Background WQ Analytics on the Upper FSDRIP Channel

East (upstream) end of the FSDRIP flood control channel (mid-Mission Valley reach of the Lower San Diego River) viewing west from Qualcomm Way bridge to Camino Del Este overpass.

Upper FSDRIP Channel Hydrology and Water Quality

This technical support memo (TSM) addresses some of the basic hydrologic and water quality information of interest in carrying out an artifical aeration system study on waters located within the upper FSDRIP channel of the Lower San Diego River. FSDRIP, a flood-control channel extending roughly 7,000 ft downstream from the Qualcomm Way (*Q'Way*) bridge to just east of the SR163 bridge crossing was constructed over 30 years ago and placed in service in 1987. The channel is fairly wide (50-100 ft) but reasonably shallow (5-12 ft at most locations) under dry-weather flow (DWF) conditions. Original channel depth was designed for up to 22 ft when flowing full, prior to spilling onto the valley floor/flood plain. The volume of water contained within the channel is in the vicinity of four million cubic feet (30 Mgal) under DWF conditions. The river improvement project was designed not only to effectively mitigate against major flooding of the valley floor but also to enhance riparian habitat and improve water quality. Over the last decade, low dissolved oxygen (DO) levels have been monitored by SDRPF's Riverwatch group within this reach of the river during periods of low flow. Resultant fish kills, malodors and other unattractive consequences of eutrophication, occured most extensively during the late summer of 2014 and again in 2015. The past several year's have seen some improvement.

A site at the upper-most end of the channel, just west of the *Q'Way* bridge (cover photo), was selected to install an array (five) of solar-powered surface water aerators during the first week of Oct. 2017. The aerator array and associated data loggers were removed in late Nov. following seven weeks of dry weather flow. In order to determine how much they may help in improving the dissolved oxygen (DO) content of the river water, a water characteristics study was implemented to better define oxygen levels and other water quality metrics upstream, at and downstream of this array. The analytics provided in this memo are intended to be of general support in reviewing preliminary field data and formulating future study efforts.

This technical meno (TM-1/18) contains six sections:

1 - Background data on DO concentration levels as well as streamflow (ADWF) and water temperatures monitored by SDRPF's RiverWatch team over the past 13 years. [Charts 1.1-1.3]

2 - Interpolated *Q'Way* DO Metrics (2005-2017) During DWF conditions. [Charts 2.1-2.3]

3 - Interpolated *Q'Way* DO Metrics During the 2017 DWF period. [Charts 3.1-3.4]

4 - Interpolated *Q'Way* WQ Metrics During the 2017 DWF period [Charts 4.1-4.4]

5 - Background WQ Data Interpretation.

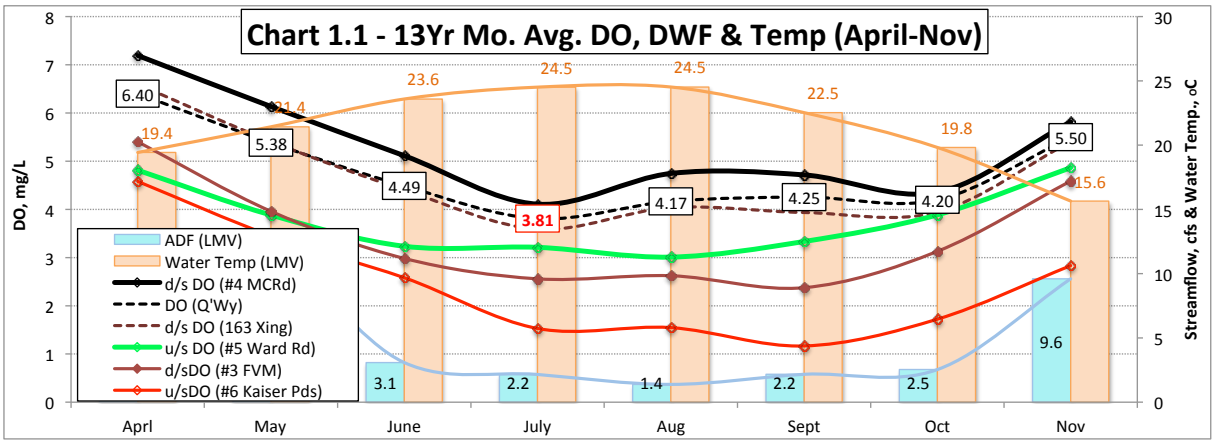
6 - Technical support references pertaining to stream channel aeration and monitoring.

