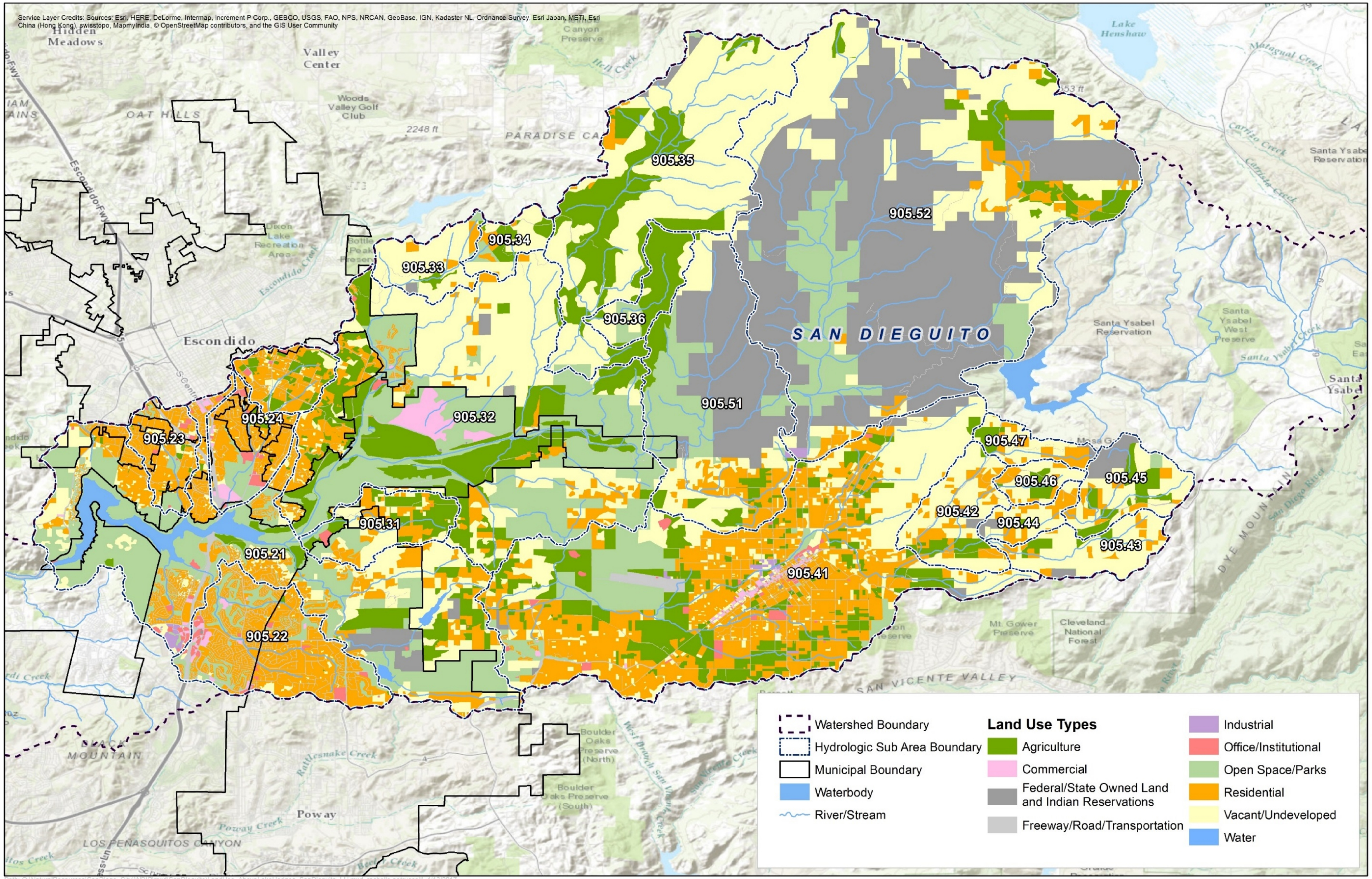

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Figure 1-1. Land Uses Within the Hodges Reservoir Drainage Area

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Major tributaries to the Reservoir include:

- Four direct tributaries (drain directly to the Reservoir):
  - Del Dios Creek
  - Felicita Creek
  - Green Valley Creek
  - Moonsong Creek
- Two upstream tributaries (indirect or intermittent connection to the Reservoir)[3]:
  - Kit Carson Creek
  - Santa Ysabel Creek[4]
- Four indirect tributaries that flow to Santa Ysabel Creek prior to entering the Reservoir:
  - Guejito Creek
  - Santa Maria Creek
  - Sycamore Creek
  - Cloverdale Creek

Kit Carson and Santa Ysabel Creeks both flow through a natural wetland upstream of the Reservoir during lower Reservoir level conditions. This process is discussed further in Section 3 and is detailed in the Hodges Reservoir – Conceptual Model Technical Memorandum (Appendix A).

The elevation of Hodges Dam spillway is 315 feet, which corresponds to a storage capacity of 30,250 acre-feet and maximum Reservoir water depth of 115 feet. The historical minimum water surface elevation is approximately 275 feet, which corresponds to a storage capacity of 5,000 acre-feet. The Reservoir level is primarily related to the pumping needs of water suppliers (City of San Diego, 2014b).

1.2 Regulatory Background

The San Diego Regional MS4 Permit (Order No. R9-2013-0001, as amended by Order Nos. R9-2015-0001 and R9-2015-0100) requires the municipal Copermittees in each of 10 WMAs in the San Diego region to develop Water Quality Improvement Plans. These plans must identify the priority water quality conditions and highest priority water quality conditions of concern in each WMA and establish goals, strategies, and schedules to address the highest priority water quality conditions. The Copermittees, following a two-

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[3] Kit Carson Creek and Santa Ysabel Creek will be referred to as the upstream tributaries to the Reservoir; however, it should be noted that the drainage areas are starkly different for these two creeks. The Kit Carson Creek drainage area is approximately 8.5 square miles, while Santa Ysabel Creek drainage area is approximately 214 square miles.

[4] Santa Ysabel Creek becomes San Dieguito River after the confluence of Santa Ysabel and Santa Maria Creeks.

year collaborative process with watershed stakeholders, completed the final San Dieguito River WMA Water Quality Improvement Plan in September 2015. The plan was accepted by the Regional Board in February 2016 and is currently being implemented.

The San Dieguito River WMA Water Quality Improvement Plan identifies bacteria impairments at the Pacific Ocean as the highest priority water quality condition throughout the WMA during the wet season. During the dry season, this condition is identified only as a priority water quality condition below the Reservoir. Both the Regional Board and members of the public have requested that the Copermittees further evaluate the Reservoir's nutrient impairments as a potential highest priority water quality condition. In its Water Quality Improvement Plan acceptance letter dated February 17, 2016, the Regional Board stated that a nutrient impairment in the Reservoir is, "significantly impacting the use of Lake Hodges waters for municipal water supply, restricting water supply blending opportunities, and increasing treatment costs for downstream water supply agencies" (Regional Board, 2016). Figure 1-2 illustrates an algal bloom in 2014 at the Reservoir. Algal blooms, which are most often related to excess phosphorus in fresh surface water, can impair the functionality of a drinking water reservoir by causing taste and odor issues, filter clogging, and disinfection byproduct precursors (City of San Diego, 2014b).

The 2012 Clean Water Act Section 303(d) list of water quality limited segments (303(d) list) identifies nitrogen, phosphorus, color, pH, manganese, mercury, and turbidity impairments within the Reservoir. The 2014 update to the 303(d) list also identifies potential pollutant sources for these impairments; the MS4 is identified as a potential source for nitrogen, phosphorus, and color. The 2014 303(d) list is currently in draft form and had not been approved at the time of development of this Study Plan. Table 1-2 summarizes the Reservoir 2012 303(d) listings and their listing criteria, including the applicable water quality objectives (WQOs), number of samples evaluated, and impaired beneficial use. After considering all the pollutants on the 303(d) list, nutrient loading (forms of nitrogen and phosphorus) is the most significant water quality problem for Hodges Reservoir (J. Pasek, personal communication).

Figure 1-2. Photos of Hodges Reservoir Without Algal Blooms Present (left) and with Algal Blooms Present (right)
Source: United States Environmental Protection Agency [USEPA], 2016

Table 1-2. Hodges Reservoir 2012 303(d) Listings

Pollutant	First Year Listed	Beneficial Use	WQO	Number of Samples Evaluated	Number of Exceedances	Potential Pollutant Source
Nitrogen	2002	MUN	N:P of 10:1[b]	98	25	Agriculture, Dairies, Unknown Nonpoint Source, Unknown Point Source, Urban Runoff/ Storm Sewers
Phosphorus	2002	MUN	0.025 mg/L, with allowable exceedance frequency of 10%[b]	97	60	Agriculture, Dairies, Unknown Nonpoint Source, Unknown Point Source, Urban Runoff/ Storm Sewers
Color	2002	MUN	15 color units[b]	20	20	Unknown Nonpoint Source, Unknown Point Source, Urban Runoff/ Storm Sewers
pH	2006	MUN	Maximum pH<8.5[b]	20	14	Source Unknown
Manganese	2006	MUN	0.05 mg/L, with allowable exceedance frequency of 10%[b]	19	9	Source Unknown
Mercury	2010	COMM/ SHELL[a]	300 ppb[c, d]	13	3	Source Unknown
		MUN	0.002 mg/L[b]	1	1	
Turbidity	2006	MUN	5 NTU[b]	20	11	Source Unknown

% = percent; COMM = commercial and sport fishing beneficial use; mg/L = milligrams per liter; MUN = municipal and domestic supply beneficial use; N:P = nitrogen-to-phosphorus ratio; NTU = nephelometric turbidity unit; ppb = parts per billion; SHELL = shellfish harvesting beneficial use; WQO = water quality objective

Notes:

a. COMM and SHELL beneficial uses are not identified in the San Diego Basin Plan as beneficial uses within Hodges Reservoir, but these beneficial uses were one of the lines of evidence used by the Regional Board to add mercury to this listing.

b. Regional Board, 2011

c. Office of Environmental Health Hazard Assessment (OEHHA), 1999

d. The objective of 300 ppb (or 0.3 milligrams of mercury per kilogram of fish) was used as a screening value to protect human health when consuming fish. The San Diego Basin Plan guideline states that all waters shall be free of substances that are toxic to human, plant, animal, or aquatic life.

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2 Summary of Previous and Ongoing Studies

This section summarizes the previous and ongoing studies, projects, and monitoring efforts pertaining to the Reservoir and Subwatershed (in chronological order).

2.1 San Pasqual Valley Groundwater Basin Salt and Nutrient Management Plan

The 2014 Salt and Nutrient Management Plan (SNMP) for the San Pasqual Valley Groundwater Basin (Basin) included characterization of the Basin and an evaluation of existing groundwater quality relative to groundwater WQOs for nitrate and total dissolved solids (TDS) (City of San Diego, 2014a). The plan also included an investigation of the primary sources of nitrate and TDS into the system.

The single largest contributing source of nitrogen was determined to be commercial crop fertilizer use (56% of the Basin total), followed by in-basin manure applications (21%), and landscape fertilizer use (14%). Data suggested that more nutrients are currently entering the aquifer than are being removed. Based on current land uses and land management practices, the forecast net increase in nitrate mass stored in water-bearing formations is approximately 520 United States tons annually. These groundwater modeling efforts suggested that it would take more than a decade in some areas of the Basin for surface constituents to reach the water table, and lateral groundwater movement of constituents through the aquifer occurs over multiple decades. Consequently, it may take several years to decades after implementing nutrient management strategies to effect noticeable changes in nitrate concentrations in the Basin.

According to this groundwater model, the annual nitrate mass flux from the Basin alluvial aquifer to the Reservoir could increase up to 20% over the next 50 years. This increase might occur regardless of reasonable reductions in nitrogen loading to the groundwater system over the next 50 years. The model suggested that most of the nitrate mass that is already present in the groundwater system, near the downstream end of the Basin and in the San Pasqual Narrows, will eventually flow into the Reservoir, unless intercepted/consumed by vegetation or mitigated by a physical project.

2.2 Lake Hodges Reservoir Water Quality Assessment Study, Final Conceptual Planning Report and Related Studies

San Diego County Water Authority (SDCWA) partnered with the City of San Diego and the Santa Fe Irrigation District for this initiative in 2014 (City of San Diego, 2014b). The goals of the project were to develop in-Reservoir management actions to manage and control excessive algal productivity and address the 303(d) listing of water quality impairments.

Three projects were proposed to help improve water quality and decrease algae production within the Reservoir:

- Reservoir Hypolymnetic Oxygenation System (HOS) – an HOS would add dissolved oxygen to the Reservoir's bottom water to reduce the occurrence of anaerobic conditions, thereby reducing internal cycling of nutrients.
- Combined Constructed Wetland – this constructed wetland would be used to corral algae and treat influent flows. The wetland would receive influent flows from the Green Valley tributary and pumped, skimmed water from the Reservoir surface; wetland plants would filter the algae before water returns to the Reservoir. This constructed wetland is planned to be positioned near Green Valley Creek's confluence with the Reservoir.
- Mid-Lake Vigorous Epilimnetic Mixing (VEM) – the VEM would mix shallow Reservoir areas to discourage the growth of potentially toxic blue-green algae.

As of March 2017, Public Utilities is proceeding with and has acquired Proposition 84, Round 3 (*Drought Round)* implementation grant funding awarded by the San Diego Integrated Regional Water Management (IRWM) for the HOS and wetland priority projects. The VEM will not be pursued until Public Utilities has assessed the efficacy of the future HOS. Prior to any design or implementation of these projects, a fully functional three-dimensional hydrodynamic and water quality model of the Reservoir will be developed. This model will guide these management decisions.

This water quality assessment and conceptual planning report built upon the Hodges Reservoir Watershed Natural Treatment System Implementation Action Plan (Section 2.2.1) and led to future, related studies: Lake Hodges Reservoir Sediment Oxygen Demand Study (Section 2.2.2) and Lake Hodges Reservoir Sediment Flux Study (Section 2.2.3).

2.2.1 Hodges Reservoir Watershed Natural Treatment System Implementation Action Plan

This implementation action plan was prepared in 2014 to describe the development of a conceptual Natural Treatment System (NTS) for the Subwatershed contributing to the Reservoir (San Dieguito River Valley Conservancy, 2014). The primary goal of this planning effort was to improve water quality, specifically nutrients, within the Reservoir to reduce potable water treatment costs. Secondary goals included providing habitat and species conservation benefits, minimizing conflicting land use, maximizing the potential to use multiple funding sources, and streamlining regulatory compliance. This plan specifically focused on evaluating two conceptual NTS alternatives to treat surface flows (including storm water) using the best available data, a quantitative model, and stakeholder input.

The modeling effort determined that most of the nutrient loadings to the Reservoir were from agricultural areas via Santa Ysabel Creek in an above-average water year (2010–2011). During a below-average water year (2012–2013), no discharges were observed in Santa Ysabel Creek; therefore, base flow in the urban watersheds was the predominant source of nutrient loadings to the Reservoir. Creation of small constructed wetlands at the outlet of urban drainages prior to discharging to the Reservoir was recommended after an alternatives analysis. Areas affected included the outlet of Green Valley Creek and a combination of in-Reservoir treatment wetlands (as discussed in Section 2.2). Public Utilities is currently preferential to the Green Valley Creek constructed wetlands option.

To develop an effective NTS, a monitoring program was recommended to characterize the baseline hydrology and water quality of the proposed NTS area and its contributing watersheds.

2.2.2 Lake Hodges Reservoir Sediment Oxygen Demand Study

The City of San Diego's main goals for this 2015 project were to assess the oxygen demand in the Reservoir and compare the result with that of other reservoirs. Sediment oxygen demand (SOD) and water column oxygen demand (WOD) were measured in experimental incubations using sediment and water collected from three existing sampling locations in the Reservoir (City of San Diego, 2015b).

The project found relatively high SOD (0.60-0.23 grams per square meter per day [g/m^2/d]) and WOD (0.2–0.3 milligram per liter per day [mg/L/d]), compared with SOD in other California reservoirs. The high overall oxygen demand likely results from several factors:

- Reservoir age – sediment accumulation over time.
- Reservoir trophic level – organic matter and reduced species of iron, manganese, and sulfides accumulate in the anoxic condition in bottom layers of the lake. These compounds have a high oxygen demand.
- Continued Nutrient Loading – external and internal, enhanced by anoxic conditions in the bottom water.

2.2.3 Lake Hodges Reservoir Sediment Flux Study

This 2015 study supported the *Lake Hodges Reservoir Sediment Oxygen Demand Study* conducted by the City of San Diego (City of San Diego, 2015c). The goal of this project was to investigate the effect of oxygenation on the biogeochemical kinetics in the bottom water of the Reservoir. Therefore, the study addressed the macro-scale diffusive fluxes of nitrate, ammonium, phosphate, iron, manganese, and dissolved organic carbon in both oxic and anoxic conditions in the laboratory, where oxic conditions mimicked that of the proposed HOS, as discussed in Section 2.2. Maintaining a well-oxygenated sediment-water interface favored the uptake of dissolved organic carbon (DOC) by organic microbes. By enhancing the organic matter degradation via oxygenation, accumulation of organic matter in the sediment should be limited, thereby leading to lower potential for phosphate loading from internal sediments.

2.3 San Dieguito Hydrologic Investigation

The City of San Diego conducted a modeling study in 2015 to characterize nutrient loads to the Reservoir during wet weather events from the Subwatershed with the goal of developing a long-term estimate of inflow to the Reservoir (City of San Diego, 2015a). The modification of a United States Environmental Protection Agency (USEPA) Storm Water Management Model (SWMM) hydrologic rainfall/runoff model to function as a long-term hydrologic model was the primary objective of this investigation. The model calibration period was for water years 2008 to 2011. The calibration results highlighted the importance of adequately describing the rainfall throughout the Subwatershed, and deploying recommended additional rainfall gauges. This hydrologic evaluation focused on wet weather flows into the Reservoir. Review of the results of modeling indicated that the model generally underestimates flows at the tail end of the storm hydrograph, and thus would not perform well at reproducing measured base flows in the Subwatershed, which may be significant in terms of nutrient loading.

This effort was continued in 2016–2017 to characterize nutrient loads to the Reservoir under the historical range of precipitation conditions, and to update the previously created hydrologic and water quality model of the catchment. A wet weather sampling program of surface water grab samples at up to 11 stations over seven storm events between March 2016 to February 2017 was implemented to subsequently calibrate the nutrient parameters in SWMM. The hydrology and nutrient concentration calibration results highlight the variability inherent in a complex watershed subject to variable amounts of rainfall over its area, as model predictions overestimate runoff and nutrient concentrations during some storms and yet underestimate others (City of San Diego, 2017).

2.4 Hodges Reservoir Nutrient Evaluation Technical Memorandum

This 2017 technical memorandum summarized an analysis of Reservoir and MS4 wet and dry weather water quality data collected from the Reservoir and the Subwatershed from 2008 through 2016 (San Dieguito River WMA Copermittees, 2017). The objectives of this analysis were as follows:

- ❖ Determine whether nutrient levels in the Reservoir currently exceed applicable WQOs.
  - ➢ If nutrient levels do not exceed WQOs, determine whether the Reservoir meets the delisting criteria for removal from the 303(d) list.
  - ➢ If nutrient levels do exceed WQOs, determine whether data indicate a correlation in nutrient concentrations between the MS4 and the Reservoir.

It was determined that annual mean concentrations of total phosphorus (TP) and the nitrogen-to-phosphorus ratio (N:P) in the Reservoir exceeded WQOs between 2007 and 2016. Mean TP concentrations exceeded the WQOs in all years and all strata. It was strongly recommended that future TP analyses utilize a laboratory method with a lower detection limit because the current detection limit is greater than the TP WQO of 0.025 milligrams per liter (mg/L). The mean N:P ratio exceeded the WQO only in 2016.

Mean TP and total nitrogen (TN) values in the MS4 dry and wet weather samples generally exceeded mean values in the Reservoir. However, a correlation analysis for both nutrients did not show a link between nutrient concentrations in the MS4 and in the Reservoir.

2.5 Watershed Sanitary Survey Monitoring

The Watershed Sanitary Survey (WSS) investigates the source water system used by the City of San Diego (City of San Diego, 2015d). The initial WSS was completed in 1996 and is updated every five years. The purpose of the survey is to identify actual or potential sources of local water contamination that might adversely affect the quality and treatability of water used as domestic supply for the City of San Diego. WSS efforts include routine surveys and water quality monitoring to identify trends in water quality degradation, isolate sources of contamination, and determine effects of management practices. These efforts include stream and Reservoir water quality monitoring for the Subwatershed and Reservoir.

The 2015 WSS indicated a significant decrease in mean TN values in the contributing streams and in the Reservoir since the 2010 WSS. Per recommendations in the 2010 WSS, Public Utilities continues to routinely survey land conditions and land use, monitor water quality, and limit the use of resources. Goals of these actions include meeting regulatory requirements and efficiently obtaining the necessary information to evaluate water quality, identify trends in degradation, isolate sources of contamination, and determine effects of management practices. Since the 2010 WSS, the City has also acquired parcels, conservation easements, or development rights for lands proximal to the Reservoir source waters that, if preserved, would protect water quality. These activities may have contributed to the significant decrease from 2010 to 2015 in mean stream and Reservoir TN values, but the specific reasons for the observed decrease were not provided in the 2015 WSS.

2.6 MS4 Dry and Wet Weather and Receiving Water Monitoring

The 2007 and 2013 MS4 Permits require periodic MS4 outfall and receiving water monitoring during both dry and wet weather. Although the site selection criteria and required monitoring frequency changed between the 2007 and 2013 Permits, dry and wet weather MS4 outfall data have been collected annually in the Subwatershed from 2007 to present. Beginning with the 2013 Permit, only Major MS4 outfalls (outfalls greater than 36 inches in diameter) have been sampled. Receiving water data are typically collected less frequently: nutrient data at long-term monitoring stations are collected only once per permit term under the current MS4 Permit.

The purpose of the current (2013 MS4 Permit) wet and dry weather MS4 outfall monitoring program is to assess the effectiveness of Copermittee jurisdictional runoff management programs and WQIP strategies toward (1) effectively prohibiting non-storm water discharges into the MS4; and (2) reducing pollutants in storm water discharges from their MS4s to the maximum extent practicable. Nutrients are evaluated under both the wet and dry weather MS4 monitoring programs.

Receiving water monitoring involves evaluating the physical, chemical, and biological conditions of the receiving waters and sediments during both wet and dry weather conditions. Long-term receiving water monitoring stations were established under the 2007 MS4 Permit and continue to be monitored under the 2013 MS4 Permit. Two of these stations (SDC-TWAS-1 and SDC-TWAS-2) are located within the Subwatershed. Nutrients are evaluated under both the wet and dry weather receiving water monitoring programs.

3 Conceptual Model of Nutrient Sources and Pathways

This section provides a summary of the Hodges Reservoir Conceptual Model, outlining the pathways of nutrients from and through the Subwatershed to the Reservoir, the nutrient dynamics (sources and pathways) among these components during both low- and high-water stages, and nutrient cycling among different component ecosystems. A technical memorandum describing the conceptual model and nutrient budget development is attached as Appendix A.

3.1 Nutrient Pathways and Sources

The review of previous studies and monitoring efforts revealed that the tributaries or pathways contributing nutrients from the Subwatershed to the Reservoir include the following (Figure 3-1):

- Direct tributary inputs into the Reservoir from the adjacent Subwatershed: Del Dios Creek, Felicita Creek, Moonsong Creek, and Green Valley Creek; and
- Inputs from Kit Carson Creek and Santa Ysabel Creek via a wetland located upstream of the Reservoir.

The most probable nutrient sources to the Reservoir within the Subwatershed include:

- Internal cycling,
- Non-point source loading from agricultural and other sources,
- Point source loading from the MS4,
- Imported water,
- Groundwater, and
- Atmospheric contributions.

Internal Cycling

Nutrients in the Reservoir sediments contribute a consistent internal nutrient load that can affect water quality, depending on stratification, other limnological processes, bioturbation, and water management activities. Periodic, relatively large inputs from the Subwatershed during periods of high rainfall and high Reservoir stage years may provide sediment and nutrient loads to the Reservoir that facilitate longer-term internal cycling.

Non-Point Source Loading

The following are considered potential sources of non-point source loads to the Reservoir:

- Agricultural land uses: Large areas in the Subwatershed are used for agriculture, including farms, nurseries, and orchards. The agricultural uses are especially concentrated the upper Subwatershed (Figure 1-1).

- Septic systems: Houses in rural residential areas may not be connected to the sewer system and instead use onsite wastewater treatment systems (OWTSs), also referred to as septic systems. Improper maintenance of these septic systems could contribute to nutrient loadings to the Reservoir. Although the majority of these systems exist in the upstream areas, no specific information is readily available on the number and locations of residential septic systems in the Subwatershed. This lack of information is primarily because no programs to document septic system installation and maintenance currently exist. The City of Escondido has completed a rudimentary geographic analysis and mapping of septic systems within its jurisdiction based on known water customers and sewer infrastructure. Public Utilities has also identified the Del Dios neighborhood for future analysis of septic systems. The information from these projects can be used for future modeling and source investigation efforts.
- San Pasqual Academy Water Wastewater Treatment Plant: This domestic wastewater treatment facility is located in County of San Diego and has been operated by the County since 2000. Although it is near Santa Ysabel Creek, it discharges treated wastewater to a 1-acre percolation pond/spray irrigation bed bounded by eucalyptus trees, rather than directly discharging effluent to the creek (Regional Board, 2009).
- Santa Maria Wastewater Treatment Plant: The Ramona Municipal Water District operates this plant that serves the downtown area of Ramona. The plant is capable of treating 1,000,000 gallons per day of sewer flow. The recycled water produced by the plant is used to irrigate the Mountain Woodson Golf Course and to irrigate spray fields near rangeland Road and Highland Valley Road (Ramona Municipal Water District, 2017).

