Dissolved Oxygen Demand

- DO Demand in the Water Column
  - Algal Growth and Productivity
  - Aerobic Decomposition in Water Column
  - Macroinvertebrate Influence on Water Quality
  - Hydrology and Oxygen Demand

- DO Demand in Jordan River Sediment
  - SOD and Nutrient Processes
  - Macroinvertebrate Influence on SOD

- Discussion

Light Attenuation and Algal Growth

Miller (2019a)

- Measurements from 22 sites (July-October 2009).
- Sufficient light at depth (>5%) for benthic growth except Cudahy Lane-downstream and Surplus Canal.
- Plankton flora is largely from Utah Lake and river periphyton.
- Regression analysis (N and P): no relationship with nutrient concentrations and algal biovolume
- Benthic algae measured on artificial tiles (horizontal and vertical).
  - Chl a on vertical tile > horizontal tile.
  - Benthic algal growth in LJR is significantly impacted by repetitive scouring and deposition from highly variable flow.

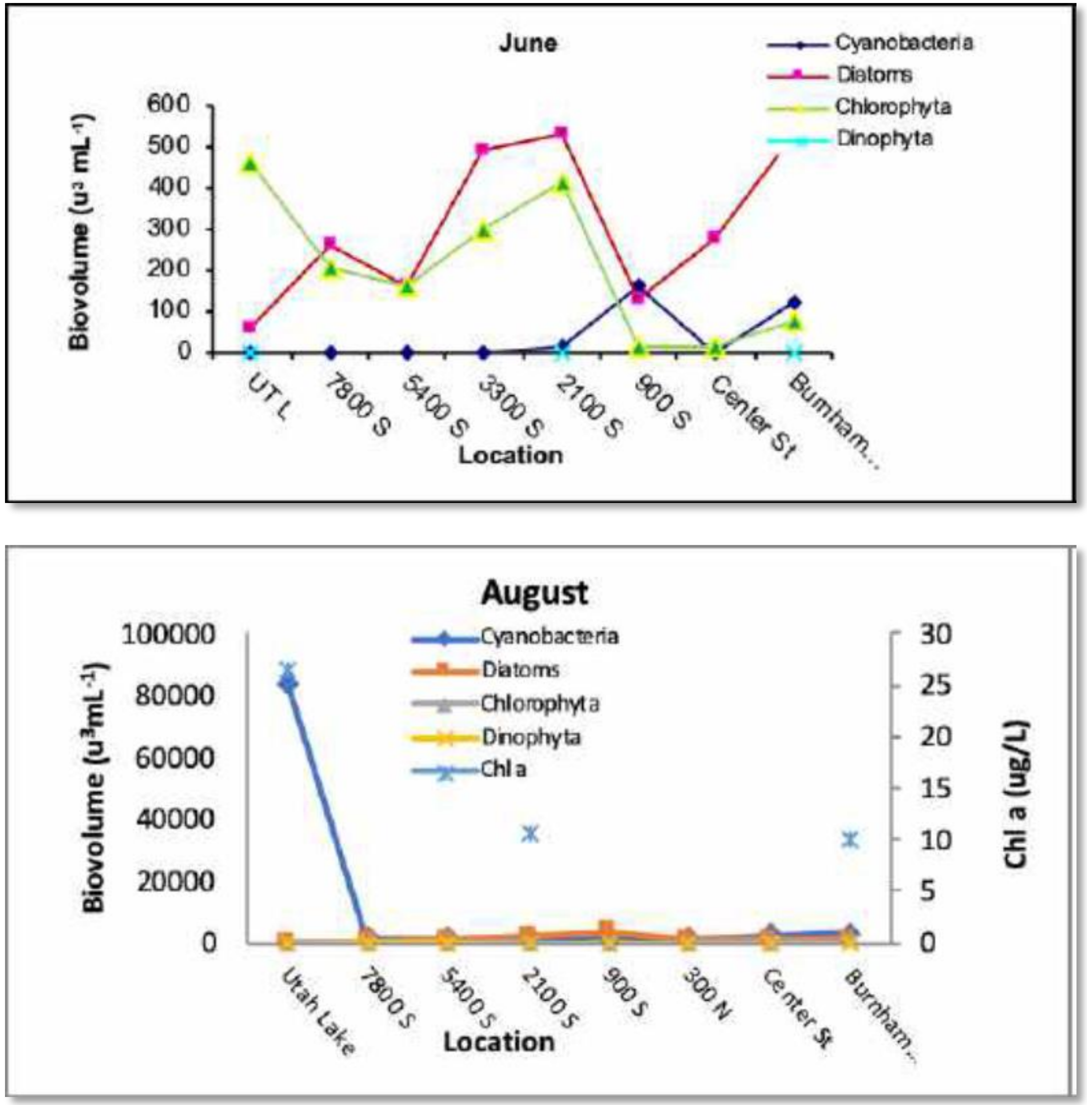


Figure 2-1

Evidence of nutrient processing

- Goel and Abedin (2016):
  - simultaneous negative flux of N and P from LJR sites.
- Follstad Shah et al. (2018)
  - differences in measured and cumulative nutrient loads between WRFs.
- Nutrient flux response and nutrient processing could be algal uptake or microbial activity.