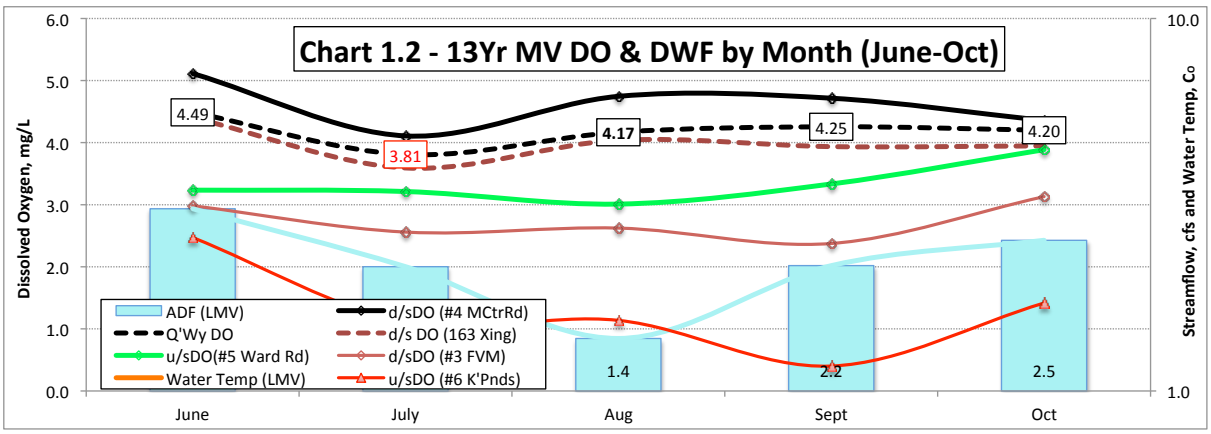
Abbreviations

ADWF - average daily dry weather flow
BOD - biochemical oxygen demand
COD - chemical oxygen demand
DO - dissolved oxygen concentration
DO4 - 4.0 mg/L DO
DOD - dissolved oxygen deficit (DO4 - DO)
DOL - dissolved oxygen load (DO x ADWF)
DOL4 - dissolved oxygen load at 4 mg/L DO
DODL - dissolved oxygen deficit load (DOL4 - DOL)
DW & DWF - dry weather & dry weather flow
FSDRIP - First San Diego River Improvement Project
Percent DO Deficit - (DO4 - DO)/DO4 x 100
Percent DODL - (DOL4 - DOL)/DOL4 x 100
SOD - sediment (or benthic) oxygen demand
u/s & d/s - upstream & downstream
WWF - wet weather flow
WQ & WQM - water quality & water quality monitoring

Lower San Diego River WQ monitoring sites in Mission Valley:
Q'Way - Qualcomm Way Bridge crossing (upper end FSDRIP channel)
MCRd - Mission Center Road (WQM site #4, mid-reach FSDRIP)
163 Xing - SR163 bridge crossing (lower end FSDRIP channel)
Ward Rd - Ward Road Bridge river crossing (WQM site #5)
Kaiser Pnds - San Diego Mission Road river crossing (WQM site #6)
ABF - Admiral Baker Field at Zion Rd. (WQM site #7)
FVM - Fashion Valley Mall (WQM site #3)
YMCA - River Gardens Preserve at Mission Valley YMCA (WQM site #2)
SDEst - San Diego River Mouth at Estuary west of Pacific Hwy (WQM site #1)

Section 1 - Mission Valley Dry Weather Flow, Water Temperature and Dissolved Oxygen (13-Yr. Mo. Averages)





