Dissolved Oxygen Levels at Mast Park East

(RiverWatch WQM Site #13)

Nov. 2018 (<15% visible water surface, extensive vegetative growth and decaying organic matter)

Nov. 2006 (>85% visible water surface, open channel flow and little accrued organic matter)

John Kennedy, P. E. and Gary Strawn, WQM Team Leaders
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Overview Mast Park East DO Levels

Dissolved Oxygen (DO) concentration levels are the most important water quality indicator of overall ecological health of a waterbody. SDRPF's RiverWatch WQM Team has been monitoring DO concentrations (as well as other water quality metrics) on a continual monthly basis since October 2004. This technical memo (TM) provides interested parties monitoring results pertaining to monthly DO levels, seasonal patterns, annual averages and decadal trends observed at Mast Park East (MPE) WQM Site #13.

Basic DO expressions and relationships used in this report are provided in **Table 1** below. The depletion threshold is the RWQCB's objective of maintaining a minimum DO of 5 mg/L in fresh inland coastal waters at all times. Over the last 15 years, the MPE site has fallen below this value 96 percent of the time. The data also indicate DO levels have been in the hypoxic zone (<2.5 mg/L) continously for the past 10 years and <1.0 mg/L (exaerobic) eight out of the last 12 months.

Table 1 - Dissolved Oxygen Expressions

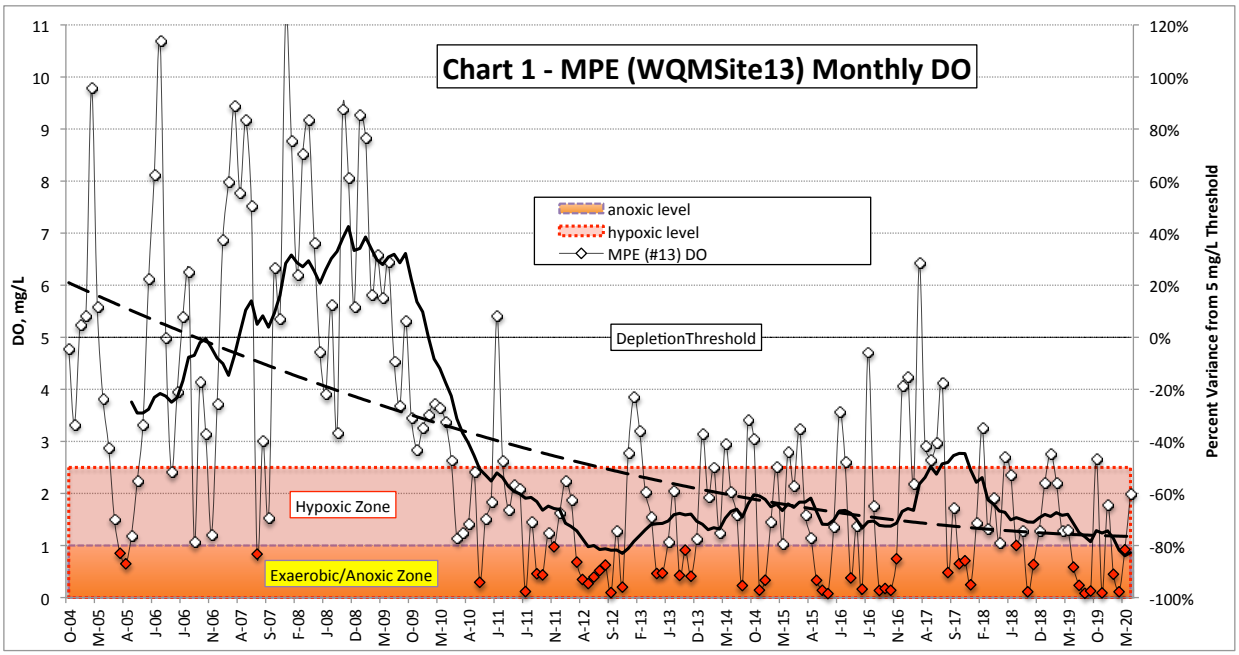
DO, mg/L	DO%Sat. @18oC	DOd, mg/L [a]	% +/- of 5 mg/L	DOh, mg/L [b]	Threshold Levels
12	124%	7	140%		
11	113%	6	120%		
10	103%	5	100%		
9	93%	4	80%		
8	82%	3	60%		
7	72%	2	40%		
6	62%	1	20%		
5.0	**52%**	**0**	**0%**		**Depletion**
4.5	46%	-0.5	-10%		
4	41%	-1	-20%		
3.5	36%	-1.5	-30%		
3	31%	-2	-40%		
2.5	**26%**	**-2.5**	**-50%**	**0.0**	**Hypoxic [a]**
2	21%	-3	-60%	-0.5	
1.5	16%	-3.5	-70%	-1.0	
1.0	**10%**	**-4**	**-80%**	**-1.5**	**Exaerobic [b]**
0.5	5.2%	-4.5	-90%	-2.0	
0	**0%**	**-5**	**-100%**	**-2.5**	**Anoxic [c]**