MS4 Point Sources

The Reservoir is surrounded primarily by residential land uses. MS4 data collected at the watershed level do not directly link outfall discharges with the nutrient impairment. No MS4 outfalls directly discharge to the Reservoir, but rather discharge to Reservoir tributaries (San Diego River WMA Copermittees, 2015). However, these data are limited, thus it is difficult to determine the contribution of MS4 loadings of nutrients to the Reservoir. Water quality monitoring at MS4 outfalls and tributaries with contributing drainage areas, under a representative range of flow conditions, could be conducted and used to model pathways of nutrients in the watershed and identify contribution of MS4 nutrient loadings to the Reservoir.

Imported Water

In 2003, the SDCWA and the Olivenhain Municipal Water District (OMWD) constructed the Olivenhain Dam as part of the Emergency Storage Project to support the municipal water supply. Olivenhain Reservoir is filled with imported water from the SDCWA aqueducts. It operates as part of a pumped storage hydroelectricity source by pumping water daily from the Hodges Reservoir to Olivenhain Reservoir (City of San Diego, 2014b). This imported water from the aqueduct system could be a potential nutrient source to the Hodges Reservoir via Olivenhain Reservoir.

Groundwater

Groundwater has been identified as a potential source of pollutants to the Reservoir:

- "For pollutants such as TDS and nutrients, groundwater may be a contributing source, as noted throughout the San Diego region (City of San Diego, 2011)" (San Dieguito River WMA Copermittees, 2015).
- Available information from groundwater modeling is limited to San Pasqual Valley Groundwater Basin, which is upstream of the Reservoir:
  - The San Pasqual Valley Basin groundwater modeling efforts suggested that it would take more than a decade in some areas of the Basin for surface constituents to reach the water table, and lateral groundwater movement of constituents through the aquifer occurs over multiple decades. Furthermore, this model suggests annual nitrate mass flux could increase 20% over the next 50 years, regardless of reasonable reductions of nitrogen loading to the ground water. Consequently, it may take several years to several decades after implementing nutrient management strategies to effect noticeable changes in nitrate concentrations in the Basin.

Atmospheric Contributions

Atmosphere contributes direct nutrient inputs through wet and dry deposition to the surface of the Reservoir. Nitrogen can also enter the system through nitrogen fixation processes occurring in the Reservoir and in the adjacent wetland. Nitrogen fixation is a biogeochemical process by which atmospheric nitrogen is assimilated into organic compounds, especially by certain microorganisms as part of the nitrogen cycle.

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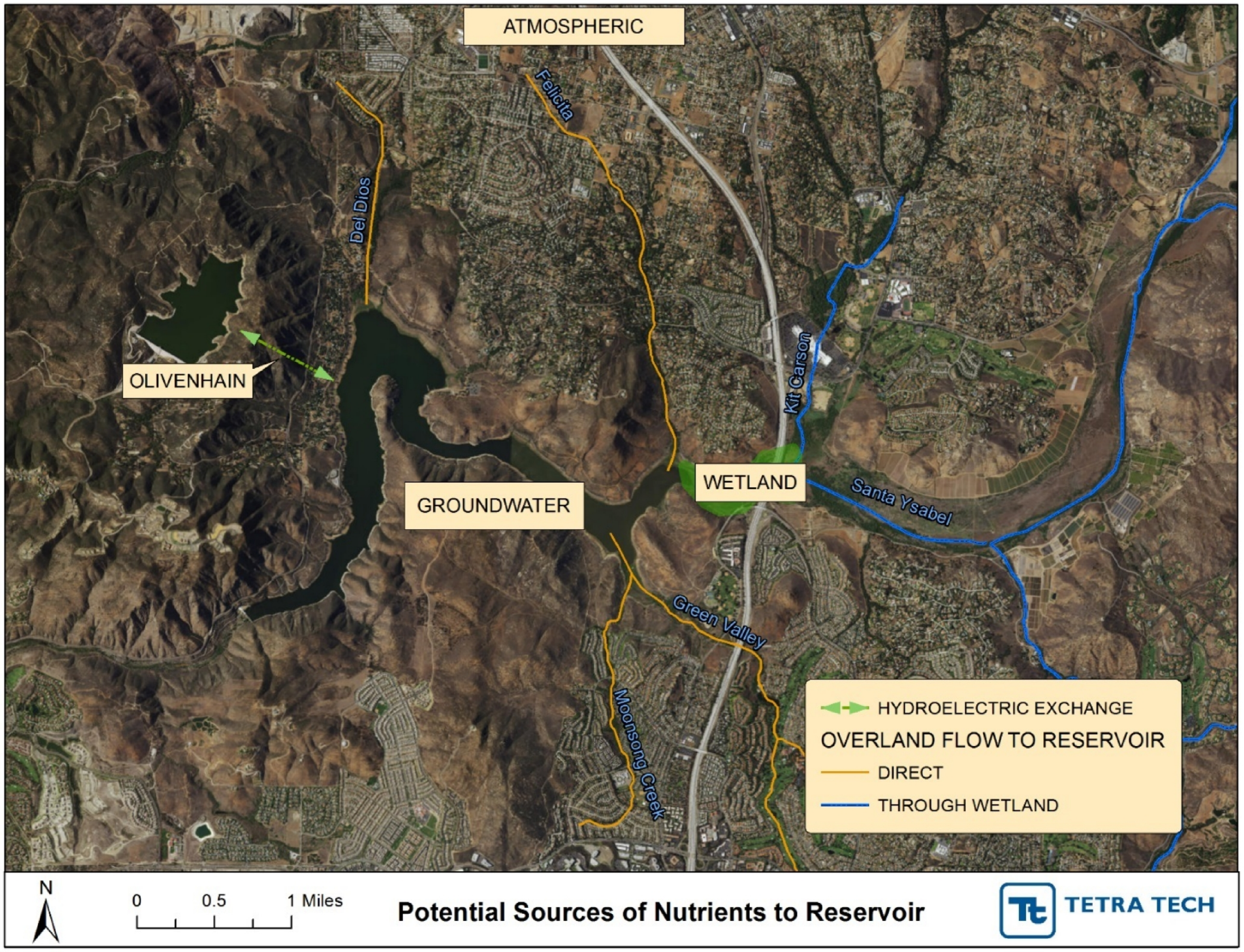

Figure 3-1. Conceptual Representation of Major Nutrient External Source Components to the Hodges Reservoir

Figure Notes: Atmosphere and groundwater extend spatially through the entire Subwatershed. Placement of identified source components is for conceptual purposes, and not meant to be spatially accurate.

Internal cycling of the Reservoir is also a source of nutrients; however, this figure is a conceptual representation of inputs to the Reservoir from external sources (e.g., the Subwatershed, groundwater, etc.)

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3.2 Two-Condition Conceptual Model

Within this conceptual model, it is assumed nutrient loads into the Reservoir are provided by the direct tributaries and upstream tributaries. Direct tributaries drain the Subwatershed areas immediately adjacent to the Reservoir and provide nutrient loads throughout the year, depending on water year characteristics. Upstream tributaries drain the larger upstream portion of the Subwatershed and provide nutrient loads to the Reservoir either directly or indirectly, via the adjacent wetland, depending on water year characteristics. This conceptual model assumes that these upstream tributaries flow through or bypass a wetland that is located on the upstream end of the Reservoir (Figure 3-1 and Figure 3-2). Recently, this wetland has mostly been dry with intermittent (e.g., every few years for several weeks) inundation by the Reservoir and intermittent flows from the upstream tributaries. During periods when the wetland is inundated (dotted line in Figure 3-2 and Figure 3-3), it is probable that these upstream tributaries have a direct surficial connection to the Reservoir and contribute nutrient loads. During drier conditions when the wetland is not inundated (Figure 3-2 and Figure 3-4), these upstream tributaries most likely lack a surficial connection to the Reservoir and either do not contribute loads or provide only limited loading to the Reservoir through the wetland, which has the ability to process a portion of that load. The direct Reservoir watershed in Figure 3-1 and Figure 3-2 refers to drainage areas adjacent to the Reservoir that do not flow through the upstream wetland.

Investigations of the land uses and hydrology of the Subwatershed revealed that the connectedness of the upstream watershed to the Reservoir was important. The upstream watershed area is much larger than the direct tributary watershed area and includes a variety of land uses that have the ability to contribute nutrient loads, which may be significant compared with direct tributary contributions. However, during the extended “low Reservoir condition,” when the upstream watershed is disconnected (at least surficially) from the Reservoir, these upstream loads would likely be greatly reduced. As a result, a two-condition conceptual model is being proposed for the Reservoir with regard to nutrient loading: high-flow/high Reservoir water level condition (high Reservoir condition) and a low-flow/low Reservoir water level condition (low Reservoir condition). There will be a transition period between these two conditions that will not necessarily be significant or lasting, but will affect the dynamics of this entire system.

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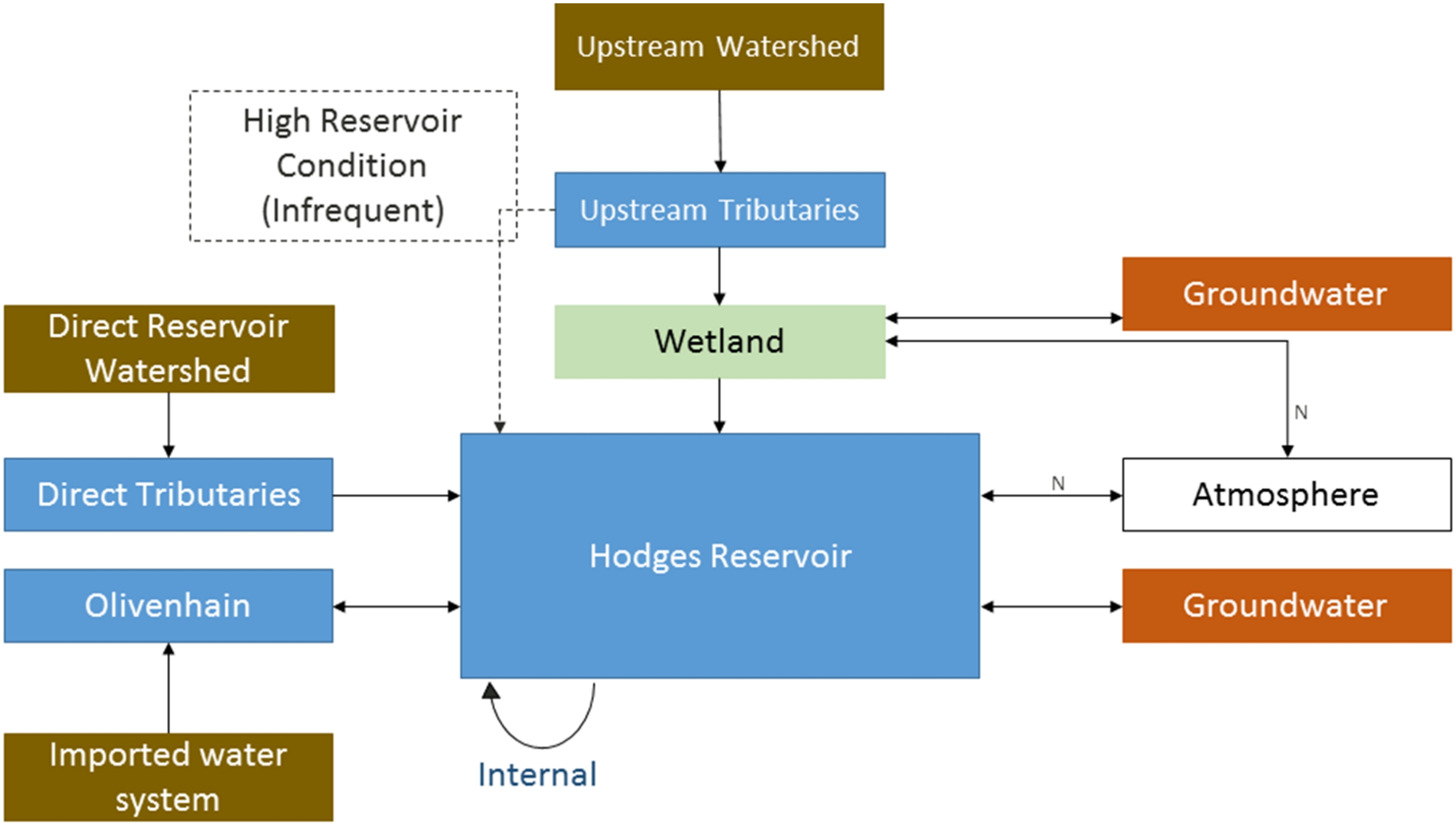

Figure 3-2. Conceptual Model of Nutrient Loading to the Reservoir (High and Low Reservoir Conditions)

Figure Notes: Upstream loading to the Reservoir via the wetland represents the low Reservoir condition; Upstream direct loading to the Reservoir, bypassing the wetland as indicated by the dotted line, is representative of the high Reservoir condition.

Direct Reservoir watershed represents the drainage areas of the tributaries that flow directly to the Reservoir, and does not include drainage areas associated with the upstream tributaries.

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3.2.1 High Reservoir Condition

During the high Reservoir condition (Figure 3-3), the wetland becomes inundated and upstream tributaries have a direct surficial connection to the Reservoir. During this condition, the wetland plays a reduced role in attenuating nutrients because more of the nutrient load flows directly to the Reservoir, rather than interacting with the wetland's sediment/water interface, where biogeochemical processing of nutrients typically occurs. Certainly, a portion of nutrients would be processed, but the wetland is less effective in its role of storing and processing the nutrients if most of the load bypasses that sediment/water interface.

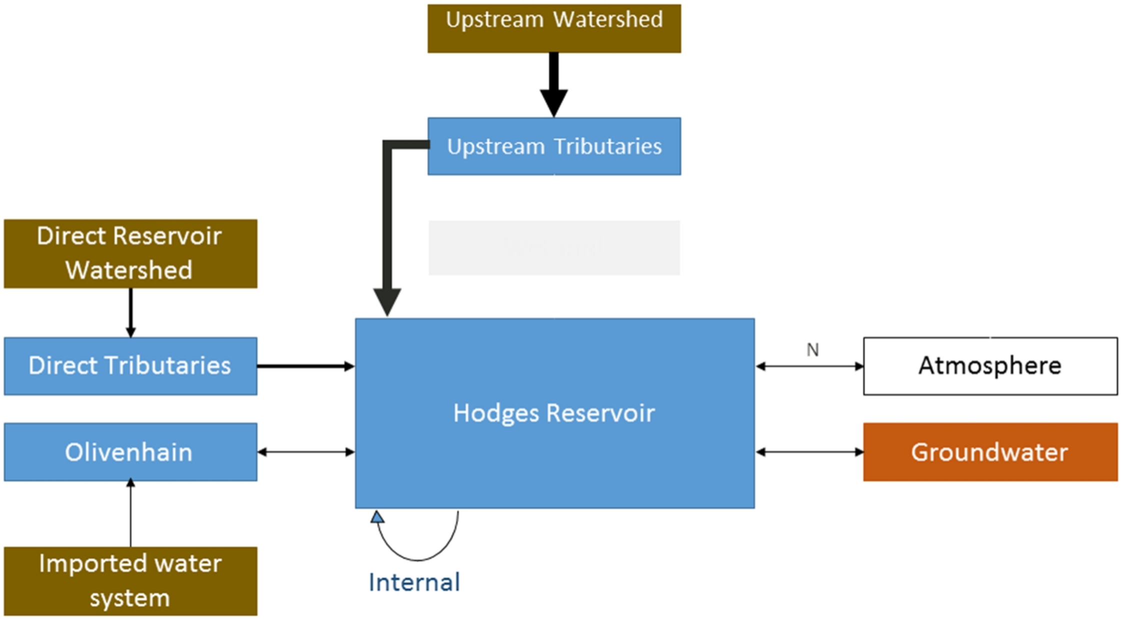

Figure 3-3. High Reservoir Condition (high-flow/high Reservoir level); the Reservoir is Connected to the Upstream Watershed

The upstream tributaries are expected to provide the largest portion of the total load during this high Reservoir condition. This load may, in fact, reload the Reservoir with nutrients, which will proceed to cycle between the sediment and water column via internal loading during subsequent dry conditions. This finding is especially true of phosphorus. A large portion of the phosphorus load, especially during high flows, is sediment bound (more so than nitrogen). Therefore, more of the relative total load of phosphorus may be delivered as particulates during the high Reservoir condition. Moreover, phosphorus has no gaseous phase, so it cannot be exported from the Reservoir system except through permanent sedimentation. In contrast, nitrogen can be transformed into and lost as a gas through a series of biogeochemical reactions. For these reasons, this reloading of nutrients is especially important for phosphorus management. The high Reservoir condition is likely less common and shorter in duration compared with the low Reservoir condition, but may be sufficient to provide a large, persistent nutrient load to the Reservoir, especially for phosphorus.

3.2.2 Low Reservoir Condition

During the low Reservoir condition (Figure 3-4), which is expected to be the most common state for the Reservoir, the upstream watershed may carry nutrient loads downstream, but these loads are largely attenuated by processing and storage in tributaries and the upstream wetland because of uptake and lack of surface flow. The wetland is not inundated during this condition and tributary flows typically infiltrate. It is suspected that nitrification and denitrification processes in the carbon-rich wetland can remove nitrogen from influent sources, and phosphorus can be removed via sedimentation of particle-bound phosphorus and sorption of orthophosphate as it infiltrates through the wetland soils. Anoxic processes in shallow groundwater within the wetland have the potential to produce soluble phosphorus along shallow groundwater flow paths. The redox condition of the wetland would strongly influence these biogeochemical reactions. As a result of this fluvial disconnection and uptake and processing of nutrients in the wetland, the relative contribution of loads from direct tributaries and internal loading is much larger than that from upstream tributaries. Internal loading would recirculate, in part, upstream phosphorus deposited during wet conditions. Nitrogen fixation would also be a significant source of new nitrogen inputs. Again, during this condition, internal loads and direct tributary loads would be expected to dominate the nutrient budget because very little, if any, upstream tributary water would be expected to reach the Reservoir. Although it is unlikely during the low Reservoir condition, sufficiently high flow from a large storm event may cause intermittent surface flows through the wetland that could cause erosion of the wetland sediments, delivering nutrients to the Reservoir from upstream.

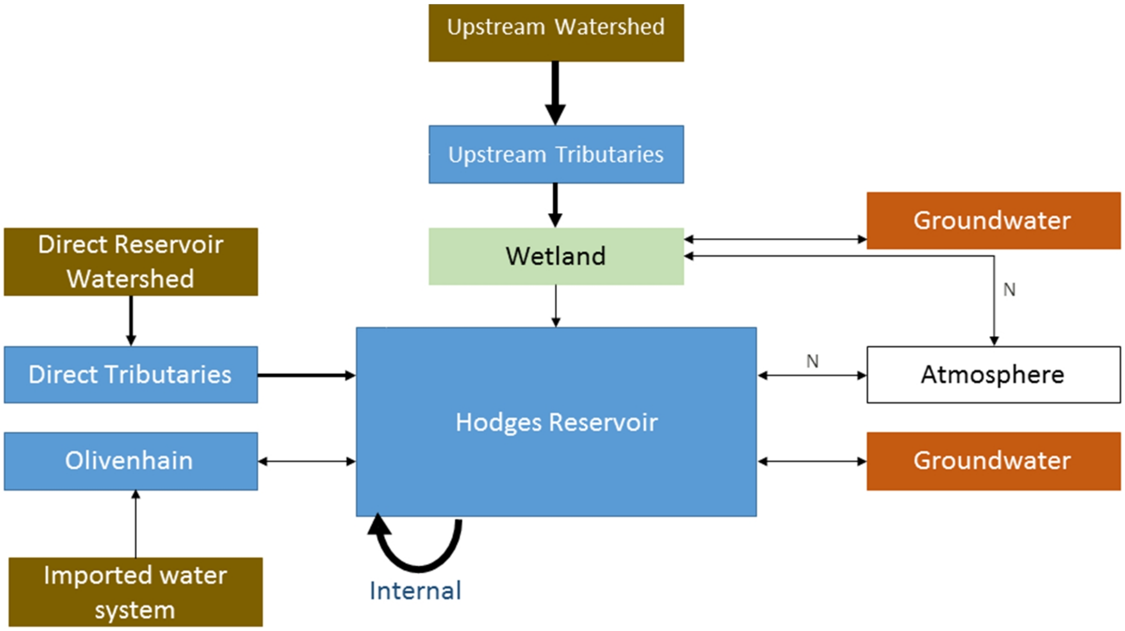

Figure 3-4. Low Reservoir Condition (low-flow/low Reservoir level); the Reservoir is Disconnected from the Upstream Watershed

3.3 Nutrient Cycling Within Component Ecosystems

Nutrients do not move passively through aquatic ecosystems. Nutrients that enter this tributary network are processed *in situ* in streams, in the upstream wetland, and in the Reservoir itself. This cycling can represent both sources and sinks for nutrients. The following sections discuss cycling in stream, wetland, and reservoir ecosystems.

3.3.1 Stream Nutrient Cycling

Stream ecosystems are not conveyances, but rather are active ecosystems with unique flora and fauna that vary depending on stream size, hydrology (including permanence), geomorphic setting, and other factors. Major nutrient inputs into a stream segment include upstream and tributary loads as well as groundwater loads. Nitrogen fixation can also contribute nitrogen to the stream segment. A portion of nutrients are taken up by benthic organisms and cycle through the food web before being mineralized and released downstream. Ultimately, nutrients that are not removed through gas loss (nitrogen) or biochemical uptake are exported as downstream load. Figure 3-5 provides a stream nutrient cycling diagram.

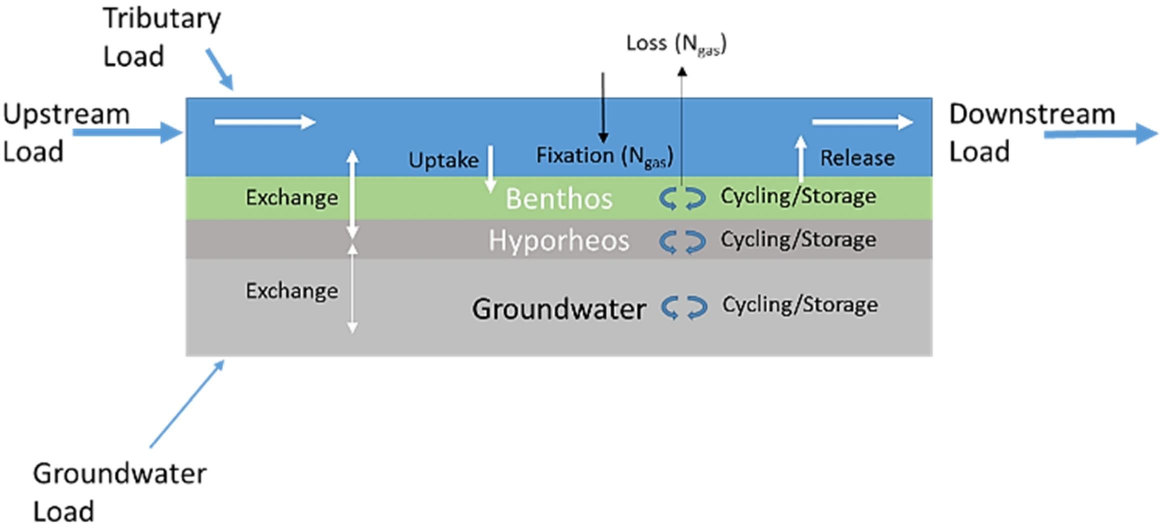

Figure 3-5. Conceptual Model of Nutrient Cycling in Tributary Streams

Figure Notes: Hyporheos is the layer of subsurface sediment where exchange and interaction of stream water and groundwater occurs.

Benthos is the layer of surface and subsurface sediments where the benthic invertebrate community exists.

Nitrogen gas fixation is a natural process where atmospheric nitrogen gas combines chemically with other elements (e.g., stream water) to form other nitrogen compounds that are then stored in the waterbody or taken up by benthic organisms.

3.3.2 Wetland Nutrient Cycling

The wetland ecosystem upstream of the Reservoir also takes up and processes nutrients, although the magnitude is uncertain. Major nutrient loads to the wetland come from upstream tributaries, adjacent tributaries, and groundwater. Wetlands possess great uptake and storage capacity for nutrients. Specifically, the carbon-rich, anoxic sediments provide an environment perfectly suited for denitrification, an anaerobic process that removes nitrogen from the water column. Nutrients are taken up by both open water and sediment biota, as well as emergent vegetation (plant biomass). These nutrients then cycle in the wetland ecosystem among different trophic levels. For instance, nitrogen can be removed by denitrification, and also can be added to the wetland through nitrogen fixation. A portion of the nutrient pool is mineralized (nutrients converted into mineral/inorganic material) and may be exported downstream via surficial flow, shallow subsurface flow, or loss to groundwater. The contribution of each of these export pathways is hydrology-dependent. Figure 3-6 provides a wetland nutrient cycling diagram.