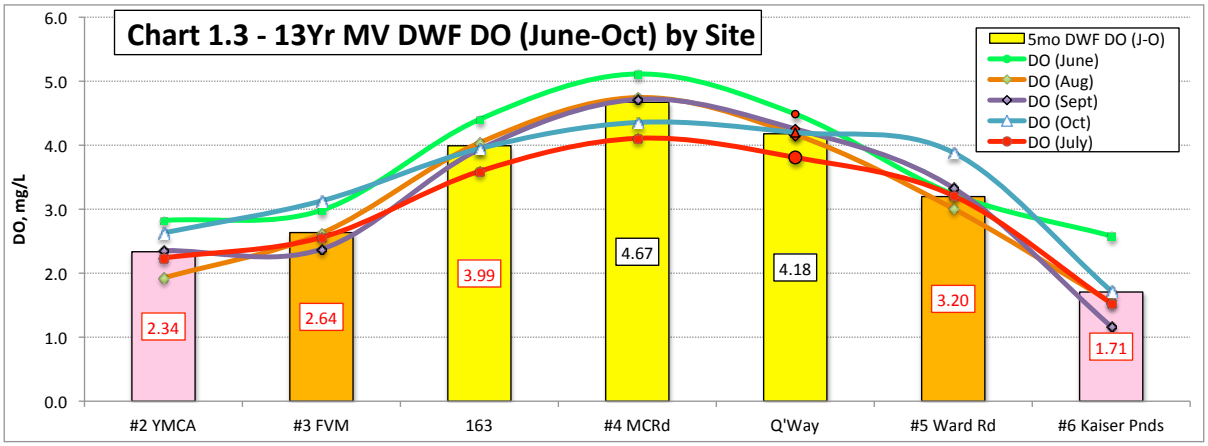


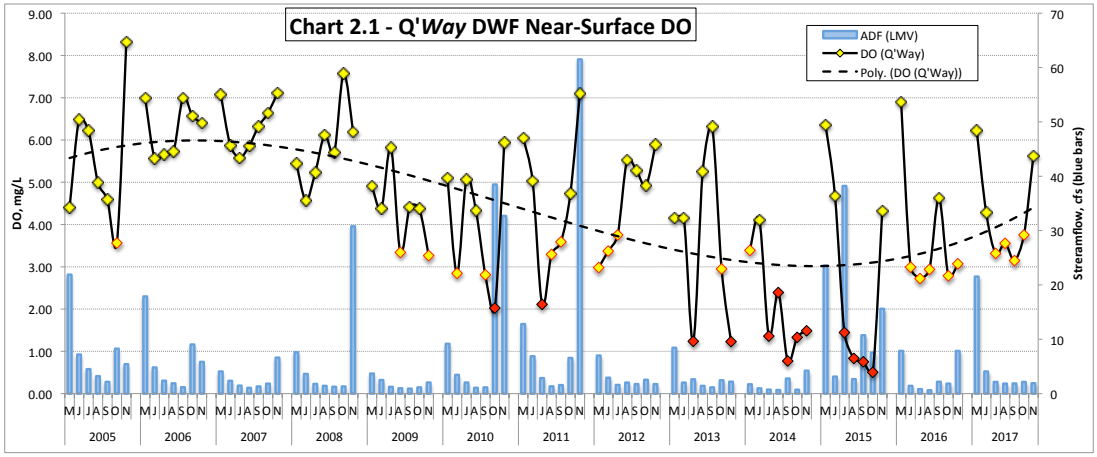
Chart 1.1 presents Mission Valley Average Daily Streamflow (ADWF-blue bars and line), average daily water temperature (tan bars and line) and average monthly DO concentrations (solid and dashed lines) for the eight dry weather months, May through November. The black line is d/s site#4 (mid-FSDRIP or Mission Center Rd-*MCRd*), the black and brown dashed lines are the upper FSDRIP *Q'Way* site and lower or d/s end of FSDRIP (*163 Xing*). Also shown are the u/s green line site#5 (*Ward Rd*), red line site#6 (Kaiser Pnds) and d/s brown line site#3 (Fashion Valley Mall-*FMV*). The near-surface DO values for the upper end of FSDRIP (*Q'Way* site) and the lower end (*163 Xing* site) are calculated based on the past 13 years of monthly RiverWatch data for site #'s 3(*FVM*), #4(*MCRd*) and #5(*Ward Rd*). Over the past 13-yrs the average DO level for in the upper FSDRIP reach (*Q'Way* site) in July (lowest DWF month for DO) is found below a DO deficit (DOD) threshold value of 4 mg/L as shown in red.

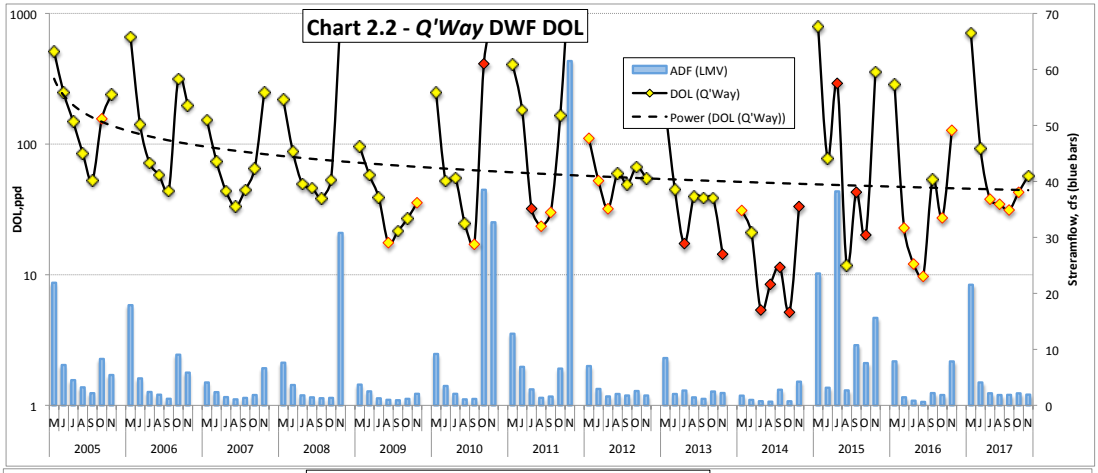
Chart 1.2 Chart 1.2 presents the same information as Chart 1.1 regarding dry-weather variation in average DO concentrations and ADWF for Mission Valley excluding the three transionial flow (from WWF to DWF and back) months of April, May and November. The June to October *Q'Way* DO values (as boxed), are calculated from u/s #5 (*Ward Rd*) and d/s #4 (*MCRd*) sites, as in Chart 1.1. July is the only month that *Q'Way* DO values average less that 4 mg/L (DOD threshold) over the past 13-yr WQ monitoring period. August is typicaly the month of lowest ADWF, followed by July and September. DO values remain below the 4 mg/L DOD threshold level throughout the five month DWF (June-Oct.) period for the two upstream sites (#5 & #6) and downstream (#3 & #2) of the FSDRIP channel.

Chart 1.3 DO concentrations for the five months of DWF (June-Oct) are provided by river site in Chart 1.3. The 5-mo. DWF averages for each site along the river are shown as bars; the individual months as lines. The FSDRIP reach averages are shown in yellow, the adjacent u/s(#5 *Ward Rd*) and d/s(#3 *MCRd*) sites in orange and the extended sites (#6 *Kaiser Pnds*) and (#2 *FVM*) in pink. Average DO levels are consistantly lower both upstream and downstream of the FSDRIP channel throughout the dry weather period. The DO values in orange (#5&#3) average between 2.5 and 4 mg/L, whereas the pink sites (#6&#2) average less than 2.5 mg/l in what is refered to as the 'hypoxic zone'. July typically represents the lowest recorded DO levels for the FSDRIP (*Q'Way*-to-*163 Xing*) reach.

Measuring the impact/effect of small surface aerators on river DO levels above 4 mgL is difficult due to the magnitude and variance in background DO. Reaeration coeffecients improve significantly as DO decreases below 3-4 mg/L and DOD rises. The optimal period for assessment studies is during the summer months of lowest DO and DWF (typically July, August and September).