a) DOd = (DO-5), where negative values represent depletion below a threshold concentration of 5 mg/L.
b) DOh = (DO-2.5), where negative values represent concentration below a hypoxic level of 2.5 mg/L.
c) Onset of hypoxic conditions in inland waters are identified as high as 3 mg/L or as low as 2.0 mg/L DO.
d) Exaerobic level; (1.0 mg/L DO) refers to the transition zone beteeen aerobic and anaerobic conditions.
e) Anoxic (DO = 0 mg/L) condition is also refered to as anaerobic.

Monthly Dissolved Oxygen Concentrations (DO)

Chart 1 presents DO concentrations (black markers) monitored at Mast Park East (MPE or WQM Site#13) on a monthly basis since October 2004. The 12-mo running average DO values (solid black line) demonstrate the eposodic decline in site DO concentrations beginning in late 2009 and persisting to present. The overall 15-yr trend in oxygen levels (or level of depletion below the 5 mg/L threshold) is shown as a dashed black line. Over the last 11 years (132 mo), there have only been two months when DO levels were recorded above 5 mg/L, in other words 98% of the time DO levels have been below the DO depletion threshold. Furthermore, DO concentrations were found in the hypoxic zone (<2.5 mg/L) for 95 out of 120 months (80% of the time) and within the exaerobic or near-anoxic zone (<1.0 mg/L) for 45 months or 37% of the time. The 12-mo running average DO value (solid black line in Chart 1) has fallen below 1 mg/L exaerobic/near-anoxic zone threshold over the past month; similar to depletion levels (~80%) experienced during the summer (J/J/A/S) and fall (O/N) of 2012.

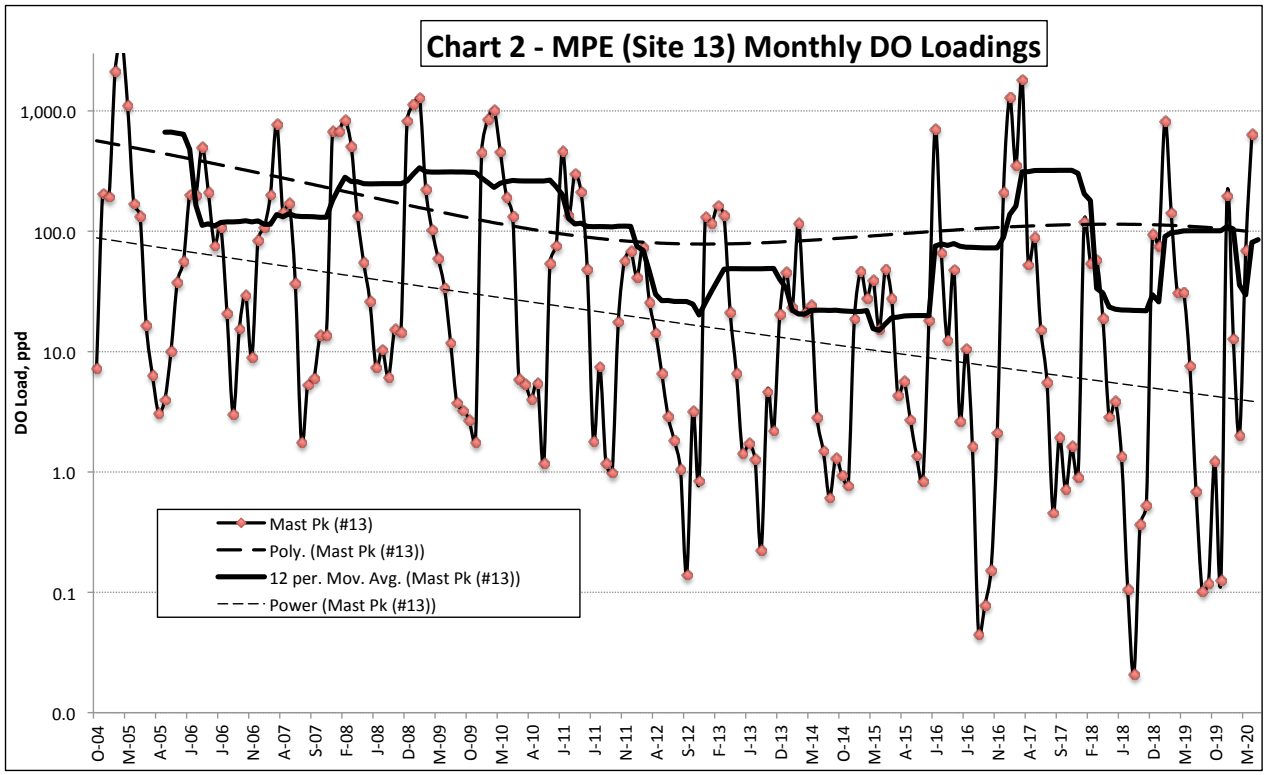
DO concentration levels at Mast Park East are representative of a highly eutrified watercourse that exhibits little seaonal excursions above the 5 mg/L depletion threshold level. This relatively shallow portion of the Upper Santee Basin reach is both heavily overgrown with invasive aquatic plants (e.g. ludwigia/creeping water primrose), filled with slowly decaying organic sediments (benthos) and buffered by organic-rich shallow wetlands. Over the past decade there have been few major flood flows (freshets) to flush this portion of the river channel. Over the past 10 years DO concentration has averaged 1.71 mg/L on a 12-month (Oct-Sept) basis and 1.12 mg/L during the 4-mo (J,A,S.O) minimum dry-weather flow (DWF) period.