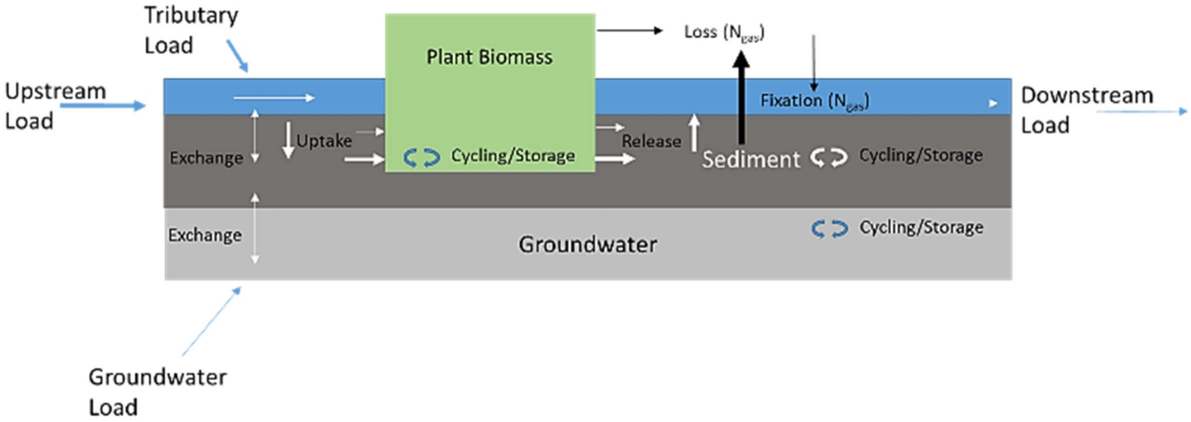

Figure 3-6. Conceptual Model of Nutrient Cycling in Wetlands

3.3.3 Reservoir Nutrient Cycling

Nutrients also cycle in the Reservoir itself. Inputs include upstream loads, tributary loads, groundwater loads, and exchange with Olivenhain Reservoir. Nitrogen fixation is also a source of nitrogen within the Reservoir. Nutrient exchange occurs among the water column, sediments, and groundwater, as in the other ecosystems. Continued loading of nutrients contributes to ongoing eutrophication in the Reservoir. The Reservoir is unique relative to the tributaries and wetland in that it becomes thermally stratified. The upper layers warm in the spring and, because of thermal effects on water density, become physically isolated from the cooler lower layers and remain so through the summer and fall. Stratification is an important physical phenomenon in deep, lentic waterbodies that drives important nutrient transformations.[5] During stratification, nutrients in the epilimnion (region above the thermocline) are taken up by algae and bacteria and move through trophic levels via consumption. Some may be released through excretion and some may be mineralized into available nutrients in the epilimnion. A portion of the particulate nutrients settle out of the epilimnion into the hypolimnion (region below the thermocline), passing through the metalimnion (thermocline). In the hypolimnion organic carbon is decomposed, consuming oxygen. This layer is isolated from the atmosphere and

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[5] Lake/reservoir stratification is the separation of lake/reservoir water into three layers: epilimnion, the top of the water; metalimnion (or thermocline), the middle layer; hypolimnion, the bottom layer.

reaeration through diffusion is insufficient to replenish oxygen; therefore, concentrations decline and the hypolimnion may become hypoxic (<2 mg/L dissolved oxygen) or even anoxic near the sediment. Because this layer is isolated from the atmosphere and reaeration through diffusion is insufficient to replenish oxygen, concentrations decline and the hypolimnion may become hypoxic (<2 mg/L dissolved oxygen) or even anoxic near the sediment. Under anoxia, insoluble phosphorus bound to metal oxides is released and becomes soluble. Organic nitrogen is also decomposed and converted into ammonium, a portion of which may be nitrified (converted into nitrites/nitrates) and then removed from the Reservoir by denitrification. Some of the dissolved nutrients may diffuse to the upper layer or be taken up by algae, which can introduce dissolved nutrients to the water column and lower layers of the Reservoir through settling. Although most of the dissolved nutrients from external sources are most likely introduced during the wet season in the winter, groundwater has the potential to provide a continuous source. During Reservoir stratification, nutrients can be mobilized from the sediments into the hypolimnion. Then, when conditions warm in the spring and cool in the fall, the lake will turn over (destratify), providing nutrients to the surface waters, which can then fuel algae blooms. Lakes/reservoirs in mild marine climates generally stay mixed through the winter. Figure 3-7 provides a reservoir nutrient cycling diagram.

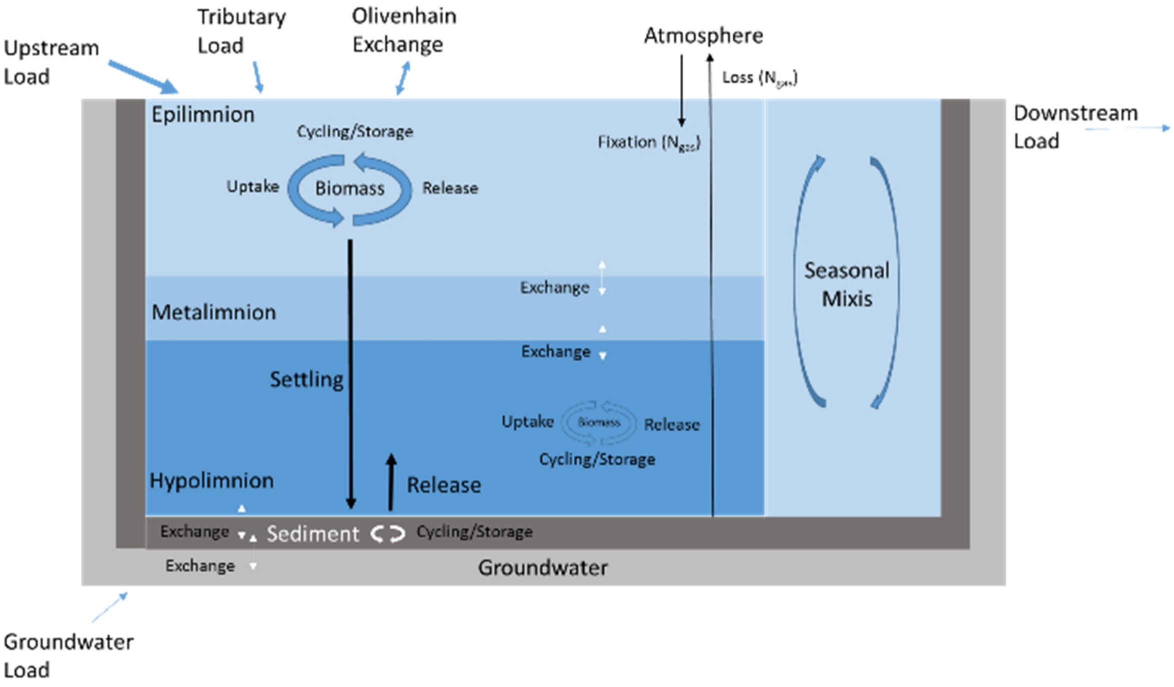

Figure 3-7. Conceptual Model of Nutrient Cycling in the Reservoir

3.4 Use of Models

The existing SWMM that was developed for the San Pasqual Basin (within the Subwatershed) was reviewed (City of San Diego, 2015a). The review indicated that the SWMM model is best applied as a storm water model for highly urbanized/impervious catchments and is less suitable for watersheds with significant amounts of pervious areas. This difference in applicability is primarily because the SWMM's single representative outflow of a watershed represents multiple land uses together, rather than accounting for different land use types. The Loading Simulation Program in C++ (LPSC) watershed model allows for assignment of multiple land uses at the subwatershed level and individual flow and loading characteristics for each land use. The Reservoir's Subwatershed includes significant amounts of pervious area, with scattered impervious areas, and a complex groundwater system, which suggests that simplified SWMM hydrology and pollutant loading simulations may make it difficult to adequately capture observed conditions. Information from the SWMM model can be used to help update the LSPC model in the future to provide a more accurate assessment of nutrient loading to the Reservoir and Water Quality Improvement Plan updates that may be needed.

A three-dimensional Reservoir model is being developed by Public Utilities, independent of potential future Subwatershed modeling driven by this Study Plan. Assuming that both models are developed, a development goal is that the models are compatible with each other.

4 Identified Data Gaps and Recommended Activities

A preliminary nutrient budget was developed for the Subwatershed. This exercise helped identify key data gaps inhibiting accurate assessment of nutrient loading to the Reservoir. This preliminary nutrient budget is discussed in Appendix A. Although data have been collected in the Subwatershed and within the Reservoir to meet goals of various programs, data critical for estimating representative nutrient loads from potential key sources and pathways in the Subwatershed are limited. Critical data gaps are summarized in order from the upstream watershed (tributaries and MS4) through the wetland system and to the Reservoir in successive sections. Furthermore, monitoring and other activities recommended to fill these identified data gaps are also briefly described. These recommendations are needed to develop a dataset that would allow calibration and uncertainty analyses of the Subwatershed loading model (Reservoir model to be developed independently by Public Utilities). Monitoring details to address the identified data gaps will be specified in a future Monitoring Plan and Quality Assurance Project Plan (QAPP) to be developed for this program upon monitoring implementation.

4.1 Tributaries Data Gaps and Recommended Activities

Tributaries within the Subwatershed have historical nutrient, sediment, and flow datasets from ongoing efforts such as MS4 receiving water and United States Geological Survey stream monitoring programs. These data can be used for model development and calibration efforts; however, during conceptual model development, spatial and temporal data gaps were identified for the Reservoir tributaries. These data gaps were separated into the direct and upstream tributaries, as defined in Section 3.

Direct Tributaries

There are four major direct tributaries to the Reservoir: Felicita, Green Valley, Del Dios, and Moonsong Creeks. Total flow, discharge rates, nutrient concentration, and load information can be estimated from existing sampling and model output. However, data gaps identified for the direct tributaries included a lack of synchronization in monitoring programs and frequency of water quality sampling, which make it difficult to calibrate a watershed model to different sources and land uses. It is recommended to continuously monitor dry and wet weather flows and increase dry weather water quality sampling frequency for the tributaries to monthly for approximately three years (final duration and frequency for monitoring will be determined upon program implementation). Additionally, targeting both small and large storm events for wet weather water quality sampling is recommended. This additional wet and dry weather sampling in the direct tributaries should also coincide with the sampling occurring in the MS4 and Reservoir. The direct tributaries, which contribute flows not affected by the wetland, will most likely have similar hydrologic responses and nutrient loadings during both low and high Reservoir conditions. Although monitoring the direct tributaries is not dependent on the Reservoir condition as it is with the upstream tributaries, monitoring will occur only when the desired conditions exist for the whole program to maintain coinciding sampling throughout the project area.

Upstream Tributaries: Two Conditions

The nutrient loads from the upstream tributaries vary between two conditions, as discussed in Section 3. The shift between these two conditions is not discrete, but rather is gradated; it is most likely that there are periods during which flow will slowly decline (or rise) until the tributaries become fully disconnected (or connected). Defining when the system is in either condition may be difficult and complex, but should be a priority for further investigation. For example, when the upstream tributaries and the Reservoir are surficially disconnected, shallow subsurface connectivity may remain for a substantial period of time, the extent and duration of which are unknown at present. It is imperative to determine the connectivity (or lack thereof) during these three periods: low Reservoir, high Reservoir, and the transition period between the two conditions.

Most of the wet and dry weather monitoring conducted in the upstream areas will likely be (and has been) during the low Reservoir condition. For this condition, it is recommended to continuously monitor dry and wet weather flows and increase dry weather water quality sampling frequency to monthly (final duration and frequency for monitoring will be determined upon program implementation). Additionally, targeting both small and large storm events for wet weather water quality sampling is recommended. The upstream tributaries will most likely have similar hydrologic responses and nutrient loadings for storm events occurring during the low Reservoir condition. Therefore, if the upstream tributaries have been adequately characterized during this condition for watershed modeling purposes, monitoring activities throughout the system may be temporarily suspended until the high-flow/high Reservoir condition occurs. Once this condition exists, sampling throughout the system will resume to characterize the high Reservoir condition.

The high Reservoir condition is less often observed in these areas, so monitoring will be opportunistic. It is recommended that the sampling frequency be increased for both dry and wet weather water quality sampling during this time so that high-water nutrient loading can be adequately characterized.

During the high Reservoir condition, nutrient load from Santa Ysabel Creek has the capacity to be substantial (with relatively smaller loading from Kit Carson Creek), and this transport will load both the wetland and the Reservoir with dissolved and particulate nutrients. Concentration data for Santa Ysabel are limited, but total loads could be estimated as part of the current dry and wet weather WSS/Public Utilities sampling program. Loads specific to a source/land use (i.e., non-point sources, MS4, and open space) could not be determined with data currently available. Kit Carson Creek does have additional data available; however, these data are also insufficient to calculate specific source/land use loads from the upstream portion of the Subwatershed. Therefore, as previously recommended, concurrent tributary, MS4, and Reservoir monitoring programs would provide the information needed to ascertain nutrient loads to sources/land uses.

Preliminary estimates of phosphorus loads for the upstream tributaries to the Reservoir are much greater than those estimated for direct tributaries during high Reservoir periods. Phosphorus loads are often dominated by sediment-bound fractions, and hypothetically, the upstream tributaries, specifically Santa Ysabel, might transport a substantial amount of sediment to the Reservoir during the high Reservoir condition. This sediment load can consist of soils naturally elevated in phosphorus. The nitrogen comparison among sources suggests that anthropogenic sources may dominate. This finding could explain the similar high Reservoir condition nitrogen loads between upstream and direct tributaries, even though the upstream discharge and drainage areas are substantially larger. It is important to remember that these conclusions are hypothetical; additional data would be needed to test these hypotheses and better fill these gaps.

Tributary Monitoring Locations

Spatially, most of the tributary sampling locations are concentrated in the western part of the Subwatershed, with most of them located at the confluence of direct tributaries with the Reservoir (Figure 4-1). Additional monitoring locations upstream of these confluence points may be added to target specific land uses and/or geologic conditions. Additional monitoring locations are recommended for the central and eastern portions of the Subwatershed, which primarily encompass the upstream tributaries to the Reservoir. Final monitoring locations will be determined upon program implementation.

At a minimum, dry and wet weather monitoring locations should be added to the confluence of major tributaries to Santa Ysabel Creek in this upstream area. Although the drainage areas of these major tributaries are large and still consist of multiple land uses, nutrient loads could still be attributed to the predominant land use in each drainage area because most of these land uses are similar in their potential to export nutrients (i.e., open space, parks, federal-/state-owned land, etc. – Figure 1-1). If finer spatial resolution is required or preferred, attempts would be made to isolate individual or similar land uses when implementing these additional stream monitoring locations. Furthermore, grab samples and non-continuous data collection can provide only minimal information for model development and calibration; therefore, continuous flow monitoring with composite sampling is recommended for consideration during program implementation.

4.2 MS4 Data Gaps and Recommended Activities

The historical data collected in the Subwatershed as part of the dry and wet weather MS4 monitoring programs do characterize discharges from the MS4, as intended, and can be utilized in model development and calibration efforts. However, during the conceptual model and nutrient budget development, some temporal and spatial monitoring data gaps were identified.

The temporal monitoring data gaps identified for the MS4 were the monitoring frequency and the disassociation with other monitoring programs in the tributaries and Reservoir. Similar to the tributaries, it is recommended to continuously monitor dry and wet weather flows and increase dry weather water quality sampling frequency for the MS4 to monthly for approximately three years (final duration and frequency for monitoring will be determined upon program implementation). Additionally, targeting both small and large storm events for wet weather water quality sampling is recommended. Because historical sampling has not occurred during the same monitoring events (wet weather) or timeframe (dry weather) throughout the tributaries, MS4, and Reservoir, it is difficult to calibrate a watershed model based on non-coupled data throughout the system. Therefore, additional wet and dry weather sampling of water quality and associated flow volumes in the MS4 that coincides with the sampling occurring in the tributary and Reservoir is recommended.

The current and historical MS4 monitoring locations for existing programs are shown in Figure 4-1. Additional MS4 wet and dry weather sampling locations will likely be recommended to support model development. These sampling locations should be strategically selected to target different land uses and geologic conditions to characterize nutrient loading from these different sources. A monitoring program, including the locations and number of monitoring sites needed, would be designed on the basis of power analyses of existing MS4 wet and dry weather data for key constituents (nutrients and sediment) and projected budgetary constraints.

4.3 Wetland Data Gaps and Recommended Activities

Santa Ysabel Creek and Kit Carson Creek are the main upstream tributaries affected by the wetland just upstream of the Reservoir during low Reservoir conditions[6], and their confluence is not distinct within the wetland system. As discussed previously, the tributary loads from these upstream areas to the Reservoir are likely to be small or non-existent, at least surficially; however, even small storms might generate loading from these tributaries to the wetland. The wetland might receive loads from the upstream watershed intermittently (small storms) and during high Reservoir condition loading. These nutrients continue to be processed and might move through the wetland ecosystem during the low Reservoir condition (e.g., during the decline in flows from high to low Reservoir conditions when shallow flows are still intact). Although most studies find stable wetlands to be a sink for nutrients (Kadlec and Wallace, 2008), this low Reservoir condition does provide an opportunity for the wetland to export nutrients to the Reservoir via shallow subsurface flow.

To understand the connection of the upstream portion of the Subwatershed to the Reservoir, it is important to study the kinetics of the wetland ecosystem. Knowledge of the water and nutrient budgets during both Reservoir conditions would allow modeling and management decisions to be made and would require an understanding of the nutrient and sediment loading to the wetland and the extent of nutrient transformations within this system.

Surface water monitoring stations are recommended at the far upstream and downstream extents, where site conditions allow. These surface water stations will help to estimate the nutrient budget of this system. This surface water sampling within the wetland will be opportunistic because, historically, this area is typically not inundated or receives very little flow.

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[6] During high Reservoir conditions, the wetland is inundated. Therefore, Kit Carson Creek and Santa Ysabel Creek both flow directly to the Reservoir and do not converge with the wetland

4.4 Reservoir Data Gaps and Recommended Activities

Independent of this Study Plan, Public Utilities has been considering and implementing best management practices (BMPs) to improve water quality in the Reservoir and to reduce nutrient loading (e.g., treatment wetlands, Reservoir hypolimnetic oxygen system, and mid-lake vigorous epilimnetic mixing). These BMPs will all have effectiveness monitoring plans in place for the time period after implementation. The goal of these monitoring plans is primarily to measure the effectiveness of reducing the nutrients in the Reservoir. Furthermore, a three-dimensional (3-D) modeling effort for the Reservoir is currently underway by Public Utilities to determine the nutrient cycling and internal loading of the Reservoir. Future Subwatershed modeling efforts will be coordinated with Reservoir modeling efforts by Public Utilities, to the extent possible, to provide a comprehensive and cohesive picture of the nutrient loads from the Subwatershed to the tributaries that enter and cycle within the Reservoir.

These ongoing and future efforts led by Public Utilities are independent of this Study Plan, which was intended to discuss only the nutrient loadings of the Subwatershed. The minimal water quality monitoring activities recommended for the Reservoir in this Study Plan are intended to provide the final link in the coupled monitoring throughout the system, but are not intended for use in Reservoir model development.

Water column concentration data within the Reservoir are abundant, but it is difficult to translate these water column concentrations to internal loads. Independent future development of a 3-D Reservoir model by Public Utilities will help provide a better understanding of internal loading. This 3-D modeling effort could be improved with fine spatial resolution mapping of sediment quality and seasonal oxygen content of the water column (oxic, suboxic, hypoxic) for the Reservoir, which can help in estimating the potential nutrient fluxes of in-Reservoir sediments.

A focus on eutrophication indicators that can be predicted by the 3-D model and also link to beneficial uses is recommended. These indicators could include, but are not limited to, MUN (cyanotoxins, trihalomethanes), REC-2 (turbidity), and aquatic life-related beneficial uses (chlorophyll-a, cyanobacterial abundance, dissolved oxygen, and pH). Risk of cyanotoxic blooms could also be modeled empirically as a function of increasing chlorophyll-a. A data gap analysis quantifying the status of data sets composed of the indicators mentioned previously and biostimulatory conditions (temperature, subsurface photo-actively available radiation, seasonal stratification, etc.) is recommended.

The Subwatershed wet weather monitoring program can be improved with a within-Reservoir program to document the amount of particulate nutrient and organic matter deposited after each wet weather event with a short-lived radioisotope (e.g., Beryllium-7) to allow validation of the delivered load to the Reservoir.

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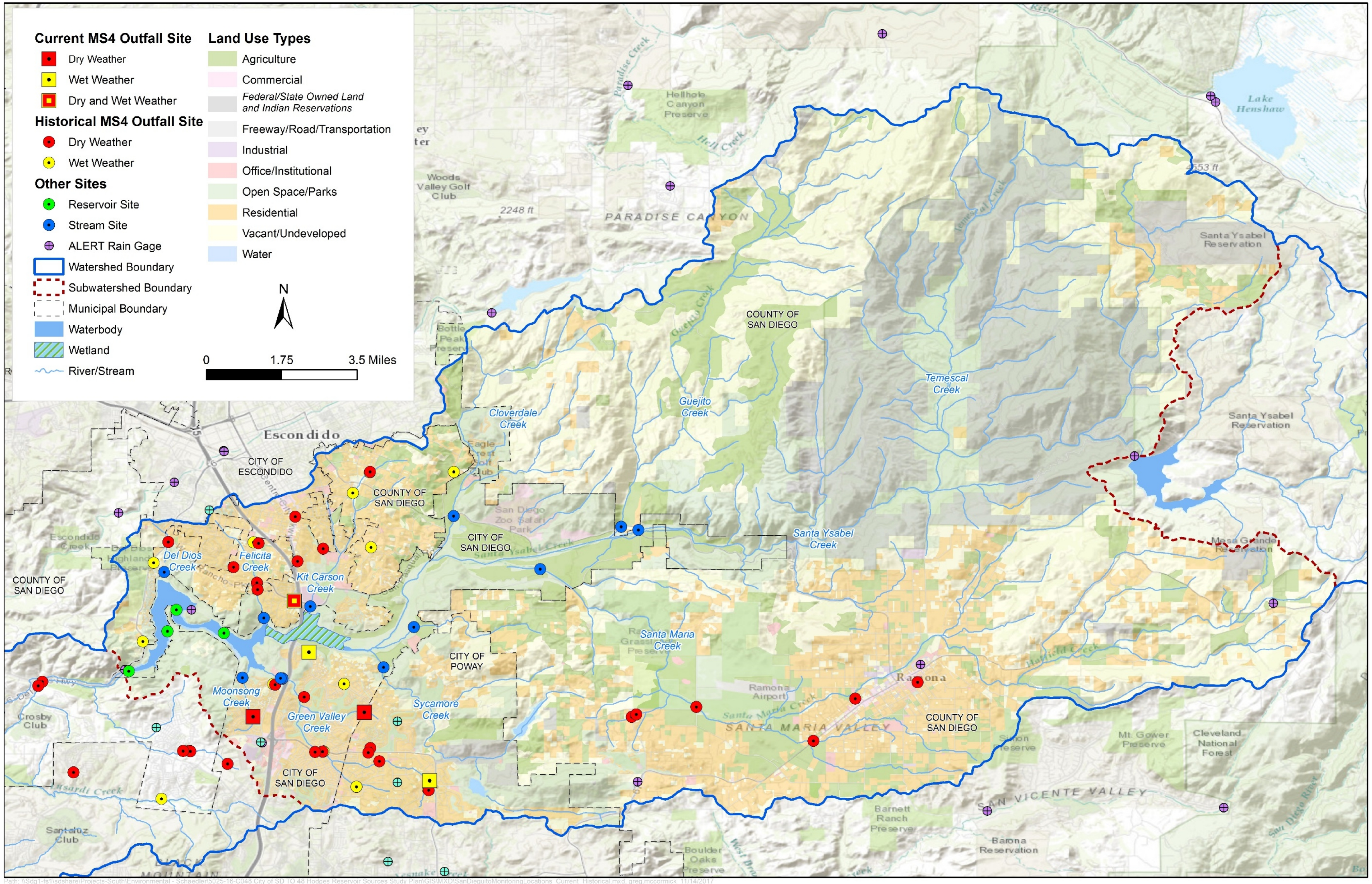

Figure 4-1. Current and Historical Hodges Tributary, MS4, and Reservoir Monitoring Locations

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4.5 Other Data Gaps and Recommended Activities

Other non-tributary direct inputs to the Reservoir include atmospheric sources, exchange from Olivenhain Reservoir, and groundwater:

- **Atmospheric inputs**. While potentially minor, atmospheric inputs have not been measured or studied specifically for the Subwatershed. Directly estimating aerial loading of pollutants is challenging and would typically take many years to determine a somewhat accurate estimate for the Reservoir and Subwatershed. However, several regional dry and wet aerial deposition estimates for nitrogen and phosphorus for the southern California region have been determined through multiple studies and can be used in lieu of direct measurements.

- **Olivenhain Reservoir.** The water that Olivenhain Reservoir receives from the aqueduct system is exchanged bidirectionally between the Olivenhain and Hodges Reservoirs. The planned three-dimensional modeling effort of Hodges Reservoir, along with endpoint average concentrations and flow volumes, could be used to estimate net transport of nutrients.

- **Groundwater loads.** Regional groundwater chemistry and water budgets from previous studies' monitoring data may be able to estimate nutrient loads to the Reservoir. If this quantification is not possible, groundwater fluxes into the Reservoir could be estimated seasonally using flux chambers and Radon-222 isotopes. This contribution is not expected to be large, based on previous studies (City of San Diego, 2014a).