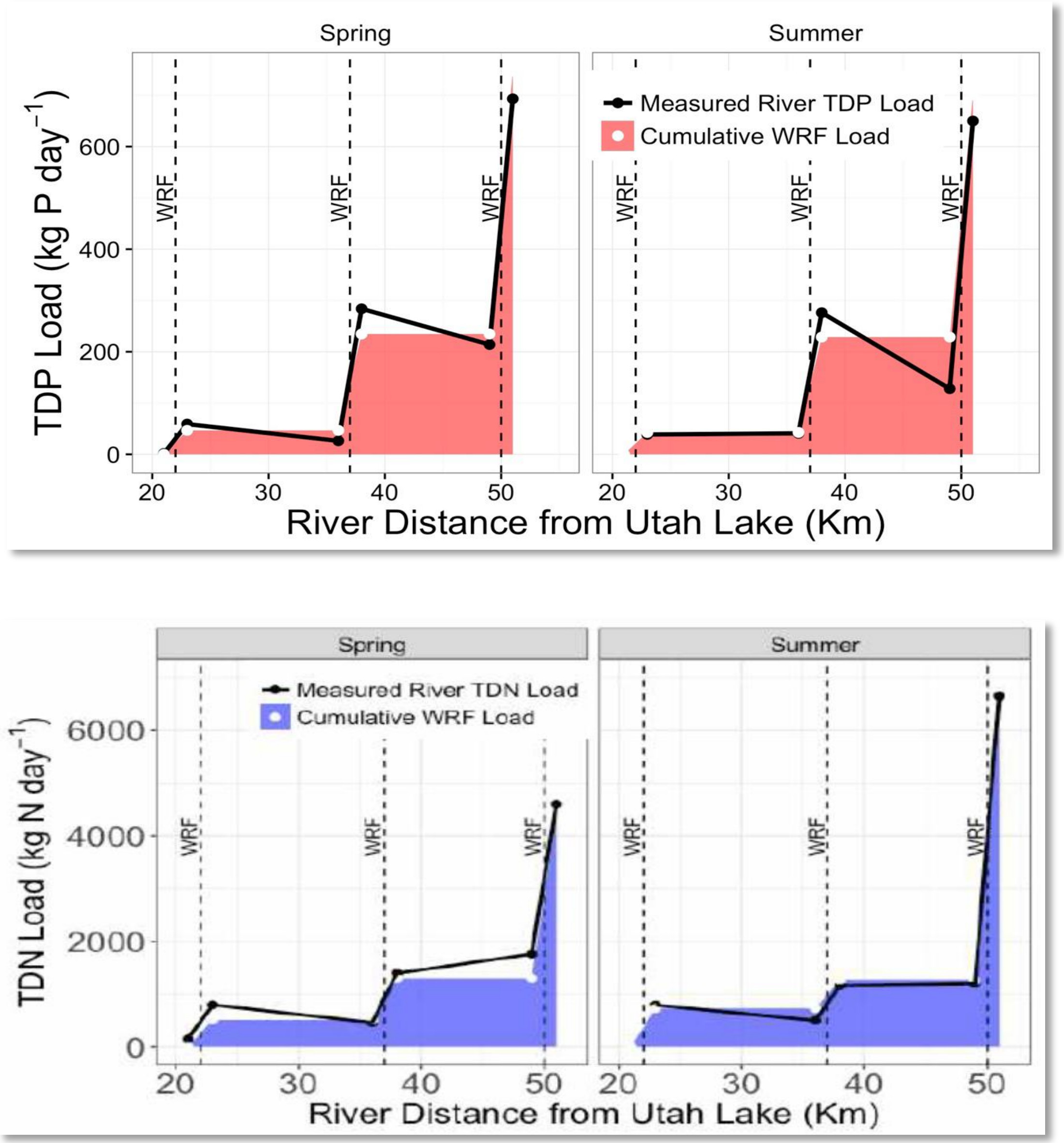


Figure 2-2

Diel DO monitoring – Miller (2019b)

- Typical diel cycle (5.5 – 9.5 mg/L)
- Peak DO consistent, minimum DO begins to sag
- Respiration influence > photosynthesis, reaeration