Section 2 - Interpolated *Q'Wy* DO Metrics During DWF (2005-2017)





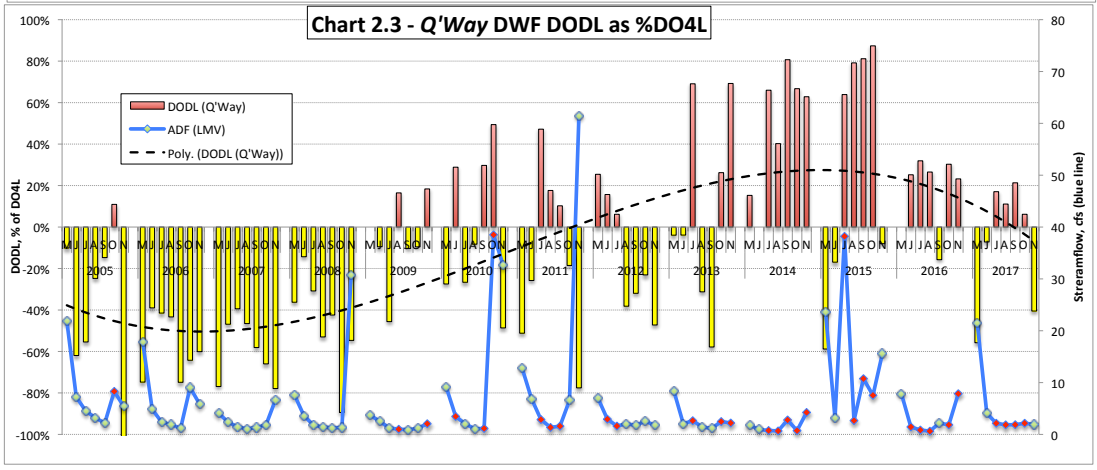


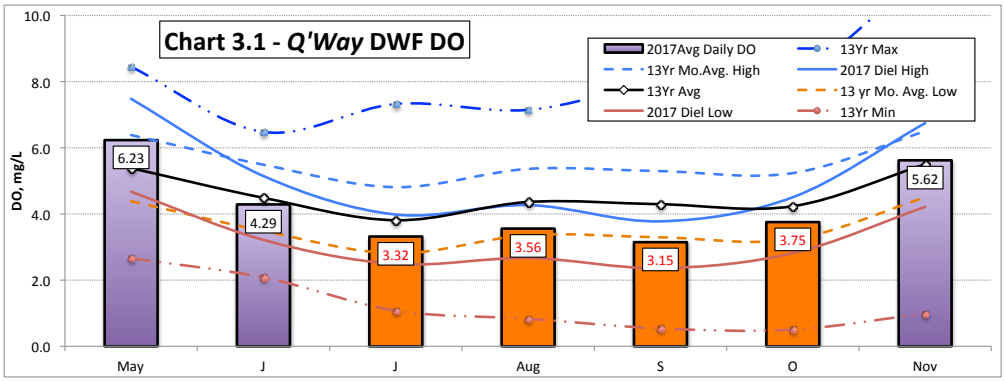
Chart 2.1 Interpolated near-surface DO levels at the *Q'Way* site during the annual 7-mo. DWF (May-Nov.) extending from 2005 through 2017 based on u/s site #5 (*Ward Rd*) and d/s #4 (*MCRd*) RiverWatch data are expressed in Chart 2.1. Monthly ADWF values (blue bars) are scaled on the right. DO values below a DOD threhold of 4 mg/L are marked red outline w/yellow fill (<4.0 to > 2.5 mg/L) and black outline markers w/red fill (0 to 2.5 mg/L), an accepted indicator of hypoxic conditions. DO levels were lowest during the 2014 DWF season in the period of extended drought but also remained low during the 2015 DWF season when streamflow (ADWF) was considerably greater. Interpolated DO values during the DWF season in both 2016 and 2017 were commonly in the DOD threshold range (<4 to >2.5) averaging 3 to 3.5 mg/L.

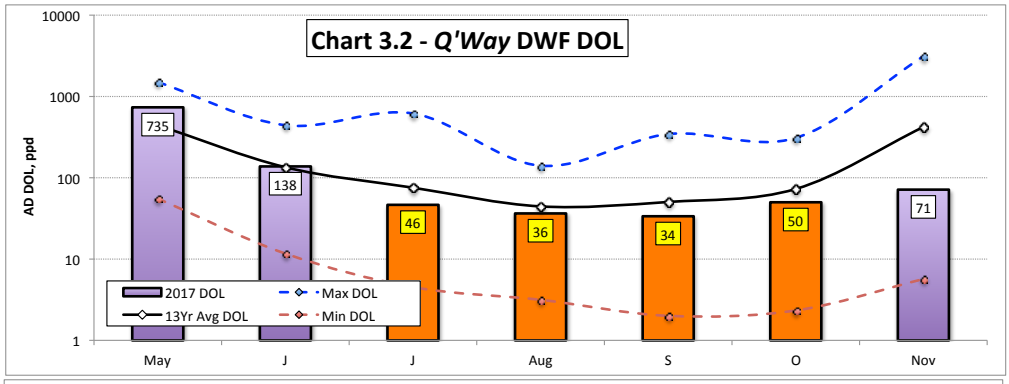
Chart 2.2 *Q'way* DO loadings (DOL = DO concentration times flow) in pounds per day over the 13-yr period are presented in Chart 2.2. The same conventions as used in Chart 2.1 apply. DWF DOL at the *Q'Way* site has generally been on the decline since 2005; most clearly when the transitional flow months of May, June and November are excluded.