- **Rainfall data**. The existing SWMM that was developed for the San Pasqual Basin (within the Subwatershed) highlighted rainfall data as a data gap for modeling purposes (City of San Diego, 2015a). Rainfall gauges that can adequately represent the entire Subwatershed spatially will be critical for developing model estimates of nutrient loading to the Reservoir and using models as a forecasting or decision-making tool. All publicly available rainfall sources (e.g., ALERT, Mesowest, National Oceanic and Atmospheric Administration [NOAA], etc.) will be utilized for future modeling efforts. The closest rain gauge to the point being modeled (e.g., tributary) will be used. In such cases where a large portion of the Subwatershed is to be modeled, it is important to use rainfall data to adequately estimate the rainfall for that entire area – rainfall at the farthest upstream location will likely be different from the rainfall at the farthest downstream location. Spatial averaging techniques (i.e., Thiessen polygon method) of multiple rain gauges are recommended for these instances.

- **Land use and septic system installations.** The current land use information provided through public venues (San Diego Association of Governments [SANDAG]) is relatively coarse, with agriculture being used as a blanket land use value in most of the upper portion of the Subwatershed. Desktop geographic information system (GIS) analyses are recommended to further define some of the "blanket" land uses (e.g., agriculture) so that nutrient loads can be accurately attributed to specific land uses. Septic system installations would also be determined by cross-referencing residential land uses with the existing water, storm water and sewer infrastructure. The “holes” of infrastructure within residential areas will provide an adequate estimate of nutrient sources from septic systems within the Subwatershed.

5 Conclusions

This evaluation includes development of a conceptual model of nutrient sources to and within the Reservoir. The conceptual model highlights data gaps in existing and ongoing monitoring efforts within the Reservoir and the various input pathways throughout the Subwatershed. Public Utilities has current and future projects focusing on within-Reservoir modeling and monitoring; therefore, this Study Plan primarily focuses on the monitoring recommendations to develop a model for the Subwatershed, which would link with the independently developed Reservoir model. The objectives of this Study Plan are as follows:

- Summarize the previous and ongoing studies and management efforts to characterize nutrients in the Reservoir and its contributing drainage area;
- Develop a conceptual model that fully characterizes nutrient sources and pathways to and within the Reservoir;
- Use the conceptual model and previous and ongoing monitoring efforts to identify data gaps in the characterization of nutrient sources; and
- Provide recommendations for future monitoring and activities to fill these data gaps and data needed to refine existing and future Subwatershed models.

Available data and documents were compiled and reviewed, with a focus on nutrient loading from the Subwatershed to the Reservoir. The literature search and data review yielded information to help identify key pathways and potential sources of nutrient loads to the Reservoir, as well as critical data gaps.

The Conceptual Model assumes the major sources of nutrient loads into the Reservoir are the tributaries (direct and upstream tributaries). The upstream tributaries must first flow through a wetland prior to entering the Reservoir. Nutrient loads may be attenuated in this wetland, depending on tributary flow conditions and Reservoir water level: the low and high Reservoir conditions. Therefore, the nutrient conceptual model for Hodges Reservoir was split into these two conditions.

During the low Reservoir condition, it is assumed that nutrient loads from upstream tributaries are largely attenuated in the wetland, and internal loads in the Reservoir and direct tributary loads likely dominate the nutrient budget. During the high Reservoir condition, upstream tributaries likely provide the largest portion of the total load and reload the Reservoir with nutrients, which proceed to cycle between the sediment and water column via internal loading during the subsequent low Reservoir conditions.

Table 5-1 summarizes the previous studies discussed in this Study Plan, highlights key findings, and notes some of the data impacts and/or gaps found through review of existing documents. Monitoring recommendations are summarized in Section 4 and will be detailed in a future Monitoring Plan and QAPP to be developed for this program. The Copermittees are committed to an open and transparent process, which would include all potentially affected stakeholders, the Regional Board, and interested members of the public. The process for developing work plans, model reports, and recommendations for the Reservoir and the Subwatershed will likely include a stakeholder advisory group as well as a technical advisory group with periodic public workshops for public input into the process.

Although this version of the Study Plan is designated as final, it is subject to future revisions based on future water quality or hydrologic information, potential BMP implementation results, regulatory, stakeholder, or public input, or other potential factors that are not available for consideration at the time of this document preparation.

Table 5-1. Hodges Reservoir Study Plan Findings and Data Gap Summary

Study Title[a]	Key Findings Related to Hodges Reservoir Nutrient Impairments (Section 2)	Data Impacts or Gaps and Recommended Activities (Section 4)
2.1 San Pasqual Valley Groundwater Basin Salt and Nutrient Management Plan	• Largest nitrogen source is attributed to agricultural activities • Lateral groundwater movement through aquifer occurs over multiple decades • Nitrate mass flux from Basin to Reservoir could increase up to 20% over next 50 years ○ Because of long transit time, impacts from previous and recent activities may be observed in the coming decades – results of future management actions may not be observed for many decades.	• The long time scale for groundwater movement poses many challenges for implementing and assessing future management actions. • Outcomes from future management efforts will largely be modeled. • Modeling is limited to upstream of the Reservoir, east of Interstate 15. Modeling might need to include areas directly adjacent to the Reservoir to determine the groundwater gradient.
2.2 Lake Hodges Reservoir Water Quality Assessment Study, Final Conceptual Planning Report and Related Studies	• In-Reservoir management recommendations were developed; three key BMP projects were selected by the City of San Diego (with staggered implementation based on effectiveness): ○ Reservoir HOS ○ Combined Constructed Wetland ○ Mid-Lake VEM • This study had multiple related studies under the program umbrella. Three of those are discussed in table entries 2.2.1, 2.2.2, and 2.2.3.	• Further assessment of Reservoir nutrient cycling (beyond routine Public Utilities monitoring) is not recommended until BMP implementation is complete. • BMP implementation includes an effectiveness assessment once construction is complete – at that time results will be incorporated into this program and any potential remaining data gaps will be assessed. • VEM implementation is contingent upon effectiveness assessment results from the HOS and Combined Constructed Wetland BMPs.

Table 5-1. Hodges Reservoir Study Plan Findings and Data Gap Summary (continued)

Study Title[a]	Key Findings Related to Hodges Reservoir Nutrient Impairments (Section 2)	Data Impacts or Gaps and Recommended Activities (Section 4)
2.2.1 Hodges Reservoir Watershed Natural Treatment System Implementation Action Plan	• Modeling determined that during above-average water years, most nutrient loadings were from agricultural areas via Santa Ysabel Creek. • Modeling determined that during below-average water years, Santa Ysabel Creek does not flow to the Reservoir; thus, most nutrient loadings were attributed to urban sources. • The Combined Constructed Wetland approach was considered to be the most cost-effective of the NTS options (Public Utilities selected installation at Green Valley Creek) included in recommendations from the study by Brown and Caldwell.	The study recommended the following: • Water quality monitoring in Santa Ysabel downstream of agricultural operations. • Del Dios septic system surface and groundwater monitoring. • Assessment of the duration and frequency of wetland inundation during above-average water years (i.e., direct connection between Santa Ysabel Creek and the Reservoir). • Assessment of multiple nutrient processing and hydrologic characteristics of the natural wetland exposed during below-average water years. • Further assessment of Reservoir nutrient cycling (beyond routine Public Utilities monitoring) is not recommended until BMP implementation is complete.
2.2.2 Lake Hodges Reservoir Sediment Oxygen Demand Study	• The study found relatively high SOD and WOD for California reservoirs.	• Further assessment of Reservoir nutrient cycling (beyond routine Public Utilities monitoring) is not recommended until BMP implementation is complete.

Table 5-1. Hodges Reservoir Study Plan Findings and Data Gap Summary (continued)

Study Title[a]	Key Findings Related to Hodges Reservoir Nutrient Impairments (Section 2)	Data Impacts or Gaps and Recommended Activities (Section 4)
2.2.3 Lake Hodges Reservoir Sediment Flux Study	• Anoxic and oxic conditions in Reservoir bottom water were assessed. • Oxic conditions mimicked that of the proposed HOS included in recommendations from the study by Brown and Caldwell.	• Further assessment of Reservoir nutrient cycling (beyond routine Public Utilities monitoring) is not recommended until BMP implementation is complete.
2.3 San Dieguito Hydrologic Investigation	• A SWMM was developed to characterize nutrient loads to the Reservoir during wet weather events from the Subwatershed.	• Calibration results highlighted the importance of rainfall data throughout the Subwatershed. • The investigation recommended that additional rainfall gauges be deployed. • Results indicated that the model generally underestimates flows at the tail end of the storm hydrograph. • Results might indicate a need for a more dynamic model for the Subwatershed – SWMM is more appropriate for primarily impervious, urban areas, whereas other models such as LPSC are able to adequately model nutrient sources from multiple land uses. This Subwatershed model will be directly incorporated/linked with the three-dimensional in-Reservoir model once developed.

Table 5-1. Hodges Reservoir Study Plan Findings and Data Gap Summary (continued)

Study Title[a]	Key Findings Related to Hodges Reservoir Nutrient Impairments (Section 2)	Data Impacts or Gaps and Recommended Activities (Section 4)
2.4 Hodges Reservoir Nutrient Evaluation Technical Memorandum	• Reservoir and MS4 water quality data collected from the Reservoir and the Subwatershed from 2008 through 2016 were summarized • The N:P in the Reservoir exceeded WQOs between 2007 and 2016. • Mean TP concentrations exceeded the WQOs in all years and all strata. • Mean TP and TN values in the MS4 generally exceeded mean values in the Reservoir. • No correlation of TP or TN was found between the Reservoir and MS4.	• TP analysis requires a lower laboratory detection limit because the MDL is higher than the WQO. • Monitoring coupled events in the MS4, tributaries, and Reservoir might provide an improved assessment of relationships between each part of the system and provide important, coupled data for use in model development and calibration.
2.5 Watershed Sanitary Survey Monitoring	• The 2015 WSS indicated that mean TN values in both contributing streams and in the Reservoir did decrease significantly since the 2010 WSS.	• A GIS survey was recommended to provide a better understanding of septic system use in adjacent residential locations to the Reservoir.

Table 5-1. Hodges Reservoir Study Plan Findings and Data Gap Summary (continued)

Study Title[a]	Key Findings Related to Hodges Reservoir Nutrient Impairments (Section 2)	Data Impacts or Gaps and Recommended Activities (Section 4)
2.6. 2007 and 2013 MS4 Permit Outfall and Receiving Water Monitoring	• Data collection was relatively infrequent. • Up to one wet weather event was monitored per year. • Up to three dry weather events were monitored per year. • Nutrient concentrations in outfalls were found to be elevated. • A correlation with tributary or Reservoir concentrations was not definitive.	• Coordinated monitoring events for outfalls, tributaries, and the Reservoir will allow for more direct comparisons among locations. • An increased number of monitoring events per year will increase statistical power for analysis. • Increased concentration and load data will assist in model development and calibration.

Notes:

a. Study number corresponds to section number in this plan where discussed.

% = percent; BMP = best management practice; GIS = geographic information system; HOS = Hypolimnetic Oxygenation System; MDL = method detection limit; MS4 = municipal separate storm sewer system; N:P = nitrogen-to-phosphorus ratio; NTS = Natural Treatment System; SOD = sediment oxygen demand; SWMM = Storm Water Management Model; TN = total nitrogen; TP = total phosphorus; VEM = Vigorous Epilimnetic Mixing; WOD = water column oxygen demand; WQO = water quality objective; WSS = Watershed Sanitary Survey

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Appendix A:

Hodges Reservoir – Nutrient Loading Conceptual Model

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TETRA TECH

FINAL TECHNICAL MEMO

To:	Jeffery Pasek, Andre Sonksen, and Andrew Funk, City of San Diego
Cc:	
From:	Tetra Tech, Inc.
Date:	March 17, 2017; *April 14, 2017 Revised; October 30, 2017 Revised; November 14, 2017 Revised*
Subject:	Hodges Reservoir - Nutrient Loading Conceptual Model

1.0 INTRODUCTION

This technical memorandum summarizes a conceptual model for nutrient transport in the Hodges Reservoir[1] Watershed and within the reservoir for the City of San Diego. Development of the conceptual model included the following steps: 1) major sources and controls of nutrient loads (pathways) into Hodges Reservoir were identified, 2) information regarding those pathways was collected or estimated, and 3) data gaps especially for the critical pathways were identified. Outcomes of this study will be used to develop an associated study plan to address data gaps and strengthen existing information and understanding of nutrient loading to Hodges Reservoir. The goal of the study plan and the conceptual model is to provide the necessary steps to ultimately develop a functional model of the complete system from the watershed, including its internal drainage pathways (e.g., tributaries, Municipal Separate Storm Sewer System [MS4], etc.) to the reservoir.

The memorandum includes:

- Background on nutrient issues in the reservoir
- Literature search and data review to support identification of potential nutrient sources and pathways in the Hodges Reservoir Watershed
- Conceptual model for nutrient transport within the Hodges Reservoir Watershed including conceptual model diagrams
- Nutrient budget based on the conceptual model to highlight important loads and data gaps, which includes preliminary estimates of the relative contribution of nutrient loads from different pathways based on existing data

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[1] Also referenced as Lake Hodges in certain documents

2.0 BACKGROUND

Hodges Reservoir was created with the construction of Hodges Dam on San Dieguito River in 1918. The dam and reservoir were purchased by the City of San Diego in 1925 and are currently operated and maintained by the City of San Diego. When full, the reservoir has a surface area of 1,234 acres, a maximum water depth of 115 feet (315 feet above mean sea level [AMSL]; Figure 1) and 27 shoreline miles. Water level is maintained no lower than 290 AMSL for daily pumping to Olivenhain Reservoir. When full, Hodges Reservoir has a water storage capacity of 30,251 acre-feet. The reservoir is located in the San Dieguito River Watershed in San Diego County, California (Figure 2) and has a 248 square mile watershed, excluding the area above Sutherland Reservoir (Figure 3). Sutherland Reservoir, which is located upstream of Hodges Reservoir, does not release water downstream and is, therefore, hydrologically disconnected from the Hodges Reservoir (Project Clean Water 2017; Figure 3). Hodges Reservoir currently serves the San Dieguito Water District, Santa Fe Irrigation District and the City of San Diego (City of San Diego 2017).

Jurisdictions in the upstream catchment to the reservoir include the cities of San Diego, Escondido, and Poway, Unincorporated San Diego County, two tribal governments (Santa Ysabel and Mesa Grande Reservations), and the Cleveland National Forest (Figure 4). Tributaries that directly discharge to the reservoir include Del Dios Creek, Felicita Creek, Moonsong Creek, and Green Valley Creek. Tributaries that discharge from directly upstream of the reservoir include Kit Carson Creek and Santa Ysabel Creek[2]. Sycamore Creek, Cloverdale Creek, Santa Maria Creek, Guejito Creek, and Temescal Creek are some of the major tributaries to Santa Ysabel Creek (Figure 5).

Hodges Reservoir has several water quality challenges including algal productivity and eutrophication (Figure 6). Specific water quality impairments include exceedances in color, manganese, mercury, nitrogen, phosphorus, turbidity, and pH according to 2010 Section 303(d) list (City of San Diego et al. 2015). Nutrients and low dissolved oxygen in the reservoir limit the use of the water supply and increase the cost for treatment (City of San Diego et al. 2015). Tributaries to the reservoir are also impaired; San Dieguito River is impaired for fecal indicator bacteria, nitrogen, phosphorus, total dissolved solids, and toxicity in the 19-mile reach above the reservoir, Green Valley Creek is impaired for sulfates, chloride, manganese, and pentachlorophenol (PCP), Kit Carson Creek is impaired for total dissolved solids (TDS), and PCP, and Felicita Creek is impaired for TDS and aluminum (City of San Diego et al. 2015). The 2014 and 2016 Integrated Report Section 303(d) list added Green Valley Creek impaired for benthic community effects, bifenthrin, chlorpyrifos, and nitrogen, and San Dieguito River impaired for benthic community effects. All things considered, nutrient loading (forms of nitrogen and phosphorus) is most significant water quality problem for Hodges Reservoir (J. Pasek, City of San Diego, personal communication).

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[2] Santa Ysabel is the main stem of the river which flows to the reservoir and also referred to as San Dieguito River (e.g., San Dieguito River Watershed Management Area [WMA] Water Quality Improvement Plan [WQIP]). The Santa Ysabel Creek becomes the San Dieguito River at the confluence of Santa Ysabel and Santa Maria Creeks.

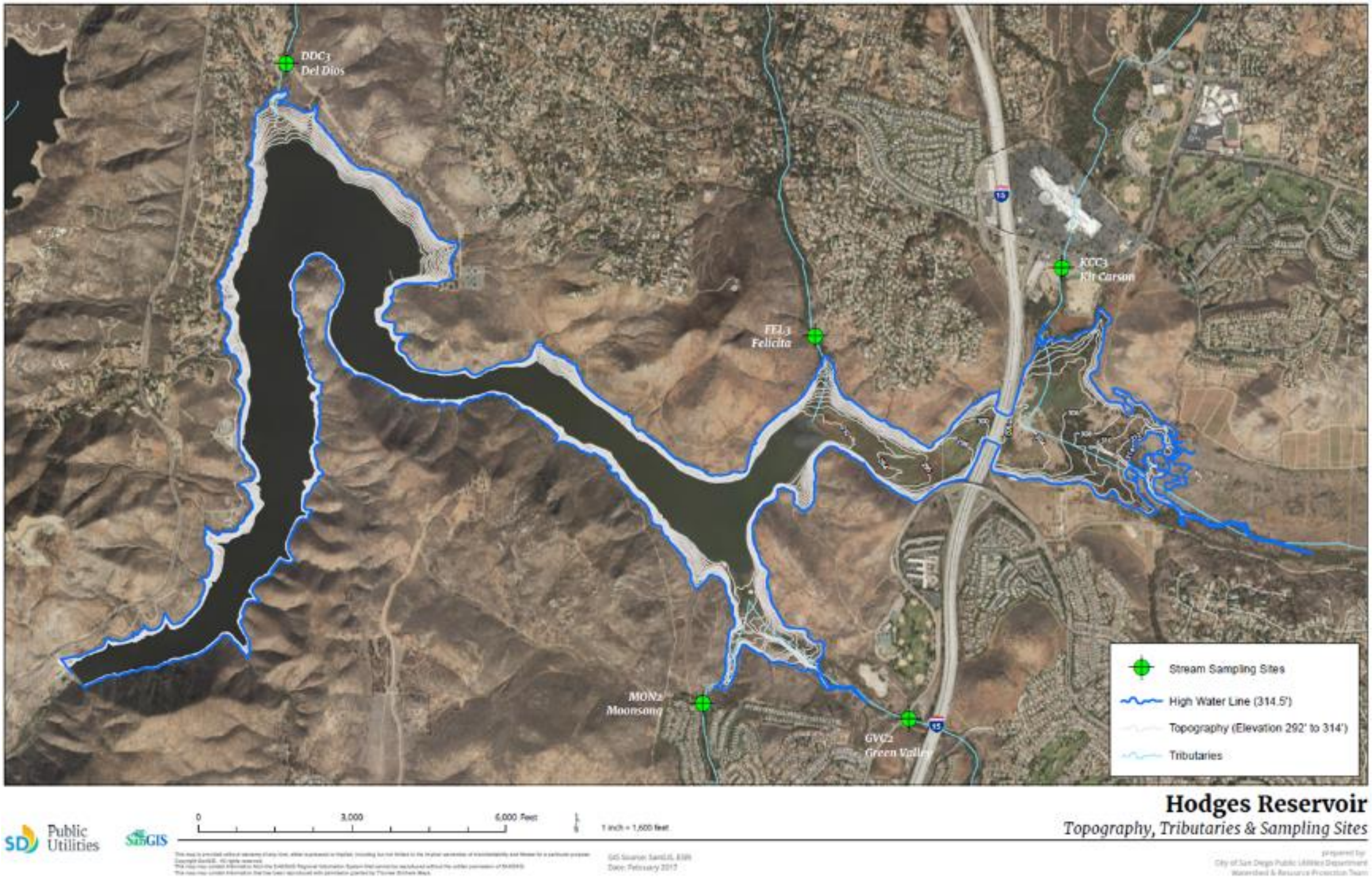
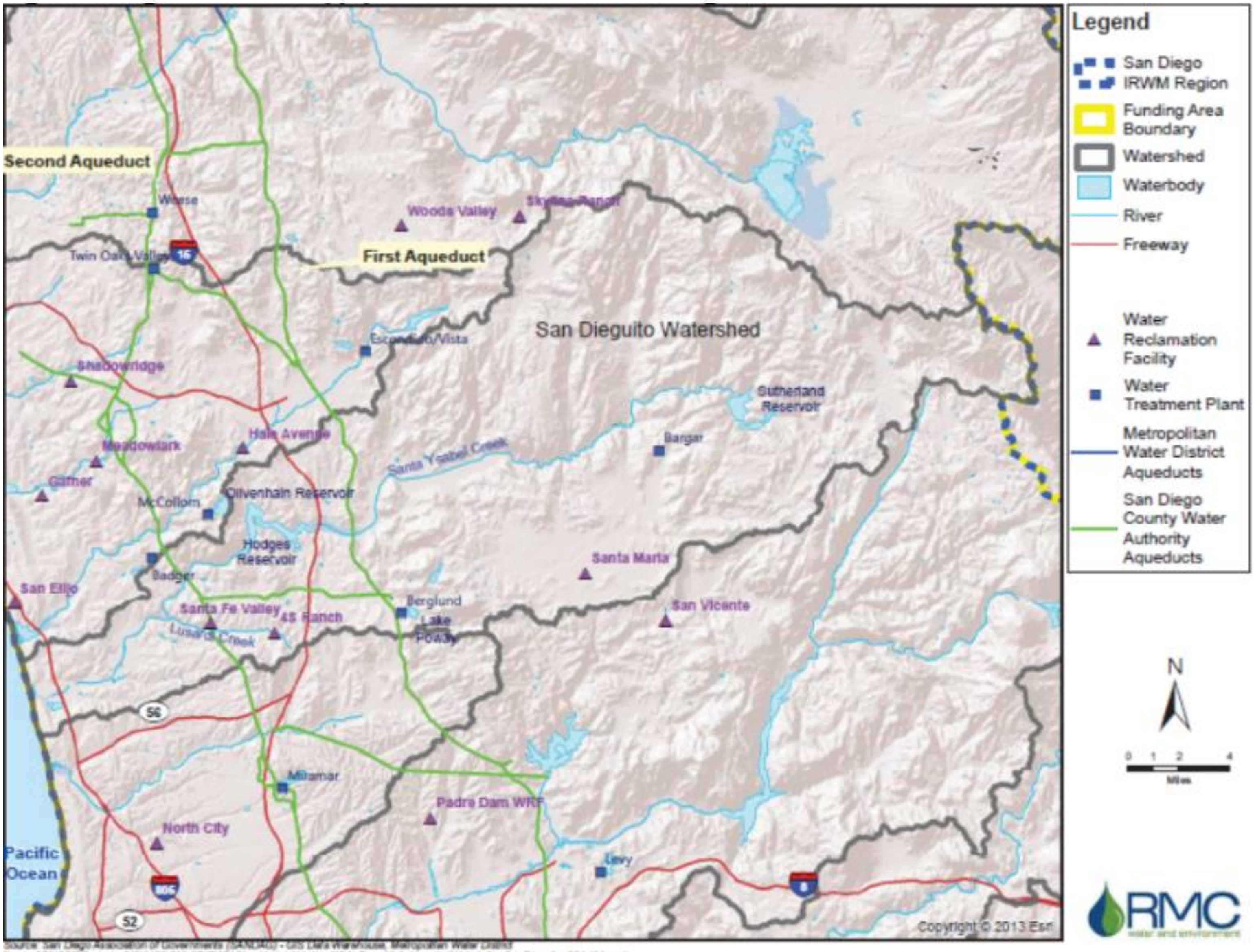


Figure 1. Topography of Hodges Reservoir; source, City of San Diego



Source: San Diego Association of Governments (SANDAG) - GIS Data Warehouse, Metropolitan Water District
\\rmcsd\RMCSD\Projects GIS\0188-003 SDIRWM Plan Update\HodgesWhitePaper\3-3_ImportedWaterInfra_SanDieguito_23Jul14.mxd