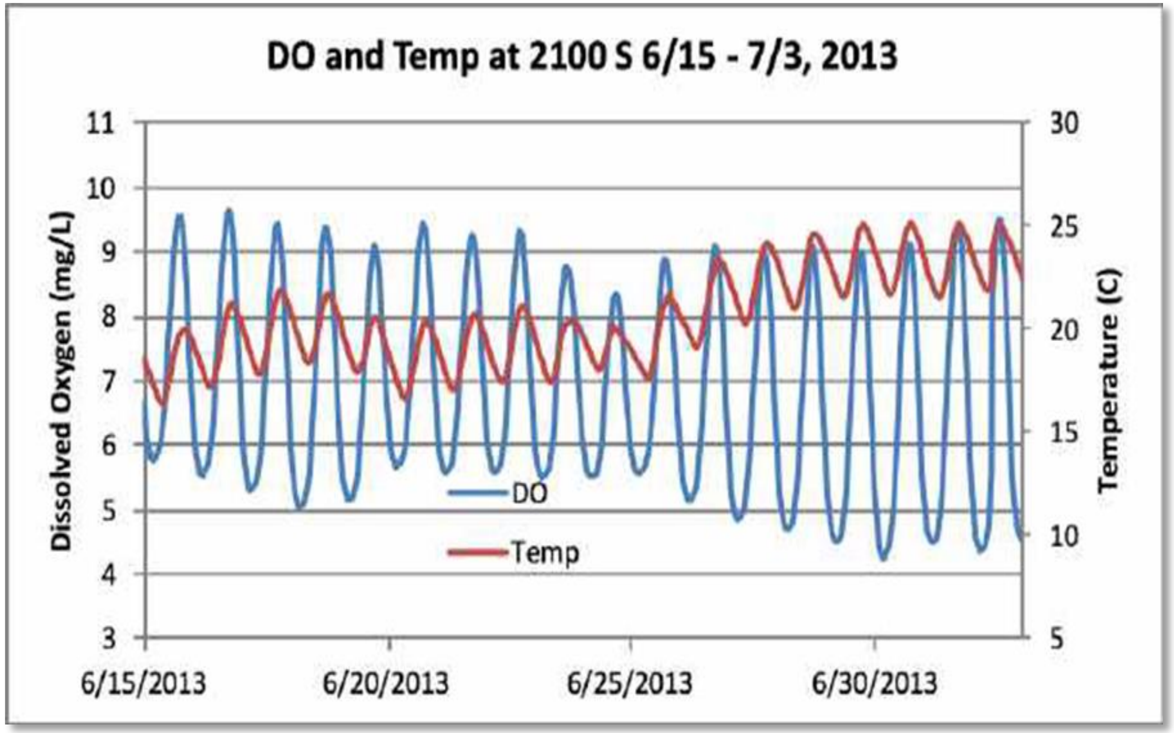


Figure 2-3

Peak DO Shift – Cirrus (2017b)

- Typical peak occurs after solar noon
- Middle LJR sites peak outside of photoperiod
- Primary productivity in UJR sets minimum DO for LJR, lowered by OM decomposition