Monthly Dissolved Oxygen Loads (DOL)

Chart 2 presents calculated monthly DO loads experienced at the MPE site based on estimated streamflow. Streamflow at Mast Park is assumed to be approximately half (45%) of the flow measured 1.4 miles downstream at the USGS gauging station (Site#11-WHB). The DO Load is the product of DO concentration times streamflow. DOL (in pounds O_2 per day or ppd) = DO (in mg/L) x average daily flow (in cfs) x 5.394 (conversion factor from mg/L to lbs/cf).

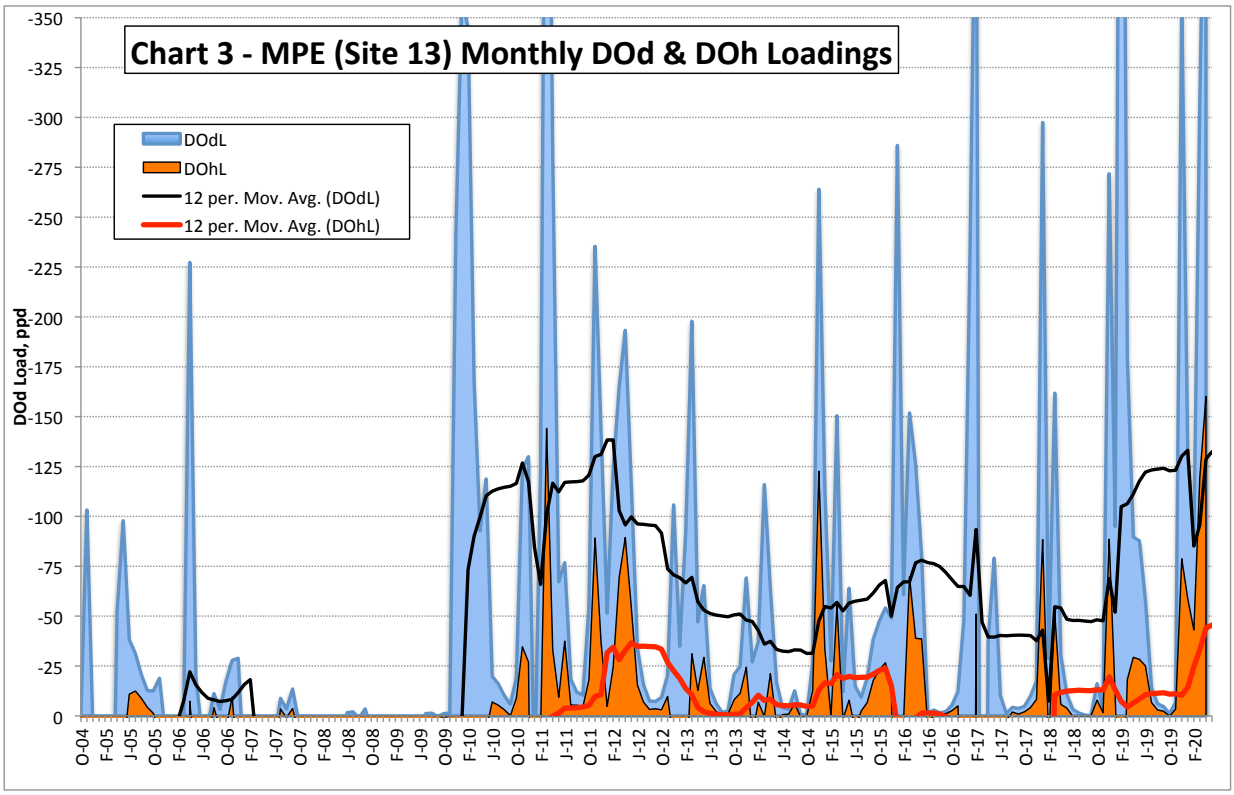
Running average DOL at Site #13 (MPE) has ranged by a factor of ten; from 30 (WY14) to over 400 ppd (WY17) during the last decade. The fluctuation is a product of both declining DO concentrations and seasonal variances in streamflow that during the WY10-14 drought cycle reached record lows. Summer minimum flow duration has tended to increase over the 15-yr monitoring period. The trend in 12-mo. running average DO loadings (solid black line) has in general been downward over 15 years although monthly loadings over the past few years has fluctuated considerably. The annual average DO load over the past decade is 160 ppd based on average daily flow; while the 4-mo (J,A,S,O) DWF period averaged less than 7 ppd. Over 85% of the total oxygen load conveyed by/in the river at this site occurs during the four wet-weather months (D,J,F,M) of the year.