Figure 2. San Dieguito River Watershed; source, Figure 2 of SDIRWM 2014

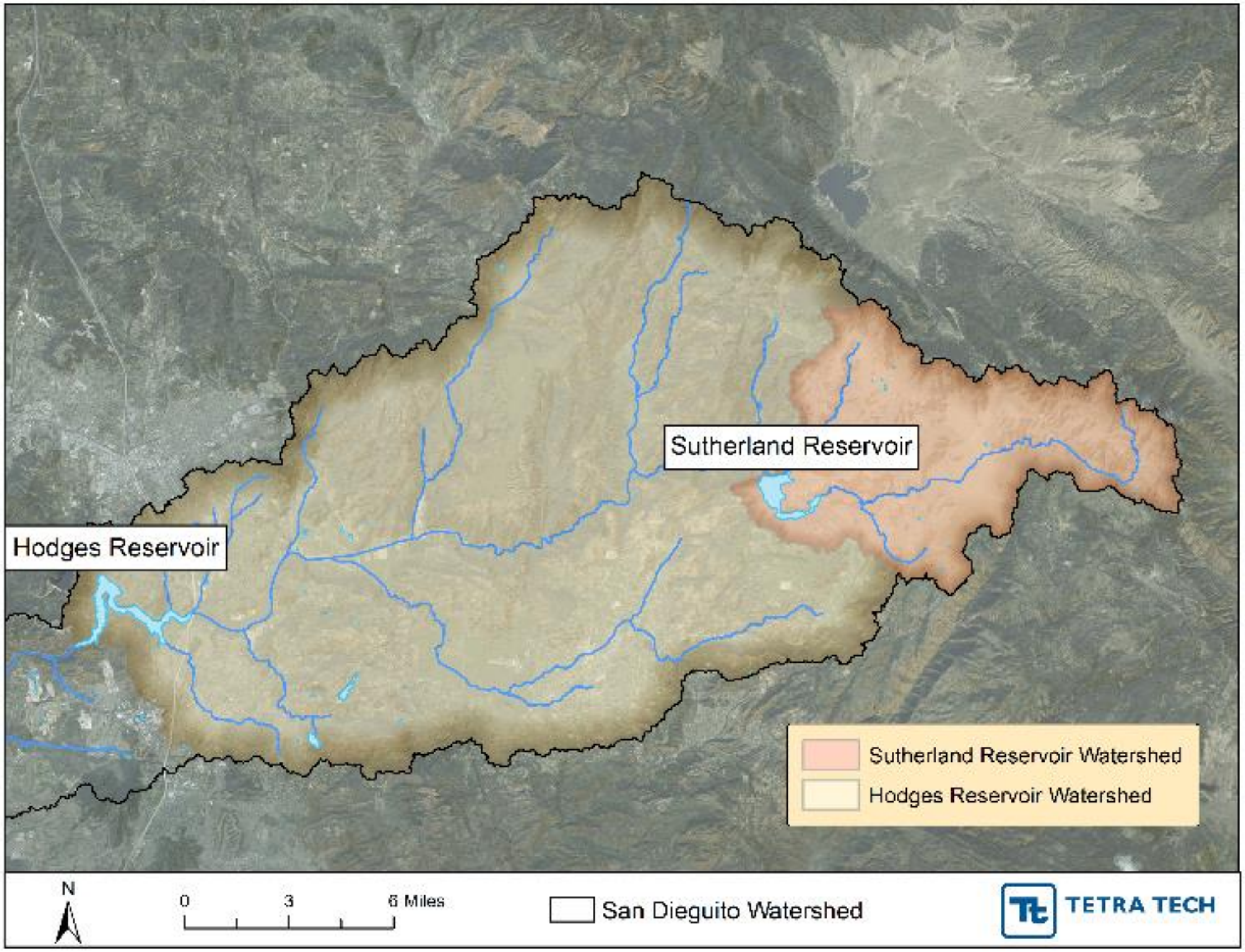


Figure 3. Hodges Reservoir watershed

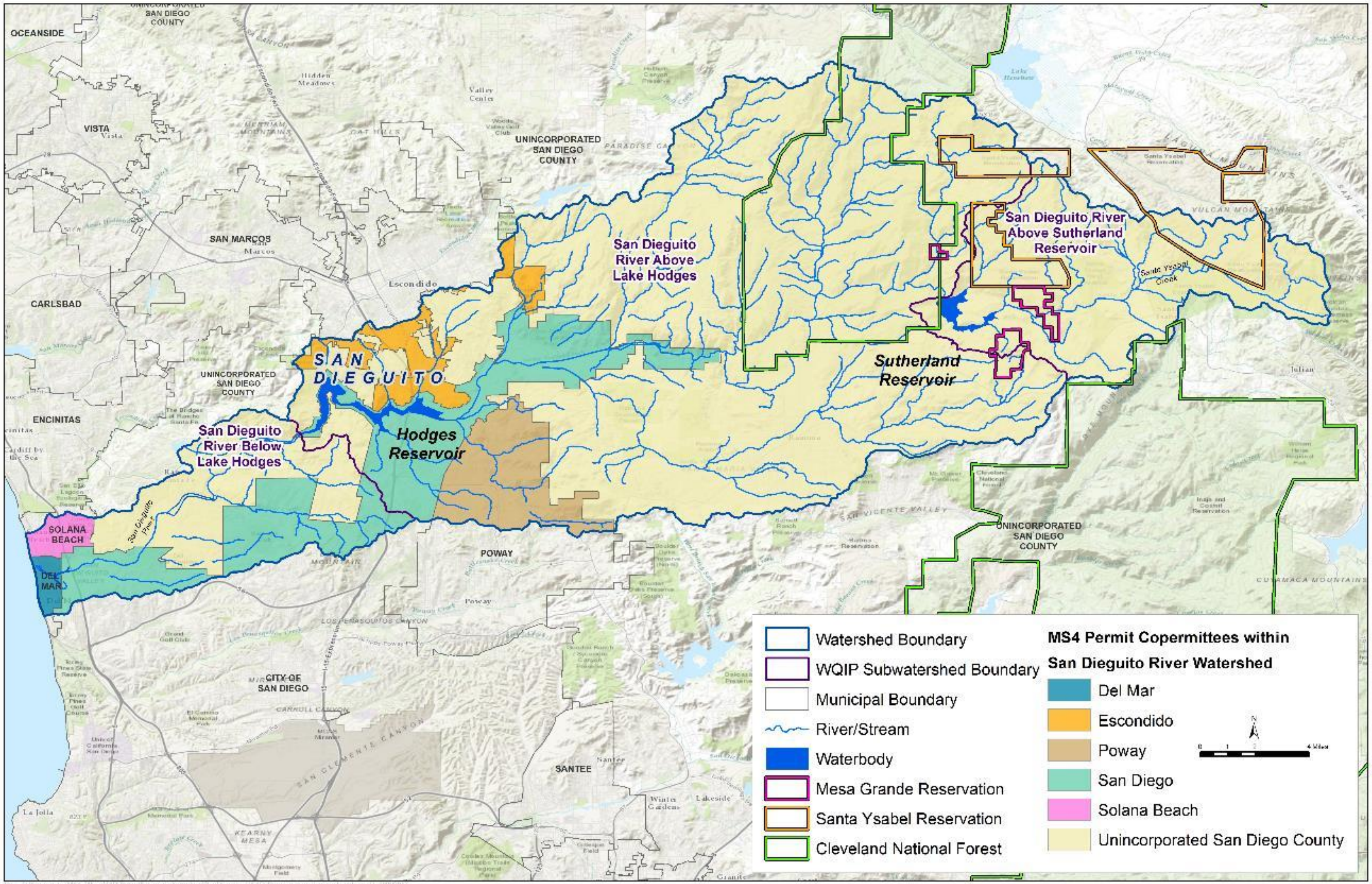


Figure 4. Jurisdictions in San Dieguito River Watershed; source, Figure B-1 of San Dieguito River WMA WQIP

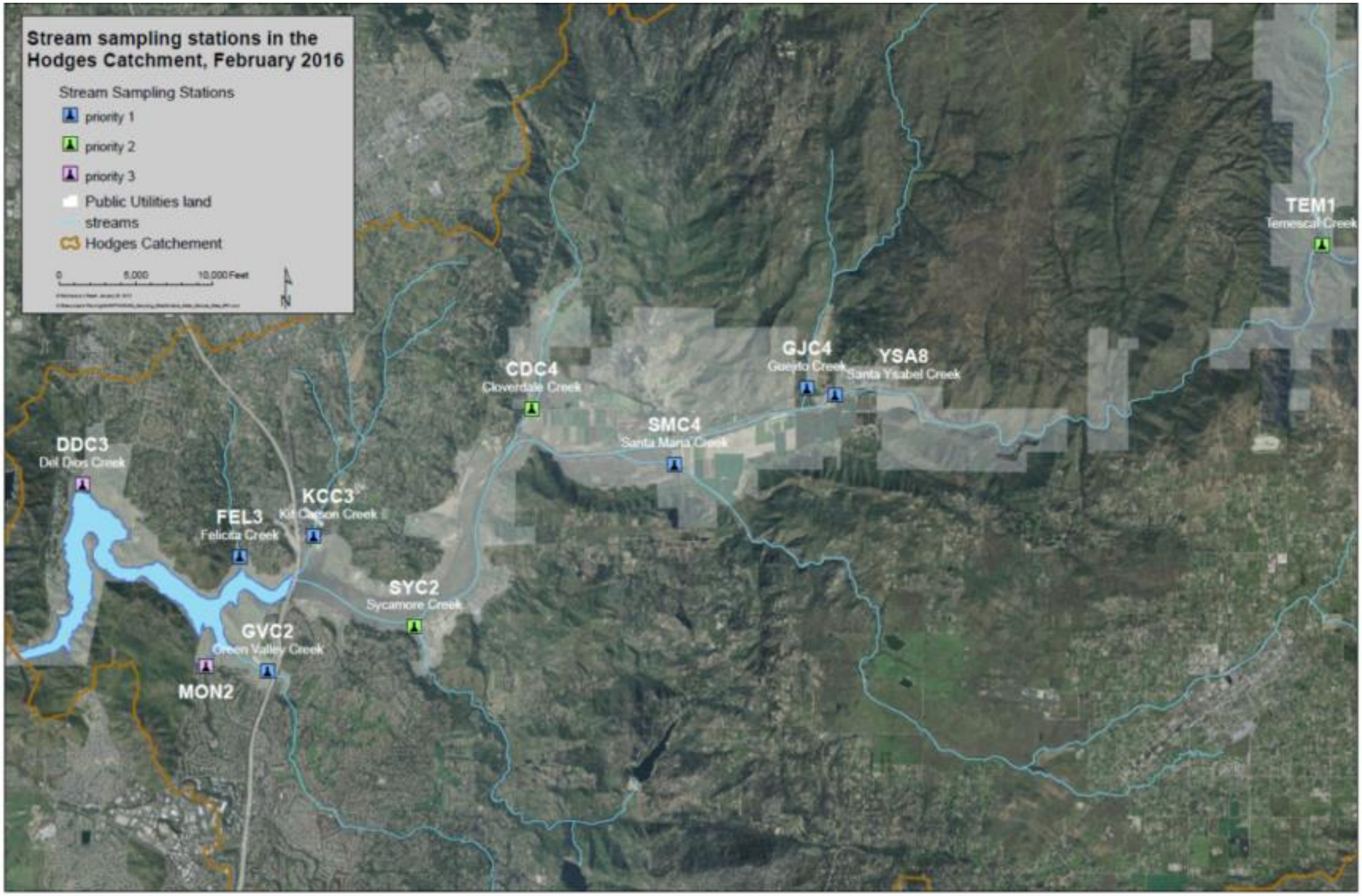


Figure 5. Tributaries to Hodges Reservoir; Source, City of San Diego

Figure 6. Algal bloom in Hodges Reservoir; source, Figure 2-1 of Brown and Caldwell 2014

3.0 LITERATURE SEARCH AND DATA REVIEW

A literature review was conducted to identify data on major nutrient sources, pathways, and loadings to Hodges Reservoir. Various documents and datasets including the documents and data provided by the City of San Diego were compiled and reviewed. An inventory of the data and the documents reviewed is presented in Table 1. A note column in Table 1 describes the types of data/information included in each of the references.

Table 1. Inventory for Hodges Reservoir Data and Documents

Ref. No.	File Name	File Type	Notes	Source
1	Attachment 1_Compendium_Compiled _FINAL	pdf	IRWMP - Compendium of Water Resource Initiatives in the Hodges Catchment	City of San Diego
2	Attachment 2_Draft Hodges Reservoir Oxygen Study 05-12-15	pdf	Sediment oxygen demand study by Dr. Beutel	
3	Attachment 3_Lake Hodges Chamber Flux Draft Report Aug 14 2015	pdf	Sediment flux study in the reservoir by Dr. Beutel: The study indicated input of phosphate and dissolved organic carbon from sediment.	
4	Attachment 4_ SanDieguito_WetWeather Sampling	pdf	Wet weather sampling plan	
5	Attachment 5_Draft Mercury Sampling Plan	pdf	Sampling plan at 4 stations (Ref. No. 6)	
6	Hodges Reservoir Monitoring Stations	pdf	Figure 1. Hodges Reservoir monitoring stations (A - D) for Sediment Study	
7-1	HODGES_CATCHMENT_ FIELD	Excel	Field measurements from stream stations in the Hodges watershed 2002-2015: stream depth, width, flow (2002-2015), temperature, etc. (approximately monthly data are available).	
7-2	Stream sample sites, Hodges Catchment 021716	pdf	Figure for stream sampling sites	
8	HODGES_CATCHMENT_ NUTRIENTS	Excel	Nutrient data from stream stations in the Hodges and Sutherland watersheds 1992-2011: The availability of data varies considerably among the stations (approximately monthly data are available).	
9	HODGES_RESERVOIR_F IELD	Excel	Field measurements (depth, temperature, pH, specific conductivity, dissolved oxygen, oxidation reduction potential, chlorophyll, Blue Green algae,	

Ref. No.	File Name	File Type	Notes	Source
			total dissolved solids) from stations in the reservoir during 1980s - 2010s	
10	HODGES_RESERVOIR_NUTRIENTS	Excel	Nutrient concentration data from stations within the reservoir during 1992-2015	
11	I05414_Draft_Lake Hodges WQ Conceptual Planning Report 03 19 2014	pdf	Brown and Caldwell Water Quality Assessment Study in 2014; Appendix F (PDF pp. 107-111) contain nutrient loadings for 2010-2011 Water Year: Above Average Rainfall and 2012-2013 Water Year: Below Average Rainfall	Internet search
12	SDG WMA WQIP	pdf	San Dieguito River WMA WQIP	
13-1	MS4Data_Hodges	Excel	MS4 outfall data for total phosphorus, total nitrogen, and nitrogen-to-phosphorus ratio (N:P) from 2009-2013 (dry weather) and 2009-2016 (wet weather). Beginning with the most recent MS4 permit, only Major MS4 outfalls (outfalls > 36-in in diameter) were sampled. • Total phosphorus 18 dry weather samples and 24 wet weather samples • Total nitrogen: 19 dry weather samples and 22 wet weather samples • N:P: 19 dry weather samples and 23 wet weather samples	Amec Foster Wheeler on Jan 20.2017
13-2	Hodges Mapping Locations	Excel	Latitudes and longitudes for MS4 outfalls (80), stream (14), and reservoir (1) sites in San Dieguito watershed for wet and dry weather; Stations 1-80 are outfalls. Beginning with the most recent MS4 permit, only Major MS4 outfalls (outfalls > 36-in in diameter) were sampled.	
13-3	Final Lake Hodges Nutrient Evaluation Tech Memo_011017	MS Word	Evaluation of nutrient water quality data from MS4 outfall, stream, and reservoir data; the report to summarize 13-1 data.	
14	Final Lake Hodges Nutrient Evaluation Tech Memo_Appendices_011017	MS Word	Appendices	
15-1	Watershed Sanitation Survey 2015	pdf	Water quality data for Hodges reservoir and upstream tributaries Appendix 5.17 and 5.18 https://www.sandiego.gov/water/quality/environment/sanitarysurvey - The data appear to be a part of 8 and 10 datasets.	Links from City of San Diego

Ref. No.	File Name	File Type	Notes	Source
15-2	Watershed Sanitation Survey 2010	pdf	Water quality data for Hodges reservoir and upstream tributaries Appendix 5l and 5m https://www.sandiego.gov/water/quality/environment/sanitarysurvey - The data appear to be a part of 8 and 10 datasets.	
16	2015 Urban Water Management Plan (City SD)	pdf	No flow or water quality data are available https://www.sandiego.gov/sites/default/files/2015_uwmp_report.pdf	
17	San Pasqual Valley, Community Plan and other docs (City SD)	Web page	No flow or water quality data are available https://www.sandiego.gov/planning/community/profiles/sanpasqualvalley/plan	
18-1	Storm Water Plans and Reports (City SD)	pdfs	No flow or water quality data are available https://www.sandiego.gov/stormwater/plansreports	
18-2	San Dieguito River Park (Joint Powers Authority)	Web page	No flow or water quality data are available http://www.sdrp.org/wordpress/	
18-3	Friends of the San Dieguito River Valley	Web page	No flow or water quality data are available http://www.fsdrv.org/	
18-4	San Dieguito River Valley Conservancy	Web page	No flow or water quality data are available http://sandieguitorivervalleyconservancy.org/sdrvc1_home1.html	
19	SanPasqual Groundwater Basin_Salt Nutrient Management Plan_2014_2	pdf	Draft Appendix B -Groundwater Model Documentation for the Salt and Nutrient Management Plan San Pasqual Valley, California Groundwater modeling was done limited to the upstream of Hodges Reservoir (east of 15); Figure B1-1 presents the study area boundary. "…only Cloverdale Creek and San Dieguito River in the downgradient portion of the Basin have perennial streamflow. The deep percolation of applied water on hillside avocado groves in Cloverdale Canyon has turned Cloverdale Creek from an intermittent stream into a perennial stream (Izbicki, 1983)."	City of San Diego
20	Hodges Hydrography_1919 thru 2016	Excel	Monthly water balance table from Feb 1919 to Dec 2016; storage 1st of month, rainfall, evaporation, leak, spill, other loss, draft, imported inflow, other known inflow, runoff including ROS, and ROS; However City of San Diego noted to not consider data post 2011 for draft and imported because data	

Ref. No.	File Name	File Type	Notes	Source
			are skewed due to the Olivenhain Pump Storage Project. Prior to 2011 draft metered in outflow pipe. Prior to 2011 imported metered in imported pipe.	
21	Agricultural_Leases	GIS shape files	A compressed zip file with the agricultural leases shapefile. These are lands that are directly lease out by the City of San Diego including the leasee name and the agricultural type.	
22	Hodges Dam Fact Sheet	pdf	'Gauge zero to be 199.58.' Based on this information reservoir water height was calculated as water level at the gauge +200 ft.	
23	San Dieguito Sampling_lab results_water years 2016 and 2017	Excel	N and P data available from WY 2016 and WY 2017 3 - 5 samples from March, April, Nov, Dec 2016 Felicita Creek (FEL3) Green Valley Creek (GVC2), Kit Carson Creek (KCC3), Moonsong Creek (MON2), Del Dios Creek (DDC3), Cloverdale Creek (CDC4), Santa Ysabel Creek (SYC2)	
24	FinalIAP_Dec2014	pdf	Final Hodges Reservoir Watershed Natural Treatment System Implementation Action Plan prepared by DUDEK	
25	Hodges_Topography_022717	pdf	Topographic map of the reservoir showing the high water line at 314.5'.	

The review revealed potential key pathways of nutrient loads to the reservoir from the Hodges Reservoir Watershed including:

- Direct inputs from the adjacent reservoir watershed via the following tributaries that discharge directly to the reservoir: Del Dios Creek, Felicita Creek, Moonsong Creek, and Green Valley Creek
- Upstream inputs via a wetland located upstream of the reservoir from the following tributaries: Kit Carson Creek and Santa Ysabel Creek

Potential key nutrient sources identified within each of these tributary watersheds to Hodges Reservoir include:

- Non-point sources (NPS):
  - Agricultural land uses: Large areas in the watershed are used for agriculture including farms, nurseries, and orchards. The agricultural uses are especially concentrated in upstream areas to the reservoir. An example of areas that are directly leased out by the City of San Diego for agricultural uses are presented in Figure 7. This figure does not account for those agricultural lands outside of the City of San Diego, which likely contribute to nutrients in the reservoir.
  - Septic systems: Houses in rural residential areas may not be connected to the sewer system and instead use onsite wastewater treatment system (OWTS), also referred to as septic systems. Improper maintenance of the septic systems could contribute to

    nutrient loading. No information is readily available on the number and locations of residential septic systems in the Hodges Reservoir Watershed, and there are no existing programs to require documentation or reporting of septic maintenance. The City of Escondido has completed a rudimentary geographic analysis and mapping of septic systems within its jurisdiction based on known water customers and sewer infrastructure.
    - San Pasqual Academy Wastewater Treatment Plant: this plant is located in the County of San Diego and has been operated by the county since 2000. Although it is near San Ysabel Creek, it discharges to a 1 acre percolation pond/spray irrigation bed bounded by eucalyptus trees per the Order No. R9-2009-0072 (SDRWQCB 2009).
    - Santa Maria Wastewater Treatment Plant: Ramona Municipal Water District operates this plant. The plant serves approximately 4,200 equivalent dwelling units single family residences in the downtown area of Ramona. The Santa Maria Wastewater Treatment plant is capable of treating 1,000,000 gallons per day of sewer flow. The recycled water produced by the plant is used to irrigate the Mountain Woodson Golf Course and to irrigate spray fields near rangeland Road and Highland Valley Road.[3]
- Municipal separate storm sewer systems (MS4): The reservoir is surrounded by residential land uses. MS4 data collected do not directly link outfall discharges with the nutrient impairment, and no MS4 outfalls directly discharge to the reservoir (City of San Diego et al. 2015). However, these data are very limited, thus it is difficult to determine the contribution of MS4 loadings of nutrients to the reservoir.
- Olivenhain Reservoir:
    - The San Diego County Water Authority (SDCWA) owns and operates the Olivenhain Dam and Reservoir. In 2003 the SDCWA and the Olivenhain Municipal Water District (OMWD) constructed the dam as part of the Emergency Storage Project with the primary purpose of supporting the municipal water supply. Olivenhain Reservoir is filled with imported water from the Second Aqueduct. Olivenhain Reservoir is connected to Hodges Reservoir as part of a pumped storage hydroelectricity source. Water is exchanged daily between Olivenhain and Hodges Reservoirs to generate peak period electricity (Brown and Caldwell 2014; Figure 8). This imported water could be a potential nutrient source to Hodges Reservoir via Olivenhain Reservoir.
- Groundwater:
    - “For pollutants such as TDS and nutrients, groundwater may be a contributing source, as noted throughout the San Diego region (City of San Diego, 2011[4]).” (p. 2-33 of San Dieguito River WMA WQIP)
    - Available information from groundwater modeling is limited to the upstream of Hodges Reservoir, San Pasqual Valley Groundwater Basin (east of Interstate Freeway 15).

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[3] http://www.rmwd.org/waste-water-operations

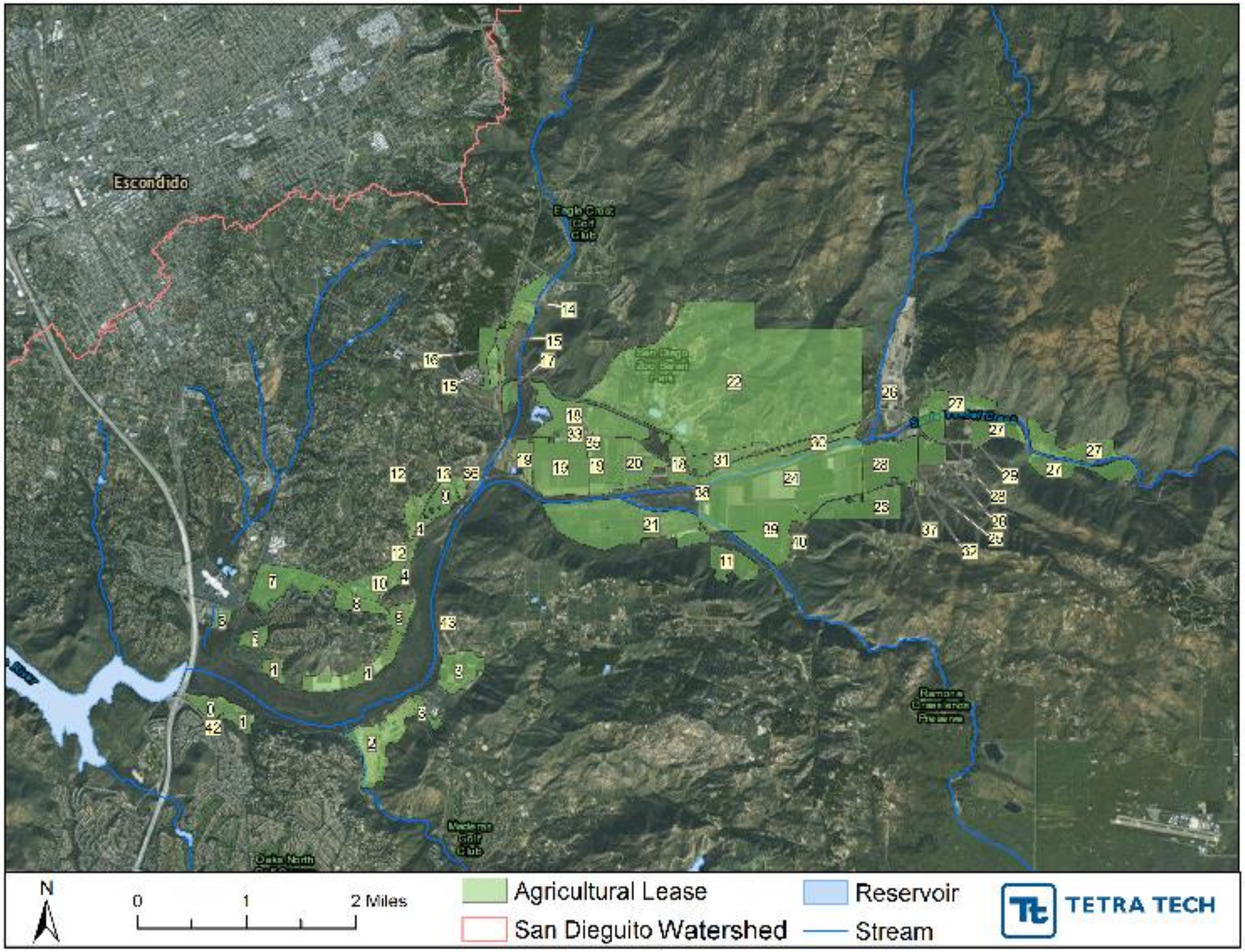

Figure 7. Agricultural leases presenting lands that are directly leased out by the City of San Diego, GIS layer for agricultural leases were obtained from the City of San Diego

Figure 8. Overview of Hodges Reservoir and Olivenhain Reservoir System, source, Figure 2-2 of Brown and Caldwell 2014

Although data have been collected over the years within and around the reservoir, data critical for estimating representative nutrient loads from potential key sources and pathways in the watershed are limited. Data availability is summarized in Tables 2-1 through 2-4 based on the conceptual model framework, which is discussed in detail in Section 4. Wherever data were available, ranges of the data were also provided with references from Table 1. Note that Tables 2-1 through 2-4 are discussed in further detail in Section 5 with regards to the nutrient budget.