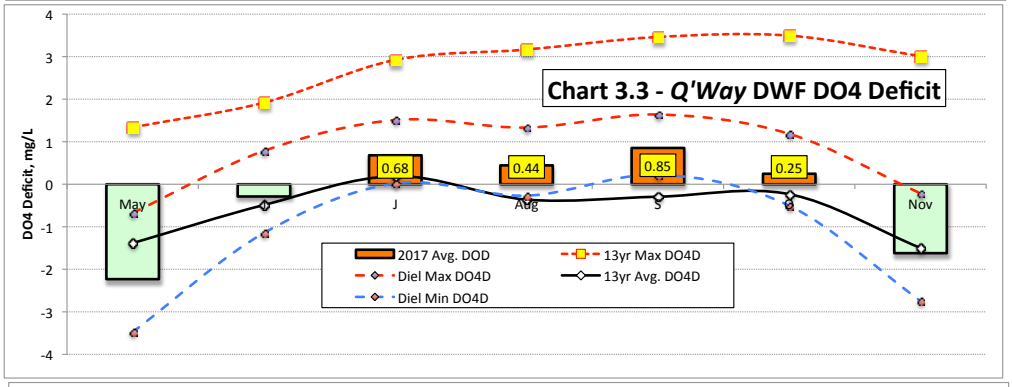
Chart 2.3 DO Deficit Loading (DODL) values are expressed in Chart 2.3. ADWF values (right side axis) are shown as blue lines; the DODL values as orange-shaded bars. The yellow shaded bars are non-deficit DO loads shown as negative percentages from the DO4L (DOL at DO = 4 mg/L). The largest deficit load (DO = 0 mg/L) would be 100%; whereas zero percent DODL occurs when the DO is 4 mg/L. The magnitude of the DODL has been declining since its maximum in 2014. The ADWF marker values that occur during months of DO < 4 mg/L are shown in red fill. There have been only two DWF months (Oct. 2010 and July 2015) when DO deficits occured when streamflow (ADWF) was in excess of 10 cfs.

Future field study efforts should be carried out during the critical months of greatest DODL that typically occur from July through October. The month of July has witnessed a near-surface DO deficit and DODL annually since 2010 in multiple portions of the FSDRIP channel.

Section 3 - Interpolated *Q'Wy* DO Metrics During 2017 DWF







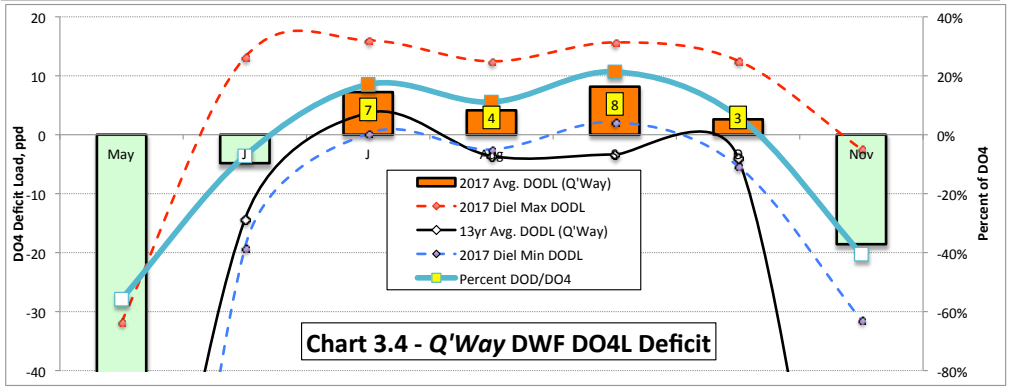


Chart 3.1 DWF DO Interpolated 2017 DO values for the seven DWF months (May-Nov.) are expressed as bars in Chart 3.1. The four DO deficit months (July-Oct.) with DO < 4 mg/L, are in orange fill with values shown in red. The lowest near-surface DO interpolated from the adjacent u/s (#5) and d/s (#4) RiverWatch sites was 3.15 mg/L, representing a DOD of 0.85 mg/L (i.e., 4.0-3.15). The 2017 diel (diurnal) variation in near-surface DO is shown as solid blue (high, occuring in the late afternoon) and red (low, occuring near/soon after sunrise) lines. The 13-yr monthly average DO for the site is shown as the black line with black value markers. The 13-yr estimated average diel (diurnal) varation in monthly near-surface DO are expressed by dashed lines; blue the daily high and red the daily low. The 13-yr monthly maximum (blue) and minimum (red) near-surface DO values are shown as heavy double-dashed lines.