Monthly Dissolved Oxygen Depletion Loads (DOdL)

Chart 3 presents DO depletion loadings (DOdL and DOhL) that represent the reciprocal amount of oxygen required daily per cubic foot of water to maintain DO above depletion threshold levels of 5 mg/L and 2.5 mg/L (hypoxic) times streamflow. The DOd (blue) and DOh (orange) loadings are shown both monthly (shaded areas) and as 12-mo running averages (solid black and red lines) for the MPE site over the past 15 and a-half years.

The 12-mo running averge average day DOdL at the site has ranged between -20 and -100 ppd while DOhL has ranged been between -5 and -50 ppd over the last decade. Peak loadings have been in excess of -400 ppd DOdL and -100 ppd DOhL during the same period (2010-2020). The average annual daily DOdL over the past 10 years is -48.5 ppd, while the 4-mo DWF average daily load is -3.9 ppd. The reciprocal of these DOdL values is the quantity of oxygen reguired daily per cubic foot of water to remain above 5 mg./L (depletion threshold) and 2.5 mg/L (hypoxic threshold), respectively.



Annual Average Dissolved Oxygen and Streamflow

The relationship between dissolved oxygen metrics (DO, DOL, and DOdL) and streamflow (expressed in cfs) for running average daily (AADF) and 4-mo dry weather (ADWF) conditions extending over the 15+ yr monitoring period are shown in **Charts 4.1-4.3** on the next page.

Streamflow (AADF-blue and ADWF-purple lines) for each water year (WY05-WY20/2) values are shown (right logritmithic axis) on each of the charts. The average annual (ADO) and average dry-weather (DWDO) dissolved oxygen concentrations by water year monitored at site #13 (MPE) are the blue and red verticle bars (left arthmetic axis) on **Chart 4.1**. **Chart 4.2** presents DO loadings (left log axis) by average annual (ADOL) and 4-mo dry-weather (ADWOL) period (blue and red verticle bars, respectively) vs streamflow (rt. axis). Dry weather DOL and ADWF are closely correlated throughout the 15-year period of record. **Chart 4.3** presents DOdL values (left arthmetic axis) by water year for average annual (blue bar) and 4-mo dry weather (red bar) conditions. Highest DWDOd loadings occur in years of greatest ADWF. WY20 values are approximations for the first-half of the current water year only.