In addition to the reviewed data, nutrient loads were estimated based on the existing Loading Simulation Program in C++ (LSPC) watershed model, as summarized in Tables 2-1 through 2-4. Note that the LSPC model was developed by Tetra Tech for San Dieguito River Watershed, and was recently updated to support ongoing Bacteria Total Maximum Daily Load (TMDL) efforts. The current model was updated/calibrated for hydrology and bacteria parameters. For use in developing the conceptual model, nutrient and sediment parameters were added based on local information and land use parameters that were used to develop a similar model for the Los Peñasquitos Watershed Management Area WQIP (Cities of San Diego and Del Mar et al. 2015). The model has not been calibrated for sediment and nutrients at this time. Model estimates should, therefore, be considered preliminary and are presented to help assess the relative contributions from different pathways for comparison and to assist in the identification of key data gaps. Updates to the LSPC model are necessary in the future to provide a more accurate assessment of nutrient loading from the watershed.

As a part of this study, an existing Stormwater Management Model (SWMM) that was developed for the San Pasqual Basin (San Dieguito watershed above Hodges Reservoir) was reviewed. This effort focused on reviewing the San Dieguito Hydrologic Investigation - Final Report (CH2MHILL 2015), as well as running the latest SWMM input file setup for both hydrology and nutrient loading simulations, and comparing outputs from the SWMM and LSPC models for flow, nutrient loads, and nutrient concentrations. This review indicated that the SWMM model is best applied as a stormwater model for highly urbanized/impervious catchments and is less suitable for the Hodges Reservoir watershed, which includes a mix of land uses with significant open space and pervious areas and a complex groundwater system. This is because SWMM does not explicitly account for different land use types and lumps different land uses at a catchment level, where a single representative outflow is simulated representing all land uses. Vegetation files may be able to provide a more accurate representation of land uses. The LSPC model allows for the assignment of multiple land uses at the subwatershed level and individual flow and loading characteristics for each land use. The Hodges Reservoir Watershed includes pervious and impervious areas with a complex groundwater system, which suggests that the simplified SWMM hydrology and pollutant loading simulation may make it difficult to adequately capture observed conditions. Information from the SWMM model can be used to assist with updating the LSPC model in the future to provide a more accurate assessment of nutrient loading to Hodges Reservoir and WQIP updates that may be needed.

Table 2-1. Nutrient budget table for sources contributing directly to Hodges Reservoir

Direct Reservoir	**Flow**	**Discharge**	**Concentration**		**Load**	
			Total Phosphorus	**Total Nitrogen**	**Total Phosphorus**	**Total Nitrogen**
	cfs	**MG/year**	**mg/l**	**mg/l**	**kg/year**	**kg/year**
Internal Load						
Water Column			0.05-0.78 (Ref. 10)	0.16-8.5 (Ref. 10)		
Sediment Release						
Total						
Atmosphere						
Dry Deposition					See Footnote 1	See Footnote 1
Wet Deposition					See Footnote 1	See Footnote 1
N Fixation			⬛		⬛	
Total						
Olivenhain Reservoir						
Total						
Groundwater						
Total						

Availability of data is indicated using different color codes:

🟧	Data available but monitoring locations or frequencies are insufficient to estimate representative loading
🟥	Very limited data available
🟩	LSPC model estimates available
⬛	Not necessary
⬜	No data available

Ranges of values based on readily available data. Data sources are shown in the parenthesis next to values.

cfs, cubic feet per second; MG/year, million gallon per year; Ref., Reference

Footnote

1. Information or output are available from the LSPC models and can be provided later. These are not necessary for the conceptual model development and only availability is shown in the table.

Table 2-2. Nutrient budget table for tributaries contributing directly to Hodges Reservoir

Tributaries in the adjacent watershed	Flow cfs	Discharge MG/year	Concentration		Load	
			Total Phosphorus mg/l	Total Nitrogen mg/l	Total Phosphorus kg/year	Total Nitrogen kg/year
Felicita Creek						
MS4			See Footnote 2 (Ref. 13-1)	See Footnote 2 (Ref. 13-1)	See Footnote 1	See Footnote 1
NPS					See Footnote 1	See Footnote 1
Natural Load					See Footnote 1	See Footnote 1
Total	0-12.33 (Ref. 7-1)	128 (Ref. 7-1)	0.08-1.0 (Ref. 8)	0.33- 9.40 (Ref. 8)	120-523 (LSPC modeled; see Footnote 4)	630-2,831 (LSPC modeled; see Footnote 4)
Green Valley Creek						
MS4			See Footnote 2 (Ref. 13-1)	See Footnote 2 (Ref. 13-1)	See Footnote 1	See Footnote 1
NPS					See Footnote 1	See Footnote 1
Natural Load					See Footnote 1	See Footnote 1
Total	0-202.19 (Ref. 7-1)	850 (Ref. 7-1; see Footnote 3)	0.07-1.06 (Ref. 8)	0.16-3.43 (Ref. 8)	648-2,751 (LSPC modeled; see Footnote 4)	3,700-15,590 (LSPC modeled; see Footnote 4)
Del Dios Creek						
MS4					See Footnote 1	See Footnote 1
NPS					See Footnote 1	See Footnote 1
Natural Load					See Footnote 1	See Footnote 1
Total	0-5.17 (Ref. 7-1)	59 (Ref. 7-1; see Footnote 3)	0.08-1.08 (Ref. 8)	0.34-5.92 (Ref. 8)	45-201 (LSPC modeled; see Footnote 4)	248-1,124 (LSPC modeled; see Footnote 4)
Moonsong Creek						
MS4					See Footnote 1	See Footnote 1
NPS					See Footnote 1	See Footnote 1
Natural Load					See Footnote 1	See Footnote 1
Total	0-17.66 (Ref. 7-1)	162 (Ref. 7-1; see Footnote 3)	0.08-3.38 (Ref. 8)	0.16-5.62 (Ref. 8)	116-488 (LSPC modeled; see Footnote 4)	668-2,691 (LSPC modeled; see Footnote 4)

Availability of data is indicated using different color codes:

🟧	Data available but monitoring locations or frequencies are insufficient to estimate representative loading
🟥	Very limited data available
🟩	LSPC model estimates available
⬛	Not necessary
⬜	No data available

Ranges of values based on readily available data. Data sources are shown in the parenthesis next to values.

cfs, cubic feet per second; MG/year, million gallon per year; Ref., Reference; MS4, Municipal Separate Storm Sewer System; NPS, non-point source

Footnotes

1. Information or output are available from the LSPC models and can be provided later. These are not necessary for the conceptual model development and only availability is shown in the table.
2. Insufficient information to identify tributary-specific concentrations
3. Average annual discharge estimated based on data from the reference; flow was measured during the sampling event, which was assumed as monthly average flow and yearly average flow was estimated using the assumed monthly average.

4. LSPC watershed loading model was developed for the CLRP; however the model has not been calibrated and validated for nutrients and sediment; ranges of values were presented to compare relative contribution from different tributaries. These estimates should not be considered as representative loads from the different sources and pathways.

Table 2-3. Nutrient budget table for upstream tributaries and wetland during the low reservoir condition

Upstream Watershed (Low Reservoir Condition)	**Flow**	**Discharge**	**Concentration**		**Load**	
			Total Phosphorus	**Total Nitrogen**	**Total Phosphorus**	**Total Nitrogen**
	cfs	**MG/year**	**mg/l**	**mg/l**	**kg/year**	**kg/year**
Tributaries						
Santa Ysabel Creek (below Sycamore)*						
MS4						
Other NPDES						
NPS						
*Natural Load***						
Total		Typically Dry; See Footnote 4 (Ref. 11)			Typically Dry; See Footnote 4 (Ref. 11)	Typically Dry; See Footnote 4 (Ref. 11)
Kit Carson Creek						
MS4			See Footnote 2 (Ref. 13-1)	See Footnote 2 (Ref. 13-1)		
NPS						
*Natural Load**						
Total	0-85.2 (Ref. 7-1)	913 (KCC+GVC+FEL; see Footnote 3; Ref. 11)			735 (GVC+KCC+FEL; see Footnote 3; Ref. 11)	3411 (GVC+KCC+FEL; see Footnote 3; Ref. 11)
Wetland						
Loads from Tributaries					See Footnote 1	See Footnote 1
N fixation						
Net Storage/Loss						
Net Surface Load						
Net Groundwater Load						
Total						

*Although considerable data have been collected at Santa Ysabel Creek, all the data were collected at or near USGS gauging station on Santa Ysabel Creek which is located far upstream from the reservoir (near the convergence of Santa Ysabel Creek and Guejito Creeks). No data were collected from the section of Santa Ysabel Creek below Sycamore Creek. See Figure 5 for the monitoring location on Santa Ysabel Creek.

**Natural load for upstream includes groundwater and atmosphere.

Availability of data is indicated using different color codes:

🟨	Data available but monitoring locations or frequencies are insufficient to estimate representative loading
🟥	Very limited data available
🟩	LSPC model estimates available
⬛	Not necessary
⬜	No data available

Ranges of values based on readily available data. Data sources are shown in the parenthesis next to values.

cfs, cubic feet per second; MG/year, million gallon per year; Ref., Reference; MS4, Municipal Separate Storm Sewer System; NPS, non-point source; other NPDES, National Pollutant Discharge Elimination System permittee other than MS4; GVC, Green Valley Creek; KCC, Kit Carson Creek; FEL, Felicita Creek

Footnotes

1. Information or output are available from the LSPC models and can be provided later. These are not necessary for the conceptual model development and only availability is shown in the table.
2. Insufficient information to identify tributary-specific concentrations
3. Data are available only for GVC, KCC, and FEL combined.
4. Zero discharge from the Santa Ysabel Creek was assumed based on observations made by the City of San Diego. The soil moisture deficit was not satisfied, so there was no observed discharge and no estimated nutrient loadings from Santa Ysabel Creek during the below average precipitation year (2012 – 2013).

Table 2-4. Nutrient budget table for upstream tributaries and wetland during the high reservoir condition

Upstream Watershed (High Reservoir Condition)	**Flow**	**Discharge**		**Concentration**		**Load**			
				Total Phosphorus	**Total Nitrogen**	**Total Phosphorus**		**Total Nitrogen**	
	cfs	**MG/year**		**mg/l**	**mg/l**	**kg/year**		**kg/year**	
Tributaries									
Santa Ysabel Creek (below Sycamore*)									
MS4									
Other NPDES									
NPS									
*Natural Load***									
Total		5,617 (Ref. 11)				840-10,460 (LSPC modeled; see Footnote 3)	27,310 (Ref. 11)	3,464-34,267 (LSPC modeled; see Footnote 3)	8,300 (Ref. 11)
Kit Carson Creek									
MS4				See Footnote 2 (Ref. 13-1)	See Footnote 2 (Ref. 13-1)	See Footnote 1		See Footnote 1	
NPS						See Footnote 1		See Footnote 1	
*Natural Load***						See Footnote 1		See Footnote 1	
Total	0-85.2 (Ref. 7-1)	630 (Ref. 7-1; see Footnote 3)	1,988 (GVC+KCC+FEL; Footnote 4; Ref. 11)	0.07-1.01 (Ref. 8) 0.03-0.32 (Ref. 23)	0.52-11.70 (Ref.8) 0.42-3.53 (Ref. 23)	348-716 (LSPC modeled; see Footnote 3)	1,601 (GVC+KCC+FEL; see Footnote 4; Ref. 11)	1,907-8,197 (LSPC modeled; see Footnote 3)	7,434 (GVC+KCC+FEL; see Footnote 4; Ref. 11)
Wetland									
Loads from Tributaries						See Footnote 1		See Footnote 1	
N fixation									
Net Storage/Loss									
Net Surface Load									
Net Groundwater Load									
Total									

*Although considerable data have been collected at Santa Ysabel Creek, all the data were collected at or near USGS gauging station on Santa Ysabel Creek which is located far upstream from the reservoir (near the convergence of Santa Ysabel and Guejito Creeks). No data were collected from the section of Santa Ysabel Creek below Sycamore Creek. See Figure 5 for the monitoring location on Santa Ysabel Creek.

**Natural load for upstream includes groundwater and atmosphere.

Availability of data is indicated using different color codes:

🟨	Data available but monitoring locations or frequencies are insufficient to estimate representative loading
🟥	Very limited data available
🟩	LSPC model estimates available
⬛	Not necessary
⬜	No data available

Ranges of values based on readily available data. Data sources are shown in the parenthesis next to values.

cfs, cubic feet per second; MG/year, million gallon per year; Ref., Reference; MS4, Municipal Separate Storm Sewer System; NPS, non-point source; other NPDES, National Pollutant Discharge Elimination System permittee other than MS4GVC, Green Valley Creek; KCC, Kit Carson Creek; FEL, Felicita Creek

Footnotes

1. Information or output are available from the LSPC models and can be provided later. These are not necessary for the conceptual model development and only availability is shown in the table.
2. Insufficient information to identify tributary-specific concentrations
3. LSPC watershed loading model was developed for the CLRP; however the model has not been calibrated and validated for nutrients and sediment; ranges of values were presented to compare relative contribution from different tributaries. These estimates should not be considered as representative loads from the different sources and pathways.
4. Data are available only for GVC, KCC, and FEL combined.

4.0 CONCEPTUAL MODELS

This section synthesizes the literature search and review (Section 3), information gathered through in-person meetings, and other supporting information relevant to development of a conceptual model that describes the pathways and controls influencing nutrient loading to Hodges Reservoir.

4.1 GENERAL CONCEPTUAL MODEL IN TWO CONDITIONS

Nutrient loads into Hodges Reservoir come from a few main pathways (Figures 9 and 10). The primary pathways are through tributaries and there are direct and upstream tributaries. Direct tributaries to the reservoir (i.e., Del Dios Creek, Felicita Creek, Green Valley Creek, and Moonsong Creek) drain the areas that directly contribute to the reservoir and provide nutrient loads throughout the year, depending on weather conditions. Upstream tributaries (i.e., Santa Ysabel Creek and Kit Carson Creek) drain the entire, larger upstream watershed and provide nutrient loads to the reservoir when these tributaries flow. These tributaries flow through or bypass a wetland that is located on the upstream end of the reservoir and lies below the reservoir high water level but above the normal pool level (Figure 11). Recently, this wetland has mostly been dry with intermittent (e.g., every few years for several weeks) inundation by the reservoir. Moreover, water from the upstream tributaries only intermittently flows through the wetland. During periods when the wetland is inundated (dotted line in Figure 9), these upstream tributaries have a direct surficial connection to the reservoir and contribute nutrient loads (high reservoir water level periods). During drier periods when the wetland is not inundated, these tributaries lack a surficial connection and either do not contribute loads or only limited loading through the wetland, which may absorb and process a portion of that load (low reservoir level periods). In addition to these tributary loads, the atmosphere contributes direct nutrient inputs through wet and dry deposition to the surface of the reservoir and provides nitrogen through nitrogen fixation (free nitrogen combines chemically with other elements to form nitrogen compounds) in the reservoir and the wetland. Groundwater also likely provides some nutrient loading directly to the reservoir. Olivenhain Reservoir is also connected to an aqueduct and provides an inter-basin water source. This exchange occurs periodically with Hodges Reservoir and, therefore, represents another nutrient loading pathway. Lastly, nutrients in the reservoir sediments may be a regular internal nutrient load that can affect water quality, depending on stratification, other limnological processes, and water management activities. See 4.3.3 Reservoir Nutrient Cycling for further details.

In investigating the watershed land uses and hydrology of the reservoir, it became apparent that the connectedness of the upstream watershed was important. The upstream watershed is much larger than the direct tributary watershed land area, and includes a variety of land uses that contribute nutrient loads. Moreover, preliminary estimates based on limited data indicate that during high reservoir water level periods, upstream watershed loads may be significant compared to direct tributary contributions (Table 2-4). However, during extended low reservoir water level periods, when this upstream watershed is disconnected (at least surficially), the loads would be greatly reduced. Small precipitation events that could mobilize nutrients from the direct tributaries, may be insufficient to yield nutrients from the upstream tributaries. These small event upstream loads would either not make it to the wetland or would be taken up and removed by the wetland. As a result, a two-condition conceptual model is being proposed for the reservoir with regards to nutrient loading: a low reservoir water level period (low reservoir condition) and a high reservoir water level period (high reservoir condition).

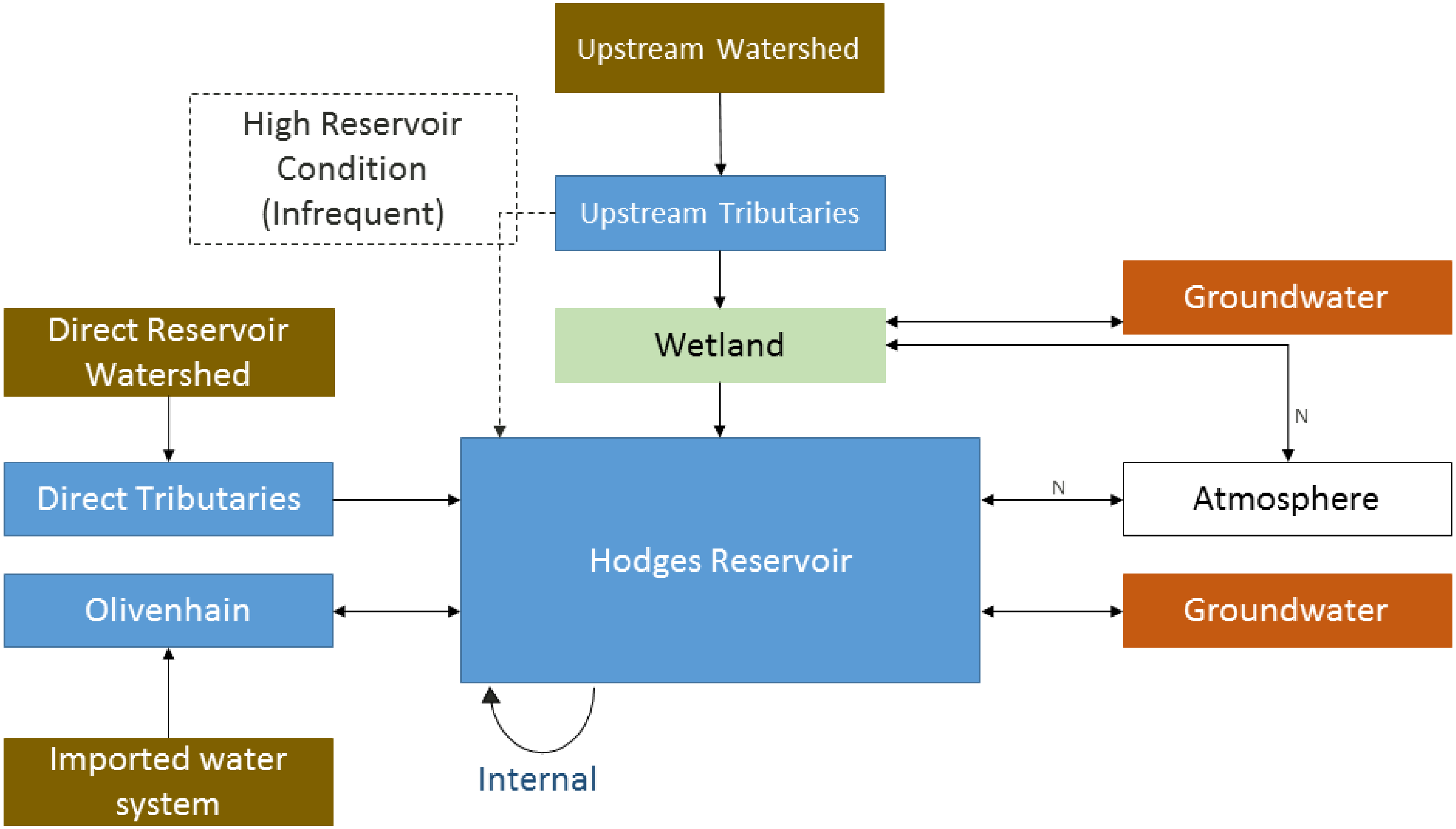

Figure 9. Conceptual model of nutrient loading into Hodges Reservoir. (High and Low Reservoir Conditions)

Figure Notes: Upstream loading to the Reservoir via the wetland represents the low Reservoir condition; Upstream direct loading to the Reservoir, bypassing the wetland as indicated by the dotted line, is representative of the high Reservoir condition.

Direct Reservoir watershed represents the drainage areas of the tributaries that flow directly to the Reservoir, and does not include drainage areas associated with the upstream tributaries.

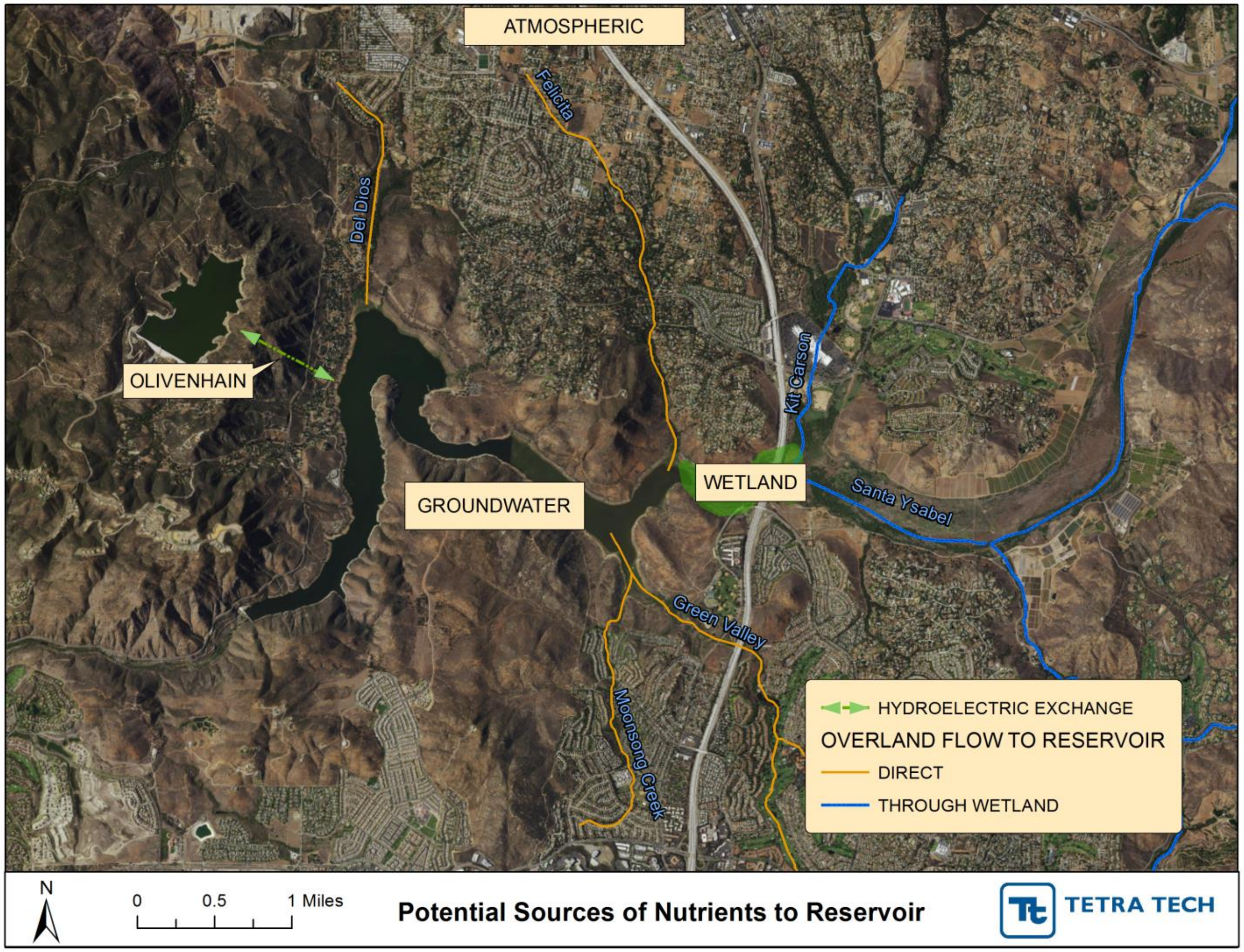

Figure 10. Satellite image of Hodges Reservoir with conceptual representative of major nutrient external source components to Hodges Reservoir labeled for visual reference

Figure Notes: Atmosphere and Groundwater extend spatially through the entire Subwatershed. Placement of identified source components is for conceptual purposes, and not meant to be spatially accurate.