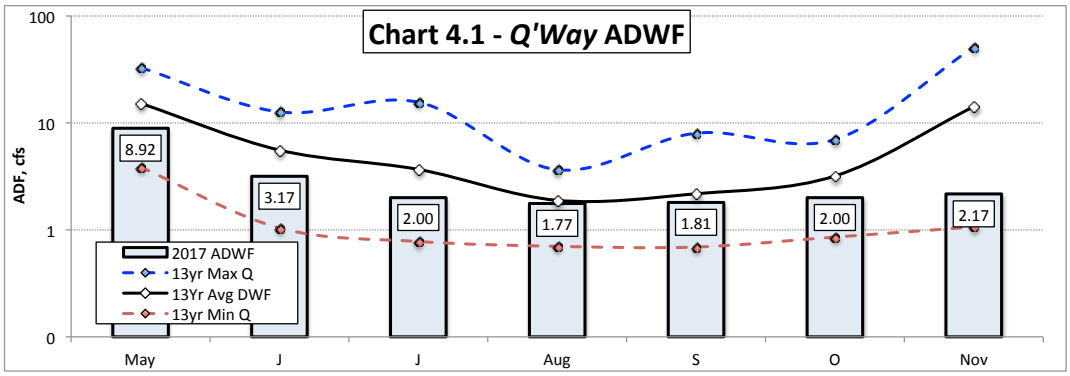
Chart 3.2 DWF DOL Interpolated 2017 DWF DO loads (product of DO concentration and streamflow) abbreviated DOL, are shown in Chart 3.2 as bars; the four deficit load months (July-Oct.) in orange with vlaues high-lighted in yellow and the three non-deficit months (May, June & Nov.) in purple. The 13-yr monthly average DOL is shown as a black line, while the monthly maximum (blue) and minimum (red) are dashed lines. The 4-mo DWF DOL for 2017 averaged just around 40 pounds per day at the *Q'Way* site based on u/s and d/s near-surface DO RiverWatch data.

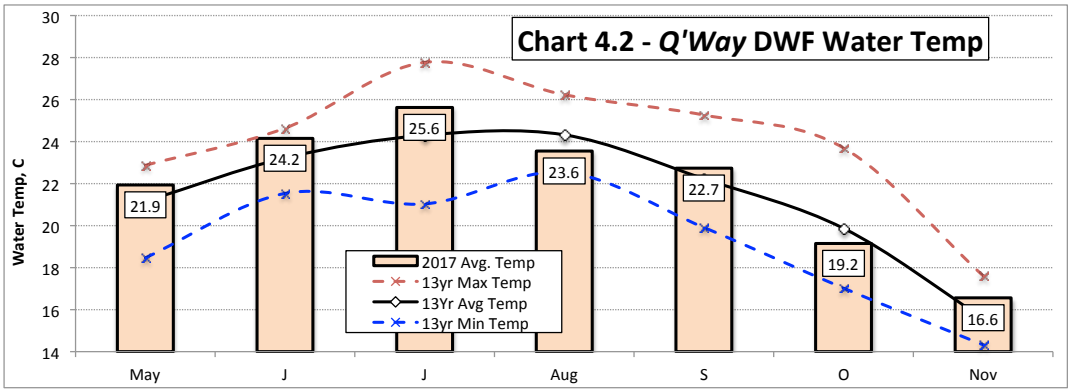
Chart 3.3 DWF DOD 2017 monthly DO deficit (DOD) values for the *Q'Way* site are shown in Chart 3.3 as orange bars with values high-lighted in yellow. The near-surface average monthly DOD over the 4-mo DWF period at the *Q'way* end of the FSDRIP channel was approximatley 0.5 mg/L. The 2017 diel range by month is shown as dashed lines; red high and blue low. The 13-yr monthly average DOD is shown as a black line, while the maximum monthly deficit is expressed by the red dashed line with square yellow-fill markers. The potential for experiencing large DOD values in this portion of the channel throughout the lowest 4-mo DWF period from July to Oct. is very high.

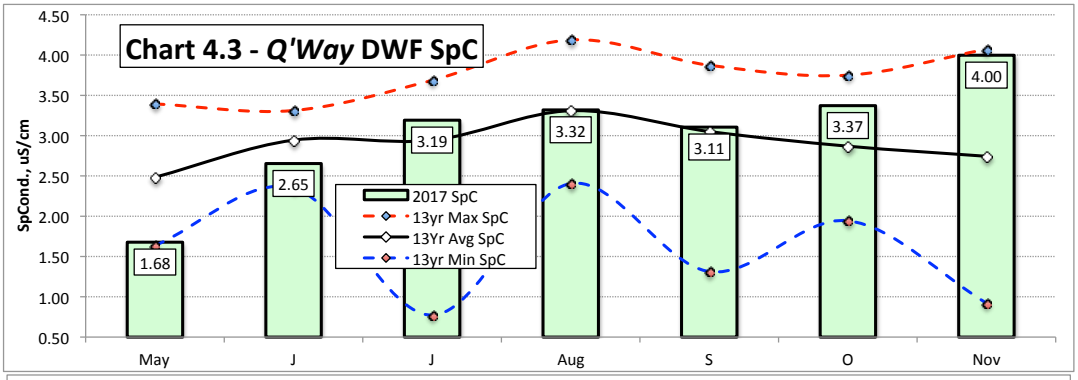
Chart 3.4 DWF DODL The DWF 2017 DOD near-surface loadings for the *Q'Way* site are shown in Chart 3.4 as orange bars with values high-lighted in yellow. The diel values are shown as dashed lines, maximum (red) and minimum (blue). The 13-yr monthly average DODL's are shown by a black line; July is the only month average deficits loads have occured over the past 13 years.

The 2017 DWF DO metrics expressed in Charts 3.1-3.4 reinforce the conclusions expressed in Section 2 regarding future field work. It is likely that if monthly ADWF values in the FSDRIP channel are as low in 2018 as they were this past year that DWF DO levels will be lower and DODL values greater than were the case this past year.