These loads indicate is that from 1 to 10 pounds of O_2 per cubic foot of water volume will be needed daily to avoid hypoxic condtions during the 4-mo. dry weather flow period and from 8 to 70 ppd throughout an entire water year. In order to maintain DO levels at or above a depletion threshold of 5.0 mg/L, from 3 to 30 ppd of O_2 per cubic foot of water are required during minimum dry weather flow conditions and between 30 and 130 pounds daily throughout the year depending on average streamflow.

Although rough correlation between DO levels and streamflows (AADF and ADWF) are evident from the monitoring data; another relevent conclusion regards the trend in DO levels over the past 15 and a-half years, irrespective of the fluctuations or variances in average daily and dry-weather streamflow. The monitoring data also show that the rate, degree and extent of decline in DO at MPE (and environs) occured due to a fairly rapid change in the biotic state of the river. This reach of the river transitioned from a relatively healthy state (ADO > 5 mg/L) to one of imbabance characterized by very low DO levels persistant throughout the year, poor circulation, high organics deposition and subsequent decomposition. This oxygen imbalance, resulting in excessive europhication, forms a localized 'nutrient sink', whereby primary production is continiously out weighted by respiration. The primary accelerant causing chronic hypoxia at the site over the past decade is believed to be the accrual of decaying biomass (predominatly ludwigia and other noxious invasives) within both the river channel (both substrate and benthos) and on its peripheral (shallow and irregular wetland) floodplain.

Artificial reaerateion may have a measurable impact on low DO levels at MPE depending on specific performace characteristics of both oxygen supply and delivery equipment, the extent and duration of its application, circulation and diffusion. The estimated volume of the third pond, situated just upstream of the footbridge (site #13) where the diffuser line is located, is in the neighborhood of 20,000 cubic feet (150 thou. gal.). To raise the DO level one mg/L at 1 cfs over a 24-hour period reguires 5.4 pounds of oxygen. Increasing DO levels within the third pond above hypoxic conditions hypothetically requires supplying 20-30 pounds of oxygen daily. Taking into consideration relative efficiencies of equipment, circulation limitations, bio-fouling and other operational constraints,; actual DO replenishment could entail twice this amount. Regardless, measurable beneficial impact on current exaerobic levels, especially immediately downstream, can be ecpected with proper operation of such devices. The long-range management approach to significantly improving oxygen levels within much of 2.3 mile reach of river (from Magnolia Ave. to Carlton Oaks CC), is expected to require dredging and removal of large quantities of organic matter (biomass) in order to reduce oxygen demand, improve channel hydraulics and help restore ecological balance to this portion of the river.

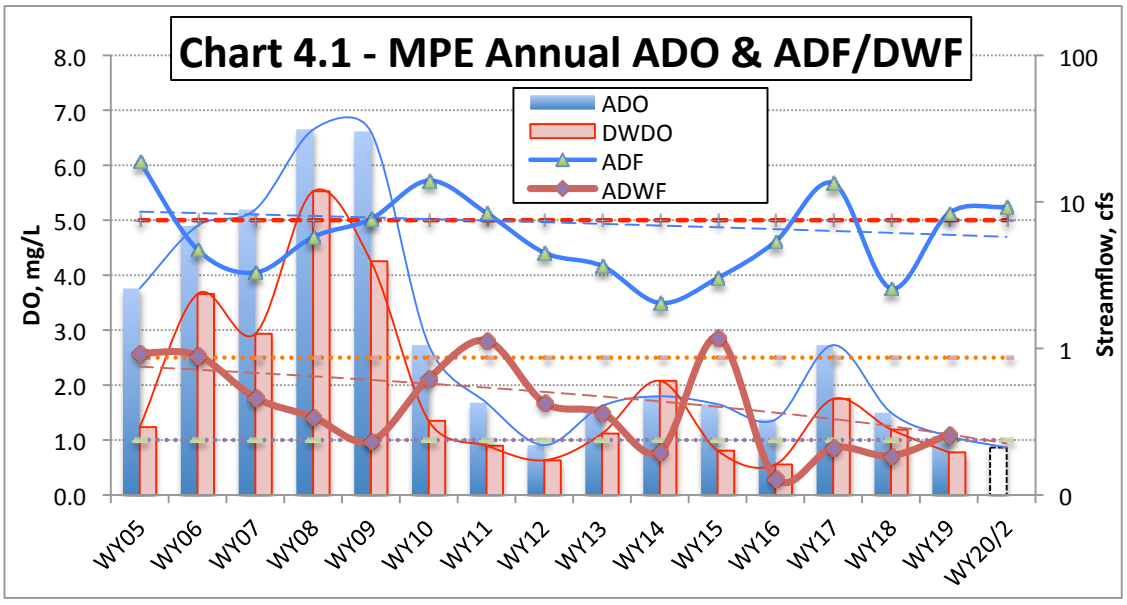


Chart 4.1 - MPE Annual ADO & ADF/DWF
DO, mg/L
Streamflow, cfs
ADO
DWDO
ADF
ADWF
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
100
10
1
0
WY05
WY06
WY07
WY08
WY09
WY10
WY11
WY12
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WY14
WY15
WY16
WY17
WY18
WY19
WY20/2