Internal cycling of the Reservoir is also a source of nutrients; however, this figure is a conceptual representation of inputs to the Reservoir from external sources (e.g., the Subwatershed, groundwater, etc.)

Figure 11. Wetland at the bicycle and pedestrian bridge in Hodges Reservoir; source, http://www.mountainbikebill.com

During the low reservoir condition (Figure 12), which is expected to be the most common state for the reservoir, the upstream watershed may carry nutrient loads downstream, but these are largely attenuated by processing and storage in tributaries and the upstream wetland due to uptake and lack of surface flow. The wetland is not inundated during this condition and tributary flows typically infiltrate. It is suspected that nitrification and denitrification processes in the carbon rich wetland can remove nitrogen from influent sources, and phosphorus can be removed via sedimentation of particle-bound phosphorus and sorption of orthophosphate as it infiltrates through the wetland soils. Anoxic processes in shallow groundwater within the wetland have the potential to produce soluble phosphorus along shallow groundwater flow paths. The redox condition of the wetland would strongly influence these biogeochemical reactions. As a result of this fluvial disconnection and uptake and processing of nutrients in the wetland, the relative contribution of loads from direct tributaries and internal loading is much larger than that from upstream tributaries. Internal loading would recirculate, in part, upstream phosphorus deposited during high reservoir conditions. Nitrogen fixation would also be a significant source of new nitrogen inputs. Again, during this condition, internal loads and direct tributary loads would be expected to dominate the nutrient budget as very little, if any, upstream tributary water would be expected to reach the reservoir. Although it is likely much less frequent during the low reservoir condition, sufficiently high flow from a large storm event may cause intermittent and temporary surface flows through the wetland or may cause erosion of the wetland, in either case delivering nutrients to the reservoir from upstream.

During the high reservoir condition (Figure 13), the wetland becomes inundated and upstream tributaries have a more significant surficial connection to the reservoir. In this condition, the wetland plays a reduced role in attenuating nutrients because more of the load flows to the reservoir and is not infiltrating into and interacting with the wetland soil interface where uptake and processing can occur. Certainly a portion of nutrients would be processed, but the wetland is more shut off from its role in storage and processing if the majority of the load bypasses that ecosystem. During the high reservoir condition, the upstream tributaries provide the largest portion of the total load. This load may, in fact, reload the reservoir with nutrients, which will proceed to cycle between the sediment and water column via internal loading during the subsequent dry condition. This is especially true of phosphorus. As mentioned, a large portion of the phosphorus load, especially during high flows, is sediment bound, more so than nitrogen. Therefore, more of the relative total load of phosphorus may be delivered as particulates during the high reservoir condition. Also, phosphorus has no gaseous phase so cannot be exported from the reservoir system except through permanent sedimentation, which can take several cycles. In contrast, nitrogen can be transformed into and lost as a gas through a number of biogeochemical reactions. For these reasons, this reloading of nutrients is especially important for phosphorus management. The high reservoir condition is likely less common and shorter in duration, but may be sufficient to provide a large, persistent nutrient load, especially for phosphorus.

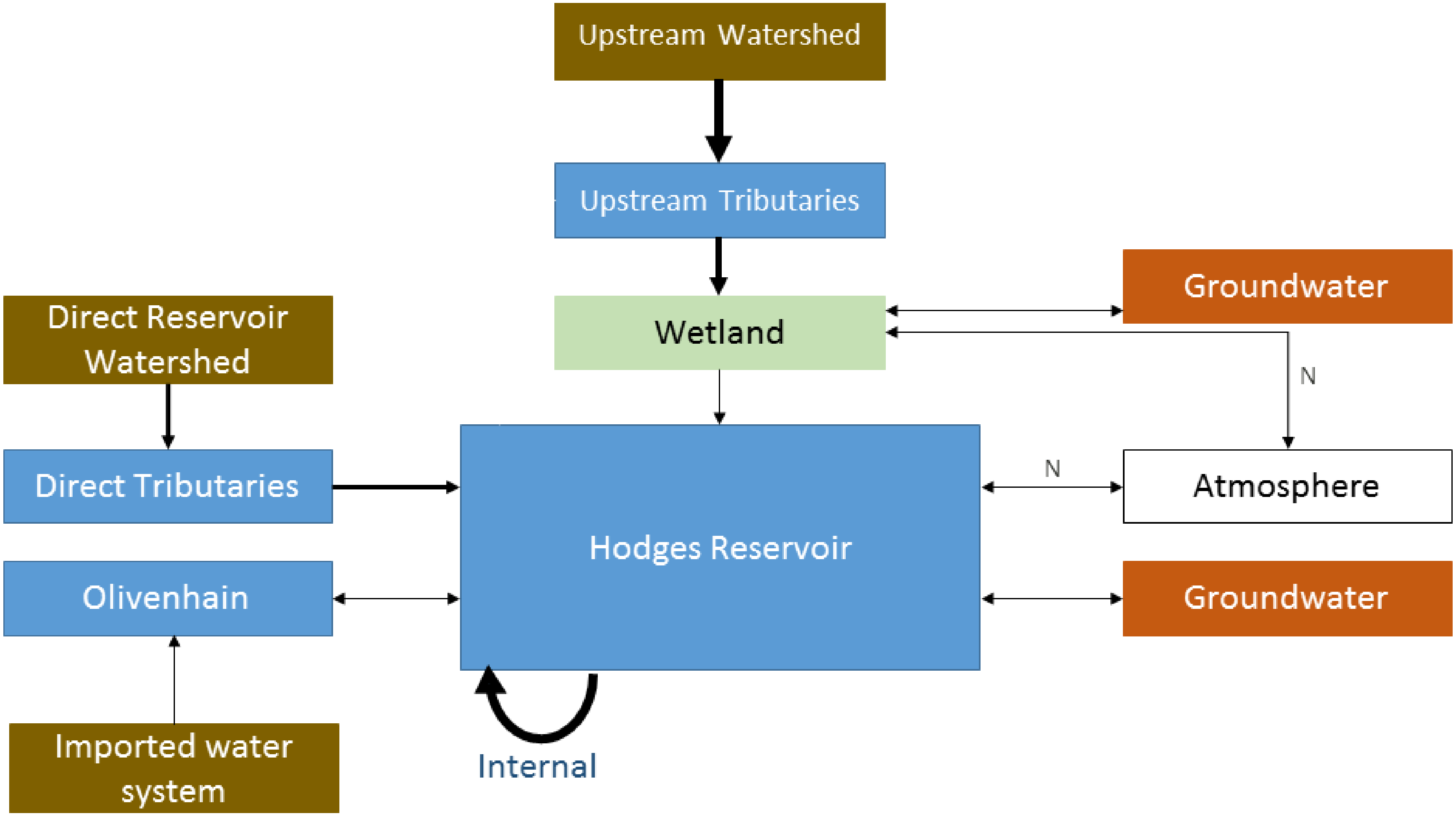

Figure 12. Low reservoir condition; the reservoir is disconnected from the upstream watershed. The size of the arrows is proportional to estimated contribution.

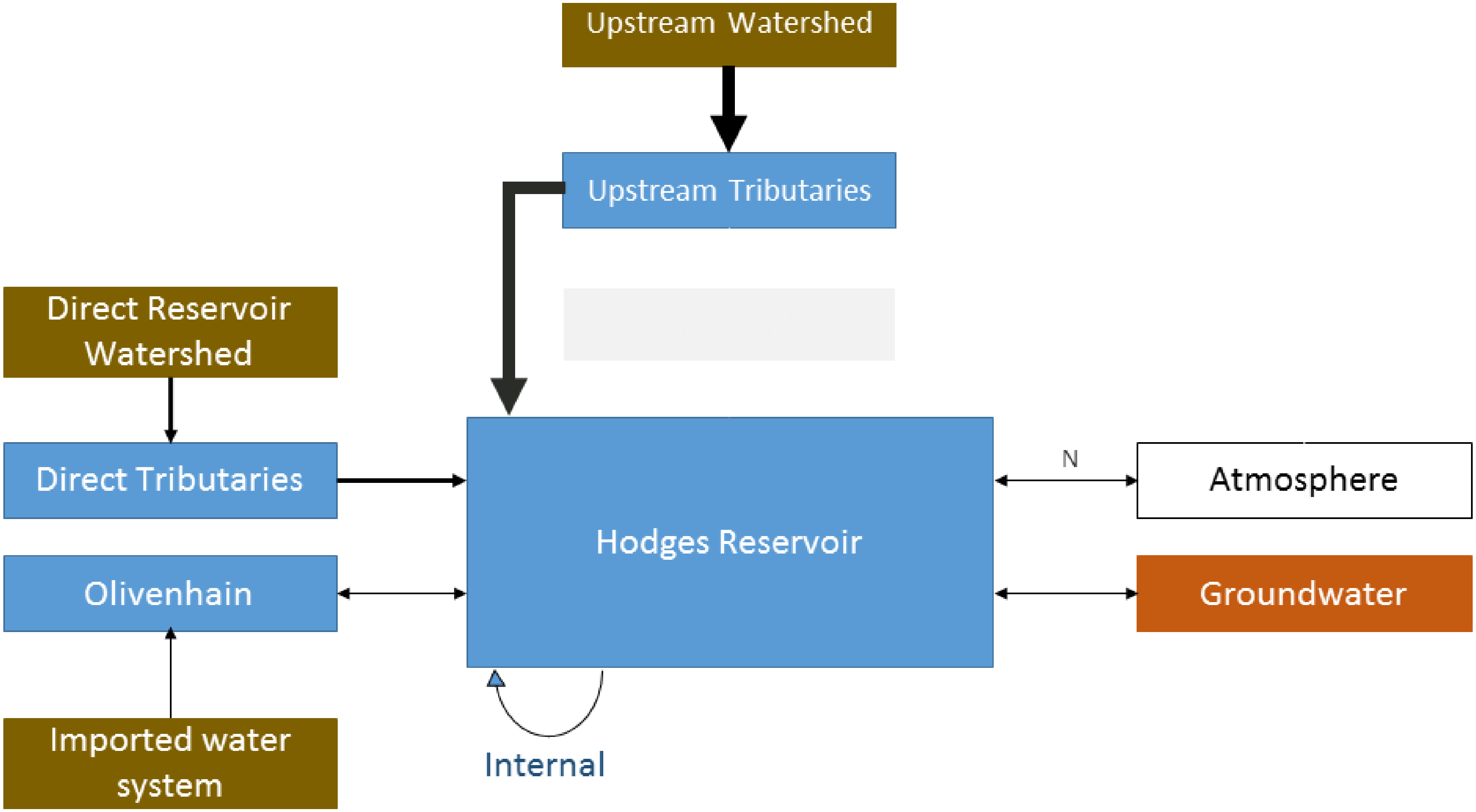

Figure 13. High reservoir condition; the reservoir is connected to the upstream watershed. The size of the arrows is proportional to estimated contribution.

4.2 LINEAR REPRESENTATION AND CONTRIBUTING LAND USES

The nutrient sources from surface flows described above for Hodges Reservoir can also be viewed in a simple linear model (Figure 14). This model shows the relative position of major tributaries and the wetland to the reservoir and also indicates the predominant nutrient generating land uses relative to the major tributaries. Natural land cover also generates nutrient loads; e.g., phosphorus naturally present in soil and soil erosion is one of the major contributors of phosphorus to waterbodies (USGS 2017). This figure also indicates the two condition model – with the upper panel (A) showing the upstream watershed as disconnected, at least surficially, from the reservoir (low reservoir condition), and the lower panel (B) showing the high reservoir condition when the upstream watershed is connected.

For the direct tributary watershed, residential nutrient loads are predominant, represented by the Cities of Escondido, Poway, and San Diego and San Diego County (Figure 15). These areas are residential land use with transportation infrastructure, commercial, and open space land uses intermixed. Parks and open space land uses are located within the City of Escondido, to the north of the reservoir. This includes Kit Carson Park (285 total acres, 185 acres of preserved open space), County-owned Felicity Park (53 total acres), and Lake Hodges open space (west of Del Dios Highway and west of I-15 adjacent to Lake Hodges) totaling 662 acres. The lower western end of the reservoir is directly surrounded by more open space. Upstream, the southern portion of the watershed draining into Sycamore and especially Santa Maria Creeks, are also dominated by residential land use (Ramona) interspersed with agriculture, open space, commercial, and transportation infrastructure land uses. The northern and easternmost upstream watershed (east of Santa Maria subwatershed) is typified by a predominance of undeveloped, natural land cover, open space, and some agricultural land use. The San Diego Zoo Safari Park occupies a large area along a small direct tributary north of Santa Ysabel Creek. Agricultural lands border the main tributary (Santa Ysabel Creek) for a distance of approximately 9.3 miles north of the wetland.

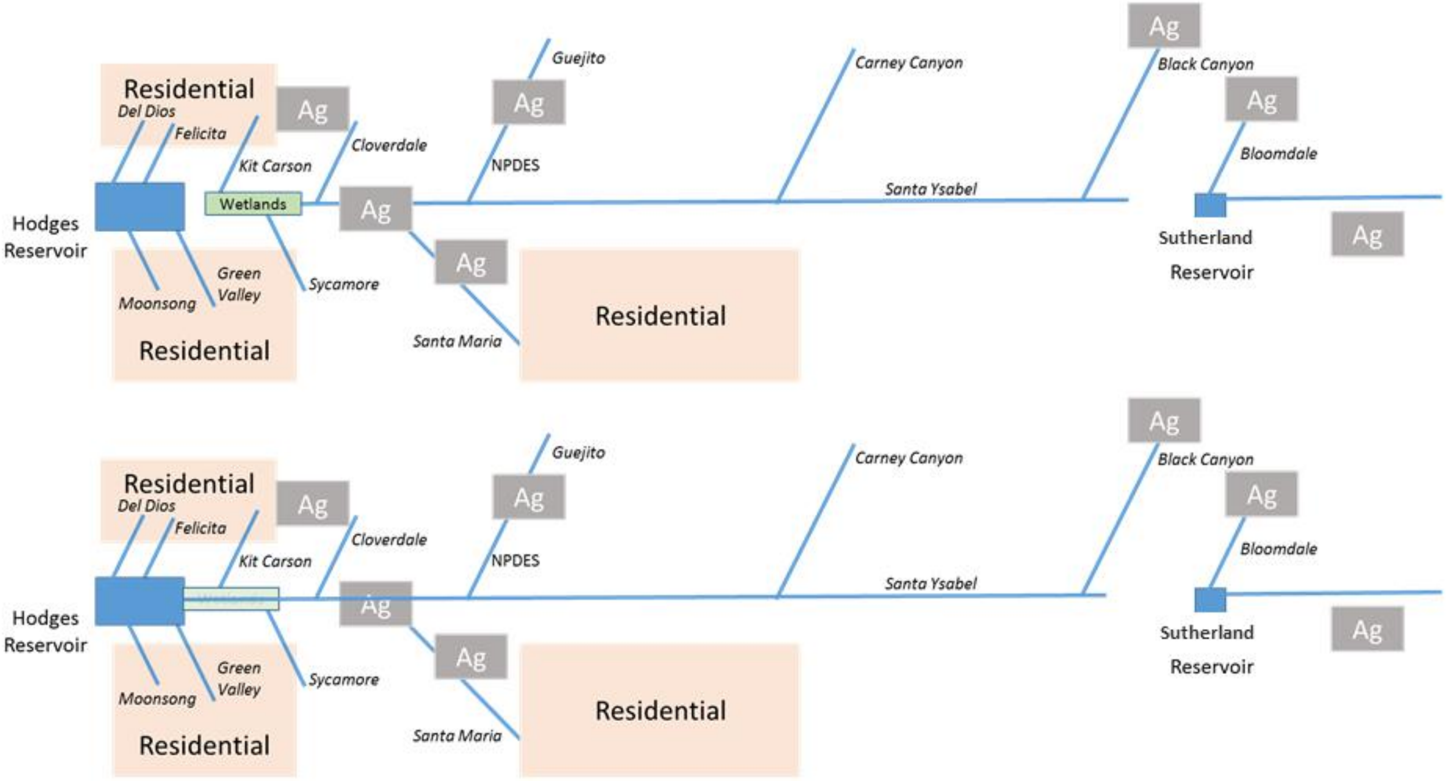

Figure 14. Linear model of the low reservoir condition (showing disconnection of wetland from reservoir) in upper panel (A) and the high reservoir condition (showing flow through wetland) in lower panel (B). Also indicated are relative positions of direct and upstream major tributaries along with major land use locations draining to different tributaries. ‘Ag’ indicates agricultural land use.

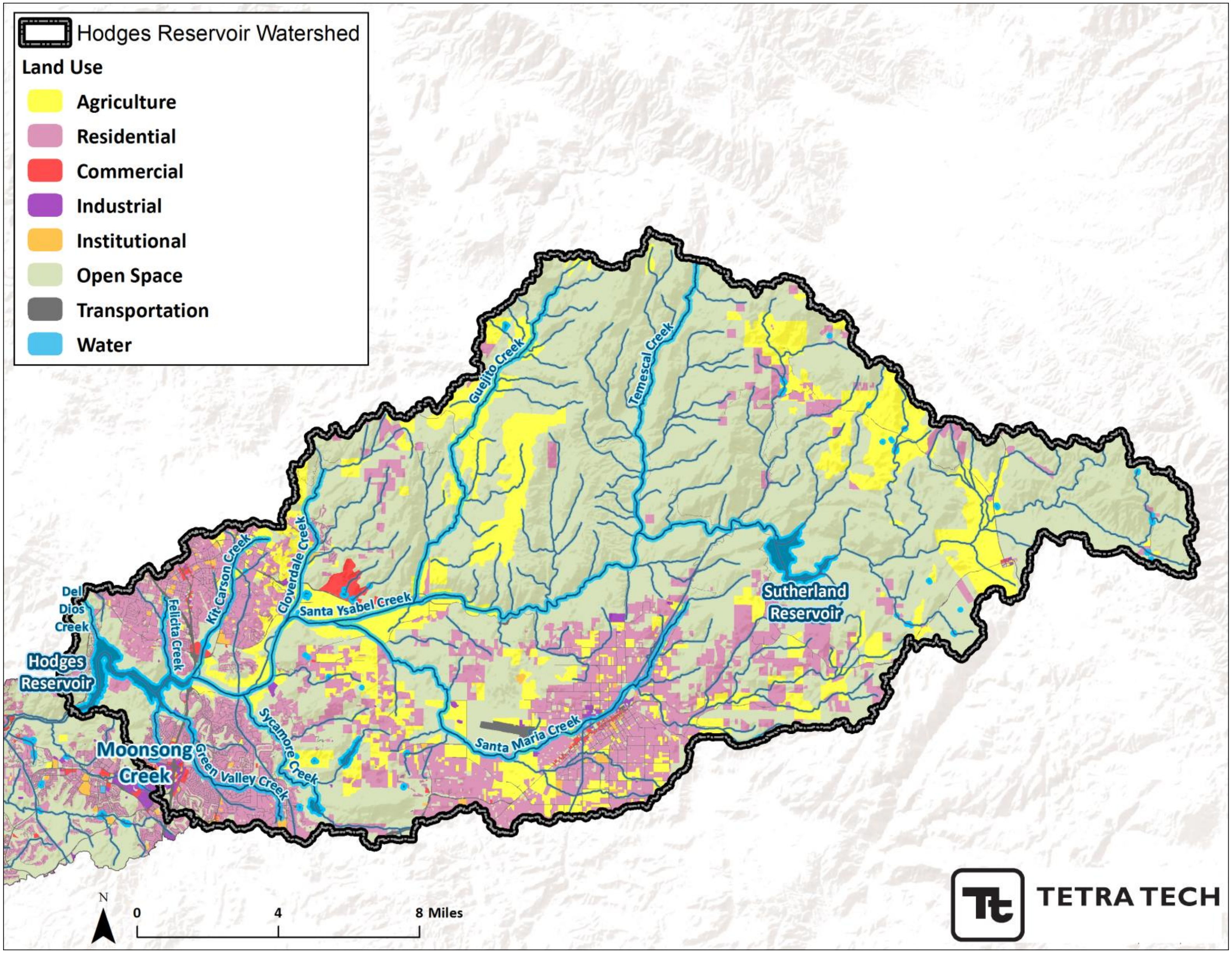

Figure 15a. Land cover map of the San Dieguito watershed, including the Hodges Reservoir Watershed. 2016 Land Use data was acquired from the SANGIS Regional Data Warehouse (http://www.sangis.org/download/), and aggregated into the subset of categories displayed in the figure

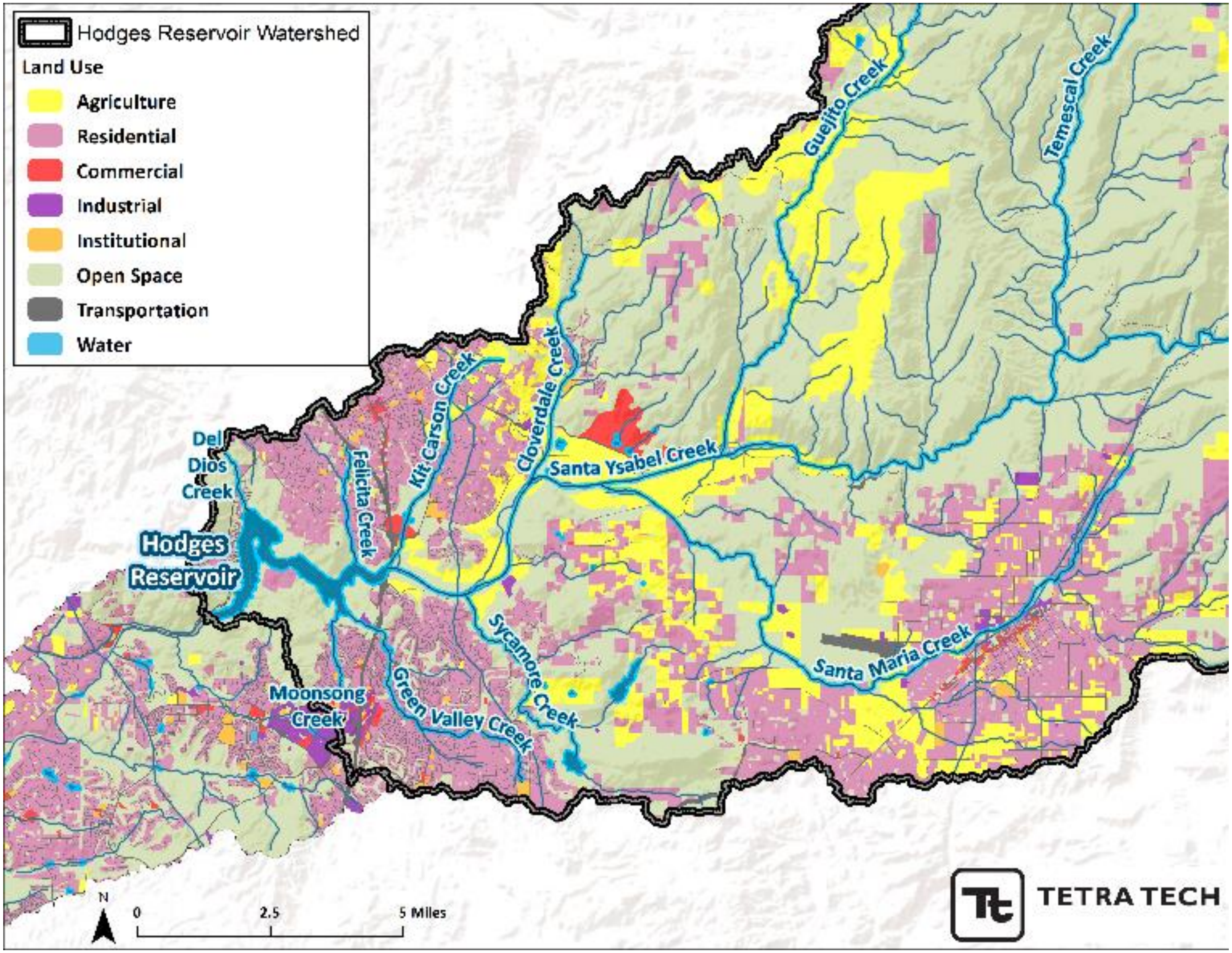

Figure 15b. Land cover map of the San Dieguito watershed, zoomed in to Hodges Reservoir. 2016 Land Use data was acquired from the SANGIS Regional Data Warehouse (http://www.sangis.org/download/), and aggregated into the subset of categories displayed in the figure

4.3 NUTRIENT CYCLING WITHIN COMPONENT ECOSYSTEMS

As mentioned, nutrients do not move passively through aquatic ecosystems in the watershed. Nutrients that enter the tributary network are taken up and processed *in-situ* in streams, in the wetland, and in the reservoir itself. This cycling can represent both sources and sinks for nutrients.

4.3.1 Stream Nutrient Cycling

Stream ecosystems are not conveyances, but rather active ecosystems with unique flora and fauna that vary depending on stream size, hydrology (including permanence), and geomorphic setting among other factors. Major nutrient inputs into a stream segment include upstream and tributary loads as well as groundwater loads. Nitrogen fixation can also contribute nitrogen to the stream segment. A portion of nutrients are taken up by benthic organisms and cycle through the food web before being mineralized (nutrients converted into mineral/inorganic material) and released downstream. Ultimately, nutrients that are not removed through gas loss (nitrogen) or biochemical uptake are exported as downstream load. See Figure 16 for the stream nutrient cycling diagram.