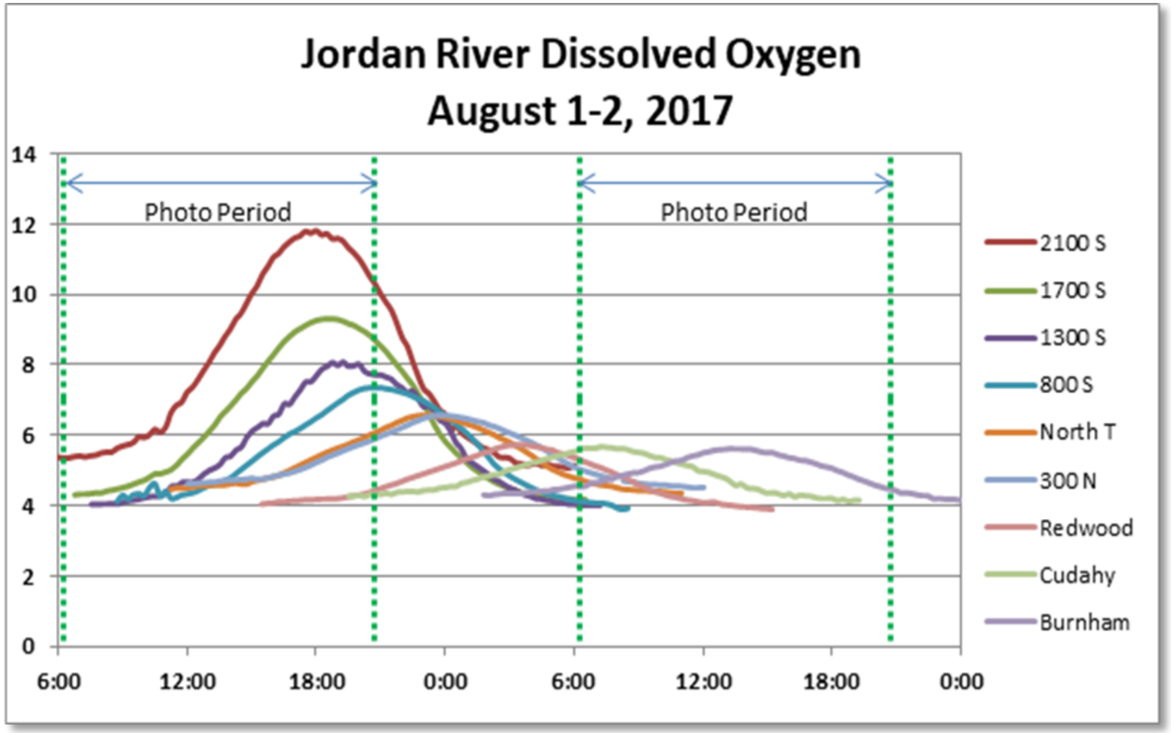


Figure 2-4

DO Demand – algal growth and productivity

BOD and CBOD monitoring

- Miller (2019b)
  - Measured monthly 2009-2012
  - Typical BOD range 2 – 5 mg/L with exceptions during wet year (2010) and immediately below Utah Lake or WRFs.
  - Seasonal assessment of 2012 did not identify consistent spatial or temporal patterns.

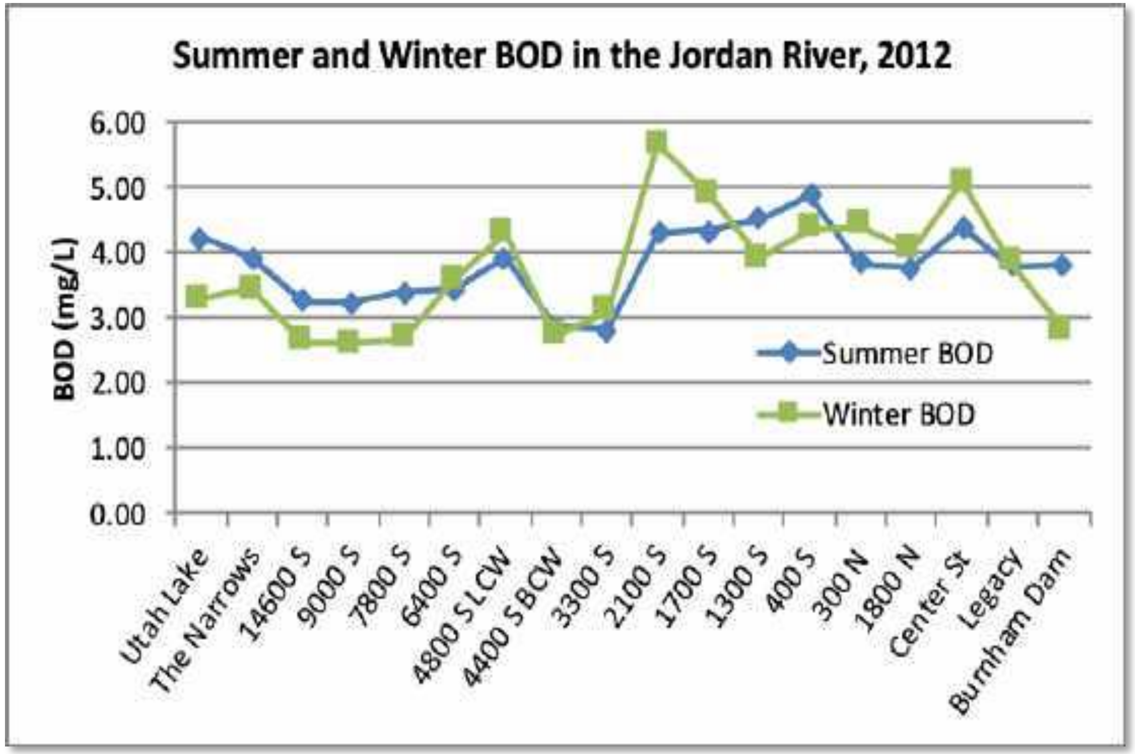


Figure 2-5

DO Demand – aerobic decomposition in water column

Ecoenzyme Activity and Growth Limitations

Follstad Shah et al. (2019b)

- Jordan River measurements are agreeable with literature for rivers although sometimes imbalanced (<1:1) for N and P.