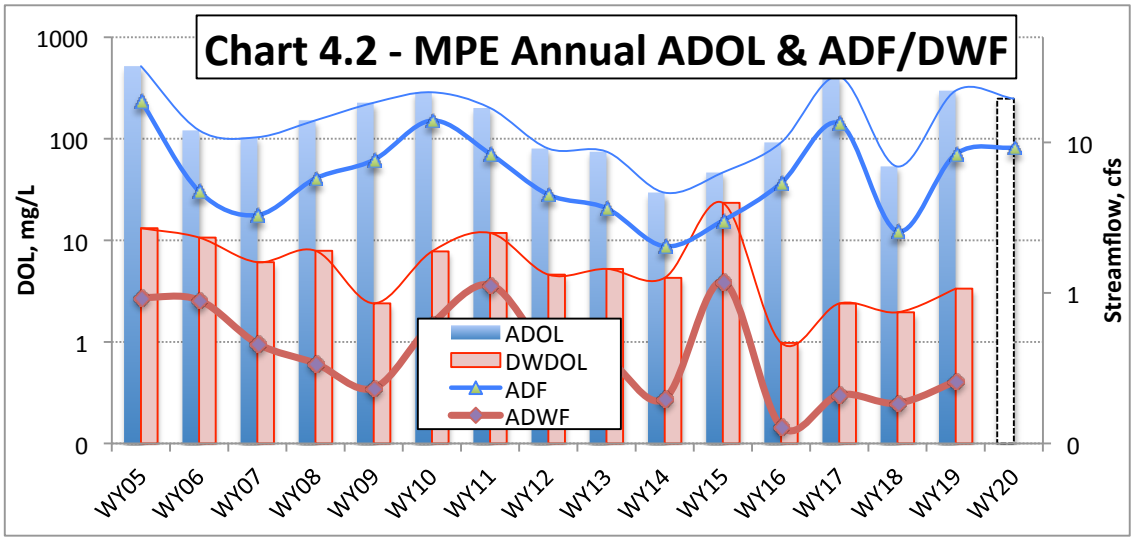
Chart 4.2 - MPE Annual ADOL & ADF/DWF
DOL, mg/L
Streamflow, cfs
ADOL
DWDOL
ADF
ADWF
1000
100
10
1
0
10
1
0
WY05
WY06
WY07
WY08
WY09
WY10
WY11
WY12
WY13
WY14
WY15
WY16
WY17
WY18
WY19
WY20

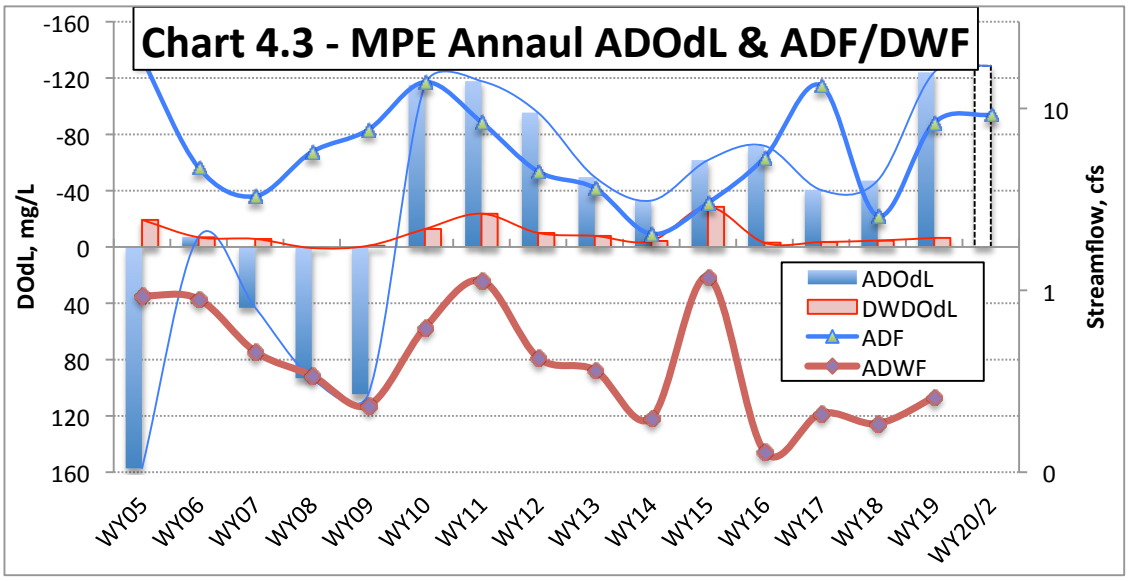
Chart 4.3 - MPE Annaul ADOdL & ADF/DWF
DOdL, mg/L
Streamflow, cfs
ADOdL
DWDOdL
ADF
ADWF
-160
-120
-80
-40
0
40
80
120
160
10
1
0
WY05
WY06
WY07
WY08
WY09
WY10
WY11
WY12
WY13
WY14
WY15
WY16
WY17
WY18
WY19
WY20/2