4.3.2 Wetland Nutrient Cycling

The wetland ecosystem upstream of Hodges Reservoir also takes up and processes nutrients although the magnitude is uncertain. Major nutrient loads to the wetland come from upstream tributaries, adjacent tributaries, and groundwater. Wetlands possess great uptake and storage capacity for nitrogen and phosphorus, and especially for removing nitrogen from the watershed through denitrification, an anaerobic process perfectly suited to the carbon rich, anoxic sediments of wetland ecosystems. Nutrients are taken up by both open water and sediment biota, as well as emergent vegetation (plant biomass). These nutrients then cycle in the wetland ecosystem among different trophic levels. For instance, nitrogen can be removed by denitrification, and also added to the wetland through nitrogen fixation. A portion of the nutrient pool is mineralized and may be exported downstream via surficial flow, shallow sub-surface flow, or loss to groundwater. The contribution of each of these export pathways is hydrology-dependent. See Figure 17 for the wetland nutrient cycling diagram.

4.3.3 Reservoir Nutrient Cycling

Nutrients also cycle in the reservoir itself (Figure 18). Inputs include upstream loads, tributary loads, groundwater loads, and exchange with Olivenhain Reservoir. Nitrogen fixation is also a source of nitrogen within the reservoir. Nutrient exchange occurs between the water column, sediments, and groundwater as in the other ecosystems. Continued loading of nutrients contributes to ongoing eutrophication in the reservoir. The reservoir is unique relative to the tributaries and wetland in that it becomes thermally stratified. The upper layers warm in the spring and due to thermal effects on water density, become physically isolated from the cooler lower layers and remain so through the summer and fall. Stratification is an important physical phenomenon in deep, lentic waterbodies that drives important nutrient transformations.[5] During stratification, nutrients in the epilimnion are taken up by algae and bacteria and move through trophic levels through consumption. Some may be released through excretion and some may be mineralized into available nutrients in the epilimnion. A portion of the particulate nutrients settle out of the epilimnion into the hypolimnion (regional below the

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[5] Lake/reservoir stratification is the separation of lake/reservoir water into three layers: epilimnion, the top of the water; metalimnion (or thermocline), the middle layer; hypolimnion, the bottom layer.

thermocline), passing through the metalimnion (thermocline). In the hypolimnion, organic carbon is decomposed, consuming oxygen. This layer is isolated from the atmosphere and reaeration through diffusion is insufficient to replenish oxygen, therefore concentrations decline and the hypolimnion may become hypoxic (< 2mg/l dissolved oxygen) or even anoxic near the sediment. Under anoxia, insoluble phosphorus bound to metal oxides is released and becomes soluble. Organic nitrogen is also decomposed and converted into ammonium; a portion of which may be nitrified (converted into nitrites/nitrates) and then removed from the reservoir by denitrification. Some of the dissolved nutrients may diffuse to the upper layer or be taken up by migratory algae like *Microcystis*, which can introduce nutrients back to the upper layer. However, the majority of these dissolved nutrients are introduced to the surface when the reservoir cools in autumn and approaches isothermal conditions. When this happens, a windy day will mix the layers together, reintroducing cool, nutrient rich water from the hypolimnion back up into the well-lit upper layers where the nutrients can fuel algal productivity. Lakes/reservoirs in subtropical climates generally stay mixed through the winter.

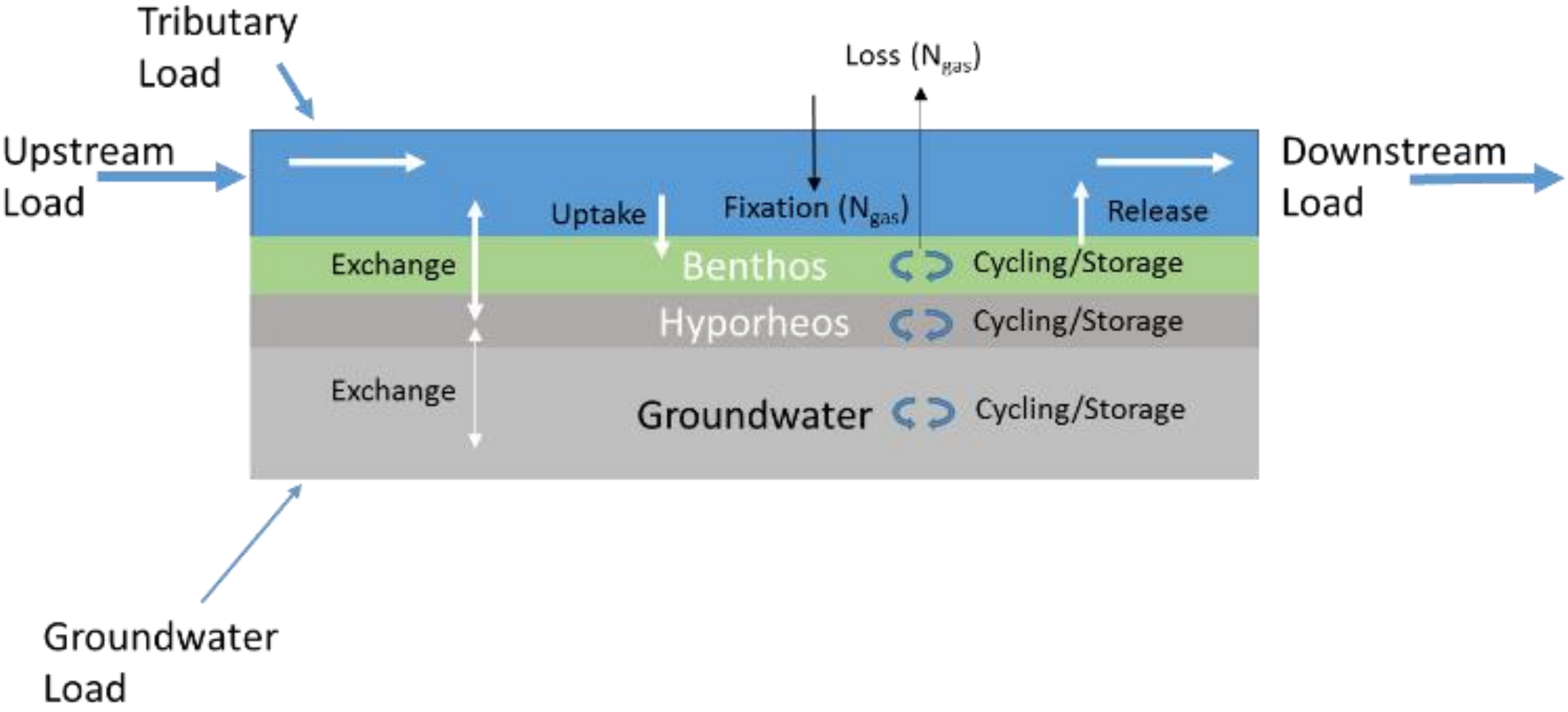

Figure 16. Conceptual model of nutrient cycling in tributary streams.

Figure Notes: Hyporheos is the layer of subsurface sediment where exchange and interaction of stream water and groundwater occurs.

Benthos is the layer of surface and sub-surface sediments where the benthic invertebrate community exists.

Nitrogen gas fixation is a natural process where atmospheric nitrogen gas combines chemically with other elements (e.g., stream water) to form other nitrogen compounds that are then stored in the waterbody or taken up by benthic organisms.

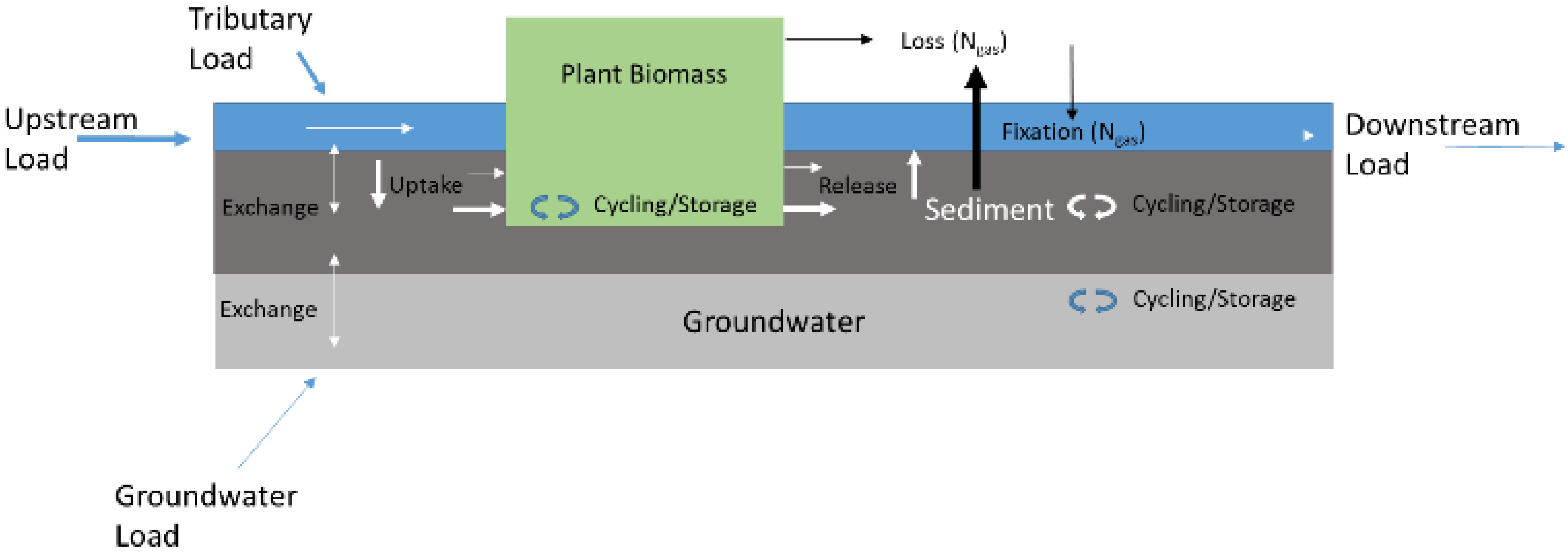

Figure 17. Conceptual model of nutrient cycling in wetlands.

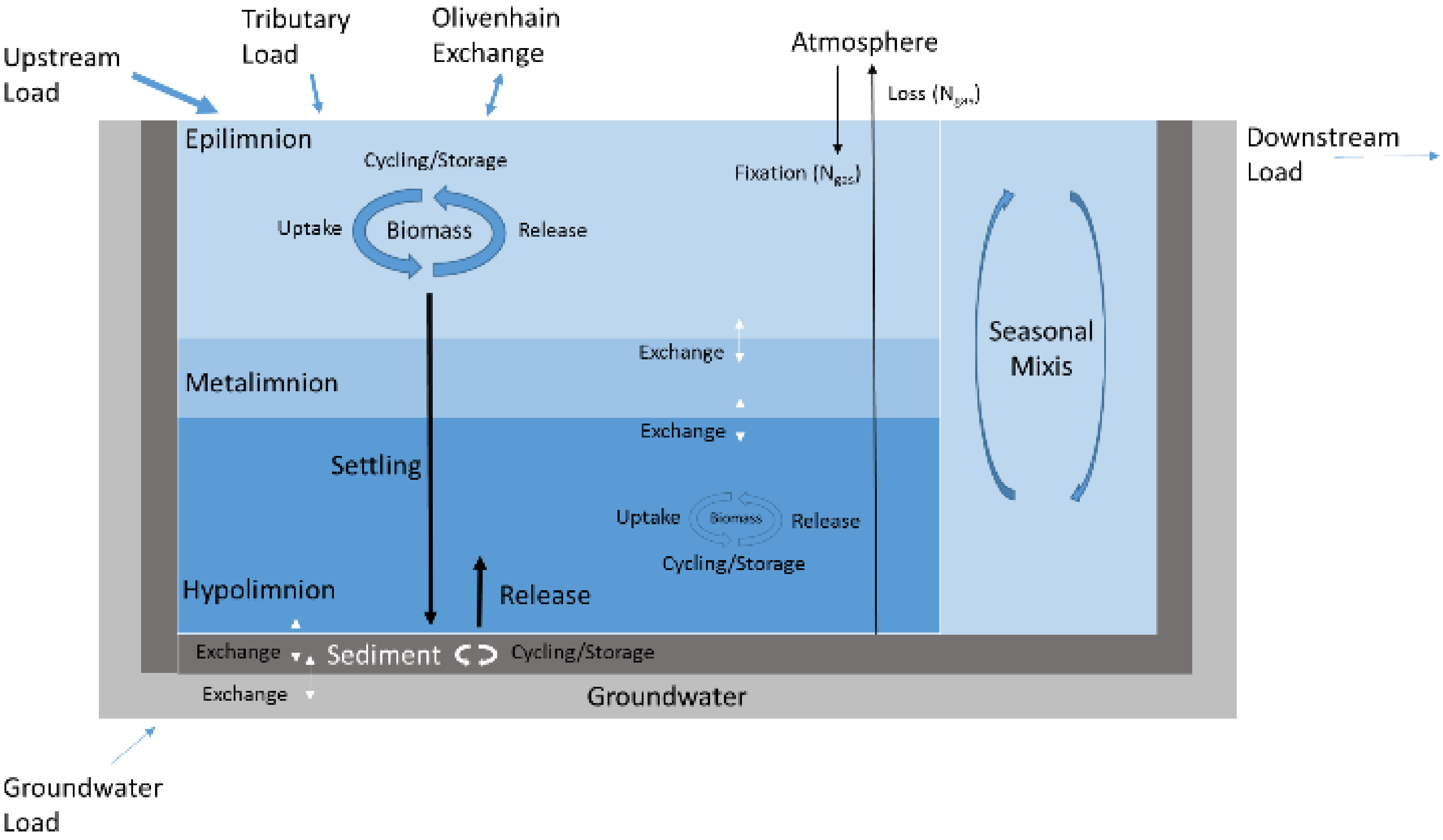

Figure 18. Conceptual model of nutrient cycling in the reservoir.

5.0 NUTRIENT BUDGET

Using the conceptual models above, a nutrient budgeting approach can be used to highlight important loads and data gaps. As discussed in Section 3, nutrient budget tables were developed for direct reservoir loads (Table 2-1), direct tributary reservoir loads (Table 2-2), upstream tributary loads during the low reservoir condition (Table 2-3), and upstream tributary loads during the high reservoir condition (Table 2-4). Also, quantitative data available to derive representative estimates are very limited and ranges of values in Tables 2-1 through 2-4 are preliminary estimates in order to compare the relative contribution from each of the key sources. Again, the goal here is not to identify specific values for each cell in the nutrient budget, but to use the tabular structure and existing data to guide study planning to fill important data gaps, leading to improved planning and decision-making by the City of San Diego.

5.1 DIRECT INPUTS

Direct inputs are composed of non-tributary inputs and tributary inputs and are discussed in that order.

5.1.1 Non-tributary

Non-tributary direct inputs to the reservoir include internal loading, atmospheric sources, Olivenhain Reservoir exchange, and groundwater (Table 2-1). Internal loading has been studied and rates for internals loads may be available from previous studies. Water column concentration data are abundant, but it is difficult to link the water column concentrations to internal loads.

Atmospheric inputs, while potentially minor, may also be available from regional dry and wet deposition estimates. Nitrogen fixation rates may be more difficult to estimate without direct measurements, but may be possible to estimate from regional studies.

Olivenhain Reservoir receives water from the aqueduct. Water quality data are likely available from that source or from Olivenhain surface water quality sampling itself as well as volume of water exchange between the reservoirs. Since exchange is bidirectional, a portion of the Hodges load is returned to Olivenhain. A simple mixing model may be possible to use, along with endpoint average concentrations and flow volumes to estimate net transport of nutrients.

Groundwater may be more difficult to estimate, but monitoring data of regional groundwater chemistry along with water budget information may be able to provide an estimate. This contribution is not expected to be large. A large knowledge gap related to this load, however, relates to the upstream wetland. During the low reservoir condition, it is possible that shallow subsurface flow occurs through the wetland and emerges somewhere offshore into the reservoir, carrying nutrient loads of unknown magnitude. Some exploration into the hydrology of the wetland-reservoir system as well as sampling of subsurface water for nutrient concentrations could help elucidate these gaps.

5.1.2 Tributary

There are four major direct tributaries to Hodges Reservoir: Felicita, Green Valley, Del Dios, and Moonsong Creeks (Table 2-2). Total flow, discharge, nutrient concentration, and load information can be estimated from existing sampling and model output. However contributory information for MS4, NPS, and natural loads was not available or was insufficient to make an estimate. LSPC modeled phosphorus loads for individual tributaries range between 45 and 2,751 kg/year. Summed across tributaries, the total phosphorus load ranged from 929 to 3,963 kg/year. For nitrogen, modeled loads for individual tributaries range between 248 and 15,590 kg/year. Summed across tributaries, the total nitrogen load ranged from 5,246 to 22,236 kg/year. Green Valley Creek had the highest phosphorus and nitrogen estimated loads followed by Felicita Creek and Moonsong Creek, which were similar, and lastly by Del Dios Creek, which had the smallest estimated total loads.

5.2 UPSTREAM INPUTS

Upstream inputs are composed of Kit Carson and Santa Ysabel Creeks, the latter being the large main tributary draining the upstream watershed. There are several large upstream tributaries to Santa Ysabel Creek, which are combined for this exercise to assume an estimate for Santa Ysabel Creek where it enters the wetland or reservoir. However, more detailed estimates of these sub-watershed loads could be made and used for future management. Upstream load estimates for these two creeks were divided into the low and high reservoir conditions.

5.2.1 Low Reservoir Condition

Low reservoir condition loads from upstream tributaries are expected to be small, as the upstream tributaries lack direct surface connections to the reservoir during this condition. However, this condition is not abrupt and there are periods as the system shifts from the high reservoir condition to the low reservoir condition, during which flow will slowly decline until the tributaries become fully disconnected. Similarly, as the reservoir increases in volume following periods of high, continuous precipitation, there may be periods when the upstream tributaries are connected for some time. In addition, even under the absence of surface connection, shallow subsurface connectivity may remain present for a substantial period of time, the extent and duration of which is unknown at present. Defining when the system is connected may be difficult and is likely not discrete, but on a continuum. Understanding this connectivity should be a priority.

Again, even in the absence of surface connection, there may be subsurface connection or even a small surface flow. Therefore, loads should be estimated for this time (Table 2-3). Santa Ysabel Creek and Kit Carson Creek are the main upstream tributaries. During low reservoir conditions, Kit Carson Creek and Santa Ysabel Creek appear to join at some indistinct point within the wetland area before discharging to the reservoir. Tributary loads are likely to be small or non-existent, at least surficially, as there is often little or no flow coming from Santa Ysabel or Kit Carson Creeks. However, even small storms may generate loads to the wetland and that may be important to quantify or document.

Lastly, even during the low reservoir condition, the wetland may export nutrients to the reservoir via shallow subsurface flow or even on the surface during occasional high flows. As stated, the wetland receives intermittent loads from the upstream watershed during storms in addition to those deposited during high reservoir condition loading. These nutrients continue to be processed and may move through the wetland ecosystem during the low reservoir condition (e.g., during the decline in flows from high to low reservoir conditions when shallow flows are still intact). In addition, sufficiently high flow during large storms may cause soil erosion in the wetland or surface flows may actually move through the wetland, in either case delivering nutrients attenuated in the wetland to the reservoir. Some understanding of the hydrology through the wetland and the extent of nutrient transformations and concentrations moving with water would be informative. A better understanding of the wetlands flora and fauna is necessary as well, and the impact on any nutrient transformations and transport. Almost nothing is known about nutrient conditions in the wetland (Table 2-3 and 2-4), including loads to the wetland, nitrogen fixation, net storage or loss due to biogeochemical processing in the wetland, or groundwater interactions.

5.2.2 High Reservoir Condition

During the high reservoir condition, nutrient loads from the upstream watershed have the capacity to be substantial and this transport will load both the wetland and the reservoir with dissolved and particulate nutrients (Table 2-4). Again, Santa Ysabel and Kit Carson Creeks are the main upstream tributaries and both discharge to the wetland before the reservoir. Concentration data for Santa Ysabel Creek are limited, but total loads have been estimated as part of a dry and wet weather sampling program. Phosphorus loads for Santa Ysabel Creek based on that sampling were estimated at 27,310 kg/year and for nitrogen, 8,300 kg/year. Total phosphorus load estimates based on models range from 1,360 kg/year to 4,663 kg/year and total nitrogen load estimates based on models range from 7,489kg/year to 26,479 kg/year.

Specific loads (i.e., MS4, NPDES, NPS, and natural) have not been determined. Kit Carson Creek has more data available. Although the data are insufficient to calculate specific source loads from the upstream watershed, a certain amount of flow, discharge, concentration and load data are available for Kit Carson Creek. Total phosphorus load estimates based on models and sampling range from 348 to 1,601 kg/year and total nitrogen load estimates from 1,907 to 8,197 kg/year for Kit Carson Creek. Combining these two tributaries results in the total upstream load estimates ranging from 1,188 to 28,911 kg/year phosphorus and 5,371 to 42,464 kg/year for nitrogen. Note that the high end of estimates for total phosphorus includes the sampling-based load, which were estimated only for total loads of Green Valley, Kit Carson, and Felicita Creeks combined (see Footnote #4 in Table 2-4).

For the model-based loads, the high end of the total phosphorus loads for the upstream tributaries (11,920 kg/year in Table 2-4) is larger than the high end of the total direct tributary load (3,963 kg/year in Table 2-2) by an order of magnitude, but those for total nitrogen are of the same order of magnitude (42,464 kg/year in Table 2-4 vs. 22,236 kg/year in Table 2-2). This is interesting and perhaps not unexpected. Phosphorus loads are often dominated by sediment-bound fractions and, hypothetically, during the high reservoir condition, the upstream tributaries, especially Santa Ysabel Creek, may transport a lot of sediment to the reservoir, including soils naturally elevated in phosphorus, but may less likely in nitrogen. The nitrogen comparison among sources suggests anthropogenic sources may dominate, and this hypothetically explains the comparable high reservoir condition nitrogen loads between upstream and direct tributaries, even though the upstream discharge and drainage area are substantially larger. It is important to remember that such conclusions are hypothetical and based on very limited data. It is clear from Tables 2-1 through 2-4. These summaries indicate that more data would be needed to test these hypotheses and better fill these gaps and the goal of the study plan being developed.

6.0 SUMMARY

Available data and documents were compiled and reviewed focusing on nutrient loading from the Hodges Reservoir Watershed. The literature search and data review yielded information to help identify key pathways and potential sources of nutrient loads to Hodges Reservoir, as well as critical data gaps. Based on this information, a conceptual model for nutrient loads and a nutrient budget for sources to the reservoir were developed.

The potential major sources of watershed nutrient loads into Hodges Reservoir are the tributaries (the direct tributaries to the reservoir and the upstream tributaries). Upstream tributaries enter the reservoir though the large wetland, in which much of the upstream nutrient load may be attenuated, therefore nutrient loads to the reservoir likely vary depending on whether the wetland is inundated or not (is disconnected or connected to the upstream watershed) the low reservoir condition and the high reservoir condition. The nutrient conceptual model for Hodges Reservoir was, therefore, split into these two conditions.

During the low condition, nutrient loads from upstream tributaries are largely attenuated in the wetland, and internal loads in the reservoir and direct tributary loads likely dominate the nutrient budget. During the high reservoir condition, upstream tributaries likely provide the largest portion of the total load and reload the reservoir with nutrients, which will proceed to cycle between the sediment and water column via internal loading during the subsequent low reservoir condition.

Nutrient budgets summarizing available data were developed. Preliminary results based on limited data, referenced in Table 2-4, indicate that phosphorus loads were dominated by the upstream tributaries during the high reservoir condition. Phosphorus loads were likely largely contributed via particulate fractions. Thus, phosphorus loads are likely proportional to sediment loads. The upstream tributaries[6] especially Santa Ysabel Creek, which drains the large upstream watershed, likely transport much larger amounts of sediment to the reservoir during high flow than the direct tributaries that drain smaller catchments.

Quantitative data that are critical to assess representative nutrient loads from the Hodges Reservoir Watershed are limited. Limited information was available to assess contributions from each of the key sources including MS4 and agricultural NPS. Critical key data gaps that need to be addressed include:

- Direct inputs
    - Tributary inputs
        - Source-specific information for MS4, NPS, and natural loads
    - Other inputs:
        - Internal loading within the reservoir
        - Atmospheric deposition (i.e., nitrogen)
        - Olivenhain Reservoir exchange with Hodges Reservoir
        - Groundwater: regional groundwater chemistry and nutrient concentration in subsurface flow in the wetland during the low reservoir condition
- Upstream inputs
    - Low reservoir condition
        - The extent and duration of surficial flow connectivity in the wetland
        - Shallow subsurface loads
        - Wetland nutrient cycling
        - Source-specific information for MS4, NPS, and natural loads
    - High reservoir condition
        - Source-specific information for MS4, NPS, and natural loads
        - Sediment loads

In addition, the City of San Diego has been considering BMPs to improve water quality in the reservoir and reduce nutrient loading (e.g., treatment wetlands, reservoir hypolimnetic oxygen system, and mid-lake vigorous epilimnetic mixing). Implementation of these BMPs in the future will likely change the nutrient loading and cycling in the reservoir. Thus, data collection should be designed to account for any changes that may result from the implementation of these BMPs in the future.

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[6] City of Escondido maintains a sediment detention basin (Eagle Scout Lake) located in Kit Carson Creek. Therefore actual sediment input from Kit Carson Creek should be evaluated with the consideration of the detention basin.

7.0 REFERENCES

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