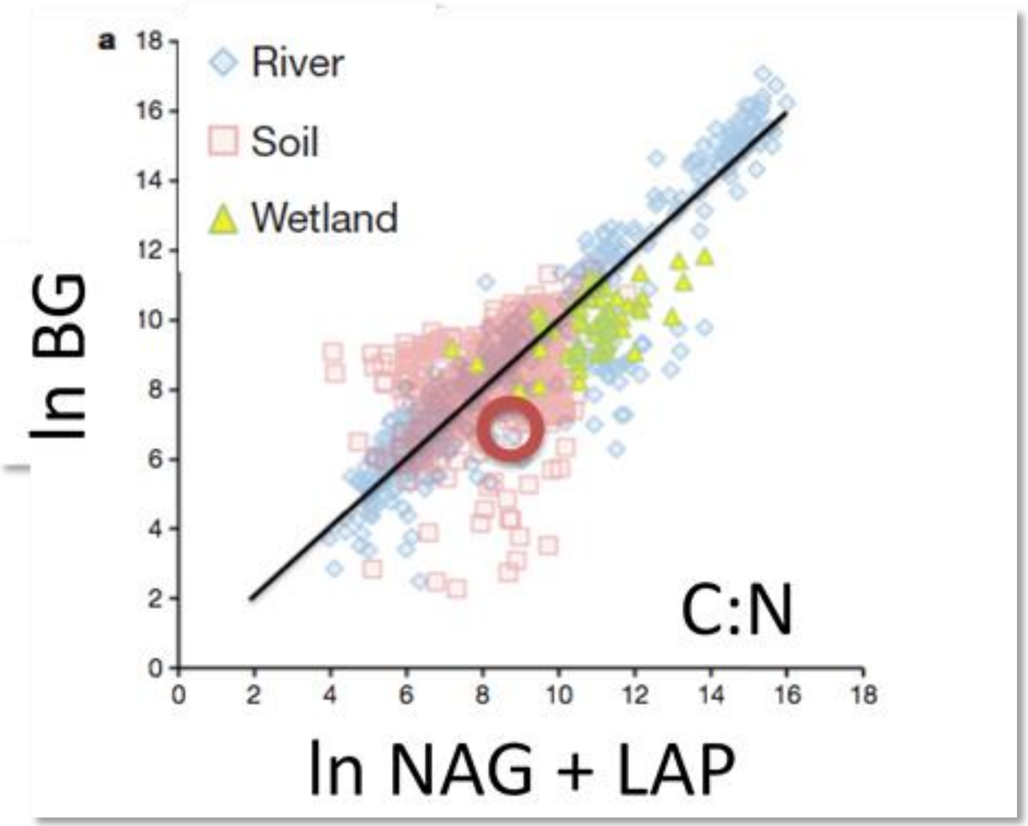


Figure 2-6

Follstad Shah et al. (2017)

- Enzymes (LAP, NAG+LAP, AP, POX, BG) are used by bacteria to mine nutrients from OM.
- Enzyme ratios indicate nutrient limits on growth.
- Analysis indicates microbes respond most to P resources compared to C or N. Seaonal measurements show higher growth rates in summer including cell structures rich in P.
- Measurements consistently showed higher rates downstream of older WRFS during fall and sometimes in spring.

Folstad Shah et al. (2019a)

- Seasonal EEA measurements collected above and below effluent in 2016.
- Regression analysis indicated EEA rates uncorrelated with each other.
- Responses did not follow global ecoenzyme relationships based on resource availability. Likely the result of large inputs of N, P, and C.

DO Demand – aerobic decomposition in water column

Macroinvertebrate Influence – water quality

Asian Clam (*Corbicula fluminea*)

New Zealand mudsnail (*Potamopyrgus antipodarum*)

- Richards (2018)
- *Corbicula* prefer well-oxygenated sediments, densities reduced in sediments with high OM and low DO.
- Consumes POM from water column/sediment and excretes nutrients in dissolved or particulate forms.
- *Cobicula* density estimates range 175-2,635/m^2 in run habitat. Potamopyrgus are estimated at 500,000/m^2 based on literature.
- Based on literature values and density estimates, Corbicula could potentially filter large volumes of Jordan River.
- Benefit to water quality dependent on reducing turbidity, allowing SAV to establish and contribute to productivity.