Glossary of Common Aquatic Terms

aerobic - relating to, involving or requiring free oxygen.
anerobic - relating to, involving or requiring an absence of free oxygen (e.g., denitrifing aquatic and terrestrial bacteria).
allochthonous - matter/material (e.g., nutrients) imported'delivered into an ecosystem.
anoxic - greatly deficient in oxygen (threshold often set at 1 mg/L instead of 0 mg/L).
anthropormorphic - having human characteristics
autochthonous - indigenous materials, rather than transported from another place.
autotrophic - of or relating to organisms (e.g., green plants, algae) that can make complex organic nutritive compounds from simple inorganic sources through photosynthesis.
autotrophic metabolism - P/R ratio <1 (Primary Production/Respiration)

benthos - flora and fauna found on bottom (and in bottom sediments) of a water body

exaerobic - zone between anoxic (0 mg/L DO) and hypoxic (2.5 mg/L DO) condition in water (threshold DO approx. 1 mg/L).
eutrophic - waters with high nutrient values, allowing microrganisms and algae to grow in large numbers. Opposite of '**oligotrophic**' (i.e. waters low in nutrients, high in DO).

heterotrophic - requiring organic compounds of carbon and nitrogen for nourishment; "most animals are heterotrophic".
hypoxic - oxygen deficiency in any biotic environment (2-3 mg/L DO threshold)
hysteresis - lag phenomenon whereby a physical proerty value (e.g., DO in water) lags a change in effect (e.g., nutrient content, streamflow, daylight)

lotic - flowing waters (much of the Santee Basin and Mission Valley are considered placid lotic systems)
lentic - relatively still waters w/minimal hydraulic through-put (e.g., ponds, lakes and wetlands), portions of the Lower San Diego River reach lentic conditions in late summer.

nutrient sink - an aquatic ecosystem which has a tendency to store organic matter and thus the nutrients within it (e.g., a marsh, swamp, bog or riparian wetland)
nutrient sprialling - the inter-dependent cycling (uptake, transformation and release) of soluable nutrients (primarily N & P) in water while being transported downstream.

primary production - (P) synthesis of organic compounds from atmospheric or aqueous cabon dioxide; principally through the process of photosynthesis (algae and aquatic plants are key primary producers in water).

respiration - (R) process in living organisms involving production of energy; typically with intake of oxygen and release of carbon dioxide from oxidation of complex organic substances. Simply put, the process whereby animals obtain oxygen from water.

Commonly Used Acronyms/Abbreviations in Aquatic Ecology

AADF - average annual daily streamflow
ADWF - average daily dry weather streamflow

BOD - Biochemical (or Biological) Oxygen Demand; amount of putrescible organic matter present in water.