Section 4 - Interpolated *Q'Wy* WQ Metrics During 2017 DWF







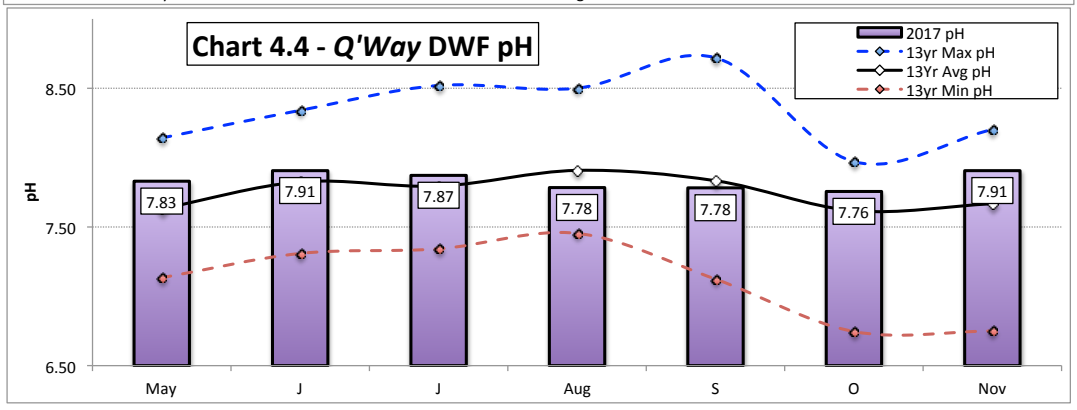


Chart 4.1 ADWF Monthly variation in 2017 ADWF (grey bars w/values) as well as 13-yr averages (solid black line) and monthly maxima (blue dashed) and minimum (red dashed) are shown in Chart 4.1 for the *Q'Way* site. Similar streamflow (ADF) values as experienced this past summer or less can be anticipated for the 2018 dry weather season.

Chart 4.2 DWF Water Temperatures With the exception of August and Oct., DWF water temperatures in the *Q'Way* portion of the channel in 2017 were slightly elevated above the 13-yr interpolated averages as shown in Chart 4.2. The 2017 DWF values are expressed within the brown bars while the 13-yr monthly average (black), maxima (red dashed) and mimimum (blue dashed) are shown as lines. Comperable near-surface water temperatures can be anticipated at the study site this coming dry season.

Chart 4.3 DWF Sp. Cond. 2017 specific conductance values at *Q'Way* are shown within green bars in Chart 4.3, while 13-yr monthly averages are shown as a black line. The 2017 May value (1.68 uS/cm) was the lowest experienced over the last 13-yrs of record while the Nov. value (4.00 uS/cm) was the highest. There has been a fairly steady increase in SpC throughout the 7-mo DWF season. Over the past 13-years average monthly SpC values typically peak in August; the month of lowest average DWF. The perpetuation of low DWF through November and the first half of December, resulted in above normal SpC values throughout the Mission Valley portion of the watershed.

Chart 4.4 DWF pH Interpolated 2017 pH values for the *Q'Way* portion of the channel are shown within the purple bars. The 13-yr averages are shown as a black line while the monthly maxima (blue) and minimum (red) are dashed. Variance in DWF pH for the site is typical and not expected to exceed the normal range (7.0 to 8.5) in the coming year.

As previously mentioned, WQ metrics for the eastern (upper) portion of the FSDRIP channel (due west of the Q'way Rd) are interpolated from SDRPF's RiverWatch data based on upstream WQM site #5 (*Ward Rd*) and downstream WQM site #4 (*MCRd*) crossings. The comparison beween 2017 results, 13-yr monthly averages and the range in values (max/min) are intended to provide a supportable basis for interpretation of field study results.

Section 5 - Background WQ Data Interpretation

- DO levels in the FSDRIP channel (site #4 *MCRd*) are continuously (during both dry and wet weather seasons over the past 13 years) greater than at neighboring upstream [#5, #6 & #7] and downstream sites [#2 & #3].

- DO concentration levels at the *Q'Way* end of the channel are believed to increase by 1.0-2.0 mg/L from the u/s site #5 (*Ward Rd*) to d/s site #4 (*MCRd*) during both the dry-weather (May-Nov.) and wet-weather (Dec-March) times of the year. The average annual gain in DO from site #5 (*Ward Rd*) to the upper FSDRIP channel (*Q'Way*) is believed to be on the order of 1.15 mg/L.

- DO concentration levels decrease by about 2.0 mg/L from site #4 (*MCRd*) to #3 (*FMV*) during the DWF period and by about 1.0 mg/L during the WW season for an average annual DO loss (decline) of 1.50 mg/L. DO levels in the FSDRIP channel, along with other Mission Valley sites (i.e., #2-#7) are typically lowest in July, that is often the month associated with greatest summer-time streamflow.

- DO gains in the FSDRIP channel from July to Aug. are typically on the order of 1.0 mg/L; gain from Aug. to Sept. is typically another 0.5 mg/L DO, although during some years small declines have been monitored. Diurnal (diel) DO flux within FSDRIP is on the order of 2.0-3.0 mg/L near the surface during the DWF period. Diurnal fluctuations are primarily driven by plant photosynthesis (daylight) and respiration (night), however, sediment oxygen demand (SOD) is also thought to present a significant loading during low flow conditions.

- Spatial 24-hr DO flux within the FSDRIP channel is on the order of 3.0-5.0 mg/L, with significant variance dependent on depth, penetration of sunlight, wind speed and degree of mixing. In deeper portions of the channel a defined hypolimnion is typically present during low flow conditions.