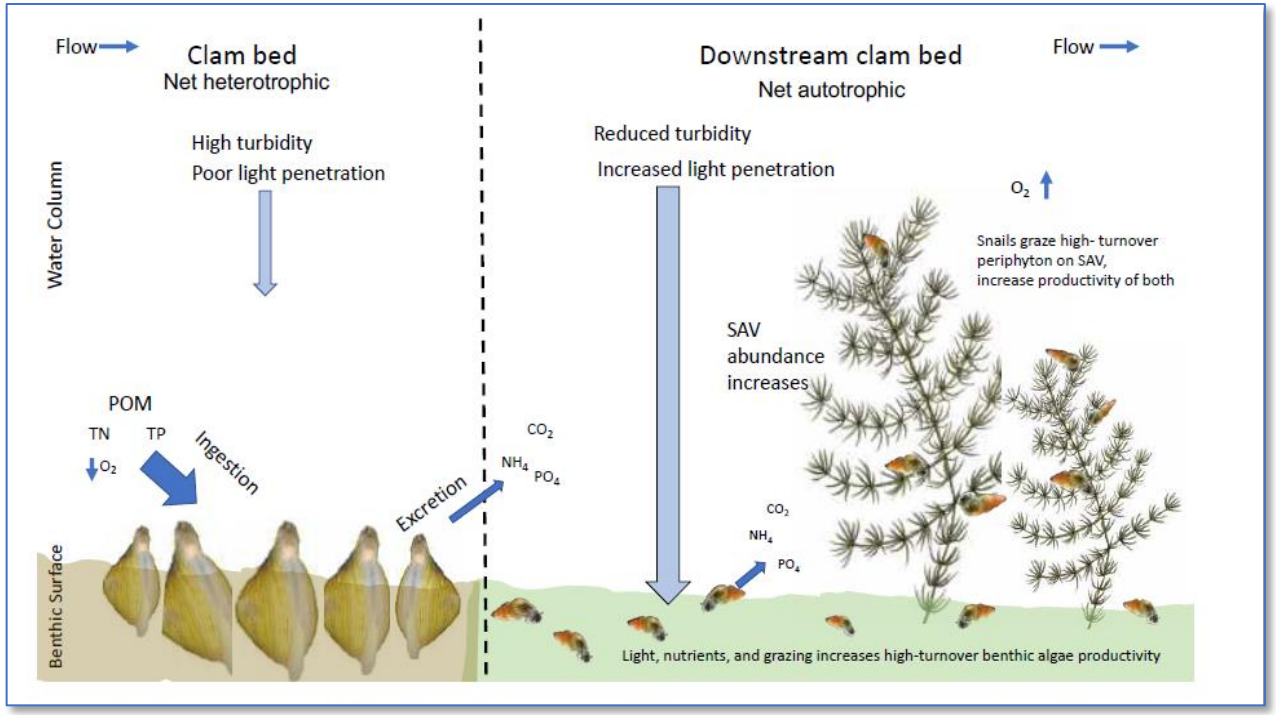


Figure 2-8

Mass balance hydrology model

- isotope tracing

Follstad Shat et al. 2018

Follstad Shah et al. 2019a

- 18 study sites from Utah Lake to 1800 North, measured spring, summer fall 2016
- Flow, $\delta^{18}O$, $\delta^{2}H$, DO sat., pH, Cl^{-}, Ca^{2+}, NO_3^{-}, and PO_4^{3-} measured spring, summer, fall 2016.
- Mass balance flows compared to Bayesisan SLM model results showed <20 percent difference for most sites.
- Results showed dominant flows to Jordan River varied spatially and temporally.
- Flow influence on LJR
    - Spring: groundwater+tribs
    - Summer: irrigation return
    - Fall: effluent discharge

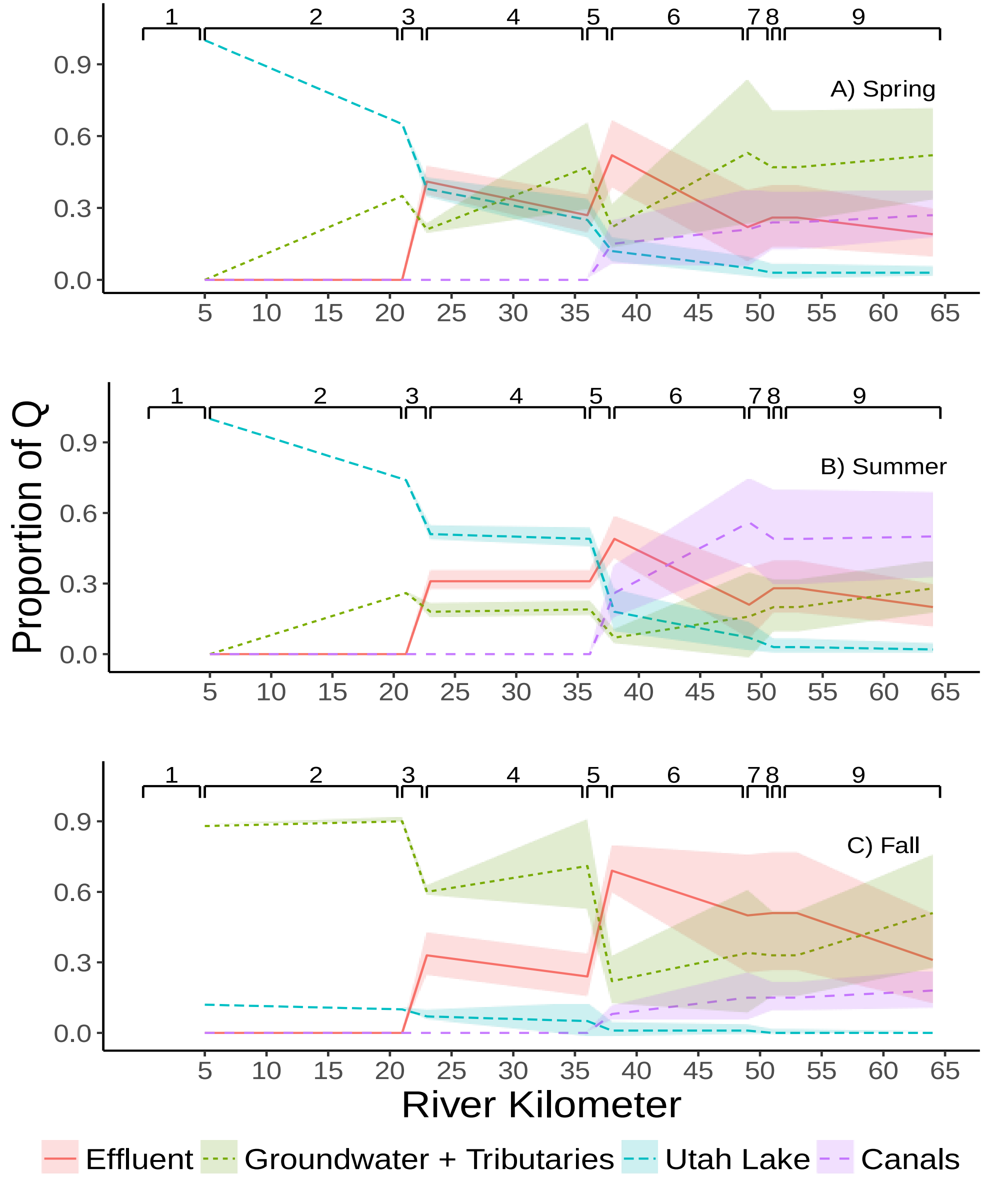


Figure 2-10

Managed flow and DO

- Cirrus (2016)
  - 2100 S. dry weather flow changes (2011-2016) and DO response at four sites.
  - Paired flow-DO data records account for travel time between sites (HEC-RAS).
  - Range of flow changes: 65 cfs increase to 26 cfs decrease, most ~ 30 cfs.
  - Summer DO increase is relatively high and lasting.

Table 2-1. Averaged Net Change in DO (mg/L) across measured events at 24 (Period 1), 48 (Period 2), and 72 hours (Period 3) after flow change.

	N	Period 1	Period 2	Period 3
2100 South	15, 13, 12	-0.04	0.13	0.06
300 North	8, 8, 7	-0.12	-0.14	-0.33
Cudahy	6, 6, 5	0.19	0.29	0.08
Burnham	12, 10, 9	0.03	0.20	0.12
River Average	45, 41, 37	0.04	0.13	-0.01
Averaged net change during two summer flow events only (July 17 and August 12, 2015)				
2100 South	2	0.05	0.35	0.32
Cudahy	2	0.15	0.32	0.24
Burnham	2	0.26	0.41	0.40
River Average		0.15	0.36	0.32

Source: Cirrus 2016 Table 3–4.

Sediment Nutrient Flux

- Goel and Abedin (2016)
  - Collected SOD and nutrient flux measurements at 1300 South, LNP in July and Sept 2015.
  - SOD measurements agreed with other research (Hogsett 2015). Ambient DO deficit ranged 72%-97%.
  - Both sites show negative flux for N and P, suggesting algal uptake and increased response following nutrient spike.
  - DNA analysis indicated conditions similar to WRF treatment with high potential for N removal and NH_4 oxidation.

- Follstad Shah (2017)
  - Ecoenzyme activity shows greater allocation to acquiring P during the summer when growth is highest.
  - Microbial activity in sediment appears limited by C and P in some seasons. Ample supply of N available throughout year.

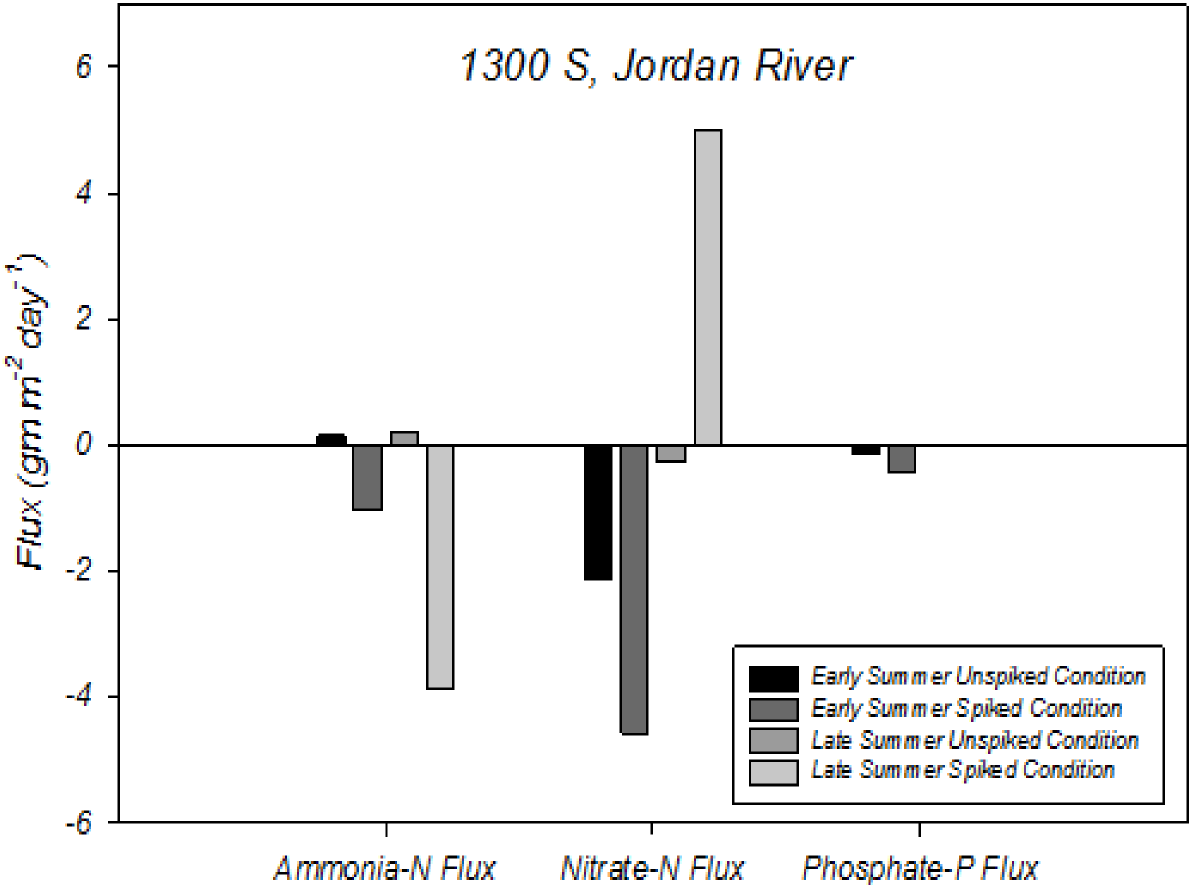


Figure 2-11

Macroinvertebrate Influence - sediment:

Asian Clam (*Corbicula fluminea*)
New Zealand mudsnail (*Potamopyrgus antipodarum*)

- Richards (2018)
  - Potential to sequester C
  - Ability to improve low DO depends on reducing O demand through respiration and decomposition of OM.
  - Oxygen demand is a fraction of SOD levels, already measured as part of previous research (e.g Hogsett 2015).

Table 2-2. Estimated O_2 consumption and CO_2 respiration rates (mg/m^2-hr) by Corbicula in run habitat sections of the Jordan River downstream of CVWRF to 900 South.

	Corbicula Density (m^{-2})[a]	Corbicula Dry Weight (g m^{-2})[b]	O_2 consumption (g/m^2-hr)[b]	CO_2 respiration (mg/m^2-hr)[c]
Median	650	0.52	0.001	0.0009
Mean (± SE)	1436 (910, 1962)	1.15 (0.73, 1.57)	0.002 (0.0013, 0.0027)	0.0017 (0.0011, 0.0023)
75th percentile	1,223	0.98	0.0017	0.0014
95th percentile	3,700	2.96	0.0049	0.0041
99th percentile	12,400	9.92	0.0159	0.0135

[a] Jordan River Corbicula density estimates downstream of CVWRF in non-pools (Richards 2017, see table 59).

[b] Based on Hakenkamp and Palmer (1999) Corbicula dry weight estimates and regression model: oxygen consumed = 0.19 + (1.58 x Corbicula dry weight (g)).

[c] Based on Bott (2007) Respiratory Quotient: 1 mol CO2 respired/1 mol O2 consumed = 0.85

Source: Richards 2018 Table 63. Note that rates of consumption and respiration have been converted to g/m^2 – hr for comparison purposes to SOD measurements.

Questions

Oxygen Demand in Water Column and Sediment

Total OM and OM Sources

- Coarse Particulate OM (CPOM)
- Fine and Dissolved OM (FPOM and DOM)
- Characteristics of OM
- OM Sources
- Future Predicted Changes
- Influence of Channel Features

CPOM Monitoring