CBOD - Carbonacious Biological Oxygen Demand (subset of BOD; other being nitrogenous actors - NBOD)
COD - Chemical Oxygen Demand; total amount of oxidizable (organic and inorganic) matter present in water.
CPOM - Coarse Particulate (>1 mm diam.) Organic Matter

DIN -Dissolved Inorganic Nitrogen (N_2) present as ammonium (NH_4^+), nitrate (NO_3^+) and nitrite (NO_2^-)
DIP - Dissolved Inorganic Phosphorous (also know a orthophosphate or PO_4^{-3})
DO - Dissolved Oxygen concentration (typically expressed in mg/L)
DOL - Dissolved Oxygen Load = **DO x rate of flow**, commonly expressed in pounds per day (ppd).
DOd = (DO-5) - amount of depleted O2 below a threshold value of 5 mg/L.
DOh = (DO-2.5) - amount of depleted O2 below a hypoxic threshold value of 2.5 mg/L.
DOdL - Dissolved Oxygen Load below depletion load level **(DO-5) x flow rate**
DOhL - Dissoved Oxygen load below hypoxic load level, **(DO-2.5) x flow rate**
DON - Dissolved Organic Nitrogen (forms include: urea, uric acid, amino acids)
DOP - Dissolved Organic Phosphorous

FPOM - Fine Particulate (<1 mm diam.) Organic Matter
LSDR - Lower San Diego River (watershed managment HSA 907.10)
MPE - Mast Park East, RiverWatch water quality monitoring site #13

ORP - Oxidation Reduction Potential (anoxic phase) **SOTE** - Standard Oxygen Transfer Efficiency (%), amount oxygen transfered/amount supplied from aeration equipment

PON - Particulate Organic Nitrogen
POP - Particulate Organic Phosphorus
PIP - Particulate Inorganic Phosphorus

SAE - Standard Aeration Efficiency (lbs/HP-hr) = **SOTR/P**, (P is power), amount O2 transferred/energy consumed
SOTR - Standard Oxygen Transfer Rate (pounds/hr)

TOC - Total Organic Carbon - the amount of carbon found in an organic compund; often used as a non-specific indicator of water quality

WY - Water Year (1st October - September 31st of following year)
12 mo. RA - Running Average value calculated over a continous 12 month period.

References

1) **Factors contributing to hypoxia in rivers, lakes, and streams,** Mallin, et al, UNC-CMS, ASLO, Limnol. Oceanogr. (p690-201), 2006 [Wiley Online Library Archives}

2) **Santee Basin Salt/Nutrient Management Plan**, Padree Dam MWD, Final Oct. 2013. *<https://www.padredam.org/DocumentCenter/View/3042/Santee-Basin-SNMP-Final-101513?bidId=>*

3) **San Diego River Watershed Monitoring and Assessment Program**, B.B. Bernstein, SWAMP-MR-RB8-20014-0001, Final Report, Jan. 20, 2014. *<https://www.waterboards.ca.gov/sandiego/water_issues/programs/swamp/docs/SD_River_Program_Document_Final_04_30_2014.pdf>*

4) **San Diego River Watershed Management Area Water Quality Improvement Plan,** Draft**,** City of Santee, May 11, 2015. *<https://www.cityofsanteeca.gov/home/showdocument?id=8271>*

5) **Lower San Diego River Dissolved Oxygen Levels,** J.C. Kennedy SDRPF RiverWatch, San Diego Eiver Coalition Meeting Presentation, June 2015. *<https://www.sandiegoriver.org/documents/DO_kennedy.pdf>*

6) **Establishing Research and Management Priorities for Invasive Water Primrose (Ludwiga spp)**, Netherland, Green & Thompson, USACOE, ERDC/EL TR-16-2, Feb.2016. *<https://apps.dtic.mil/dtic/tr/fulltext/u2/1002917.pdf>*

7) **Background WQ Analytics on the Upper FSDRIP Channel,** J.C. Kennedy, SDRPF RiverWatch TSM, Jan, 2018. *<https://www.sandiegoriver.org/docs/Resources_Online_Information_Center/TechnicalSupportMemo_FSDRIP_WQ.pdf>*

8) **Lower San Diego River Water Quality (2005-2019),** Annual Water Quality Monitoring Report, SDRPF J.C. Kennedy, Nov. 2019 *<https://www.sandiegoriver.org/docs/Resources_Online_Information_Center/2019AnnualWaterQualityReport.pdf>*

9) **San Diego River Watershed Management Area Water Quality Improvement Plan 2018-2019 Annual Report,** Project Clean Water, Final, Jan 2020. *<https://projectcleanwater-my.sharepoint.com/personal/support_projectcleanwater_org/_layouts/15/onedrive.aspx?>*

10) **Monthly WQM Report, Lower San Diego River** - SDRPF RiverWatch April, 2020 *<https://www.sandiegoriver.org/docs/Resources_Online_Information_Center/2020Apr_MonthlyWaterQualityReport.pdf>*

jck (5/1/20)