- Average DWF DO loadings within FSDRIP for 2017 were on the order of 30 lbs O_2/day; 5-10 times greater than the minimal loads experienced from July through Oct. of 2014 (3-10 lbs/day) during peak drought. The 2014 DWF season was associated with persistent hypoxia in the water column during which several locations within the FSDRIP channel experienced anoxic conditions.

- DO recovery through FSDRIP during the four low flow months (July-Oct) is on the order of 13 lbs O_2/day; however, there have been 12 times out of the last 76 dry-weather months (since 2005) when DO levels were actually lower in the

FSDRIP channel (by an average of 6-10 lbs O_2/day) than upstream at site #5 (*Ward Rd*) further suggesting a large varience in microbial activity and sediment diagenesis.

- Stream velocities through the FSDRIP channel in summer are on the order of 0.004 feet per second (fps); about 25 times less than in both the narrower and shallow u/s and d/s channels. Channel velocities in FSDRIP are, however, 4-5 times greater than u/s of site #6 in Kaiser Ponds where mean velocities canbe less than 0.001 fps.

- During DWF the FSDRIP channel contains about 30 Mgal of water compared to 50 Mgal within the three main Kaiser Ponds. FSDRIP presents a water surface area of 375,000 SF (8.5 ac) compared to Kaiser Ponds at 13.5 acres. Although he FSDRIP channel is not as deep (on average) as the ponds, it contains greater changes in gradient (three; one under each bridge crossing), receives less allochthonous 'fines' and less labile organic matter. The channel experiences greater atmospheric interchange, probably generates less SOD and witnesses less signs of protracted eutrophication than observed up stream at Kaiser Ponds, Mast Park and several other Santee Basin ponds near Lakeside.

- DO and other WQ metrics expressed in this memo are interpolated from SDRPF's RiverWatch data. Additional water quality data pertaining to the aeration array site at the eastern end of FSDRIP have been collected and analyzed by others; specifically SDSU's Graduate Research Program and the City of San Diego's Transportation and Storm Water Department. These study data are the subject of future reports and other documentation.

- Sediment (or benthic) oxygen demand (SOD) as well as water column bio-chemical oxygen demand (BOD) present in the general vicinity of the study site should be determined by field measurements to be carried out during a period of protracted DWF. Benthic oxygen demand is likely to play a significant role in overall DO dynamics and deficit loads.

- Measuring/monitoring any changes in DO concentration during operation of small solar aerators is difficult due to the large flux in spatial (depth-wise and laterally) as well as temporal (diurnal, day-to-day and flow-dependent) background DO levels. Measuring any incremental DO changes caused by aerator operation should be attempted during the times of maximal near-surface DO deficit. Based on RiverWatch monitoring results these periods are most likely to occur during times of minimal ADWF and highest water temperature.

Section 6 - Useful Technical Notes and References

Notes:

- Reaeration coefficient k_r = 0.08-0.20 in 1/day, slow moving/sluggish stream
- BOD decay rate K*d* = 0.1-0.2 in 1/day, for a low pollution level stream
- River BOD_5 = 1-5 mg/L or 10-50 lbs O_2/day at DWF of 2.5 cfs
- SOD (total benthic O_2 demand BSOD+CSOD) = 4-6 g O_2/m^2/day = 0.08-0.12 lbs O_2/100 ft^2-day (biological plus chemical) common DW occurance
- 1 watt = 0.001341 horsepower (5 - 60 watt aerators = 0.4 mechanical hp max.)
- Surface aerator 'standard operating efficiency' (SOE) = 1-2 lbs O_2/hp-hr (typ.)
- Theoretical O_2 flux from aerator units = 2-3 lbs O_2/day (8-hrs op. w/full sun)
- Minimum time for water to travel 30 ft (10 m) downstream from an aeration system array, about 2 hrs at DWF rate of 2.5 cfs.
- Diel DO change can be equal to if not greater than the rate of reaeration.
- The rate of natural aeration (photosynthesis, wind, atmospheric, gradient drop, etc.) can be 5-10 times the rate of reaeration from solar units.
- As stream flow increases, water temperatures decline and solar radiation deminishes, it becomes far more difficult to measure incremental change in near-surface DO related to solar units.
- DO Load (DOL) is a product of concentration of DO times stream flow (ADF); DO (in mg/L) x ADF (in cfs) x 5.394 = DOL (in pounds/day).
- Interpolation of *Q'Way* and *163 Xing* WQ values are based on assumming 2-to-1 proporanalities between site #4 (*MCRd*) mid-FSDRIP and respective u/s (#5 *Ward Rd)* and d/s (#3 *FVM*) RiverWatch data.
- Percent deficit of DOD and DODL are the same; (DO4-DO)/DO4 = (DO4L-DOL)/DO4L, where defict is DO concentration less than 4 mg/L.

References:

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- ***Fascinating Biogeochemistry: How Diel Cycling Complicates Surface-Water Monitoring,*** David Nimick, USGS Helena, MT (ESH8) ppp
- ***Low Oxygen and Pond Aeration,*** William Wurtz, Kentucky State U., www.ca.uky.edu/wkrec/Wurtzspage.htm.
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- ***Sediment Oxygen Demand Operating Proceedure***, EPA Science and Ecosystem Support Division, (SESDPROC-507-R4), July 22, 2015.
- ***LSDR Re-aeration***, J.C. Kennedy, SDRPF RiverWatch Data, Aug. 7, 2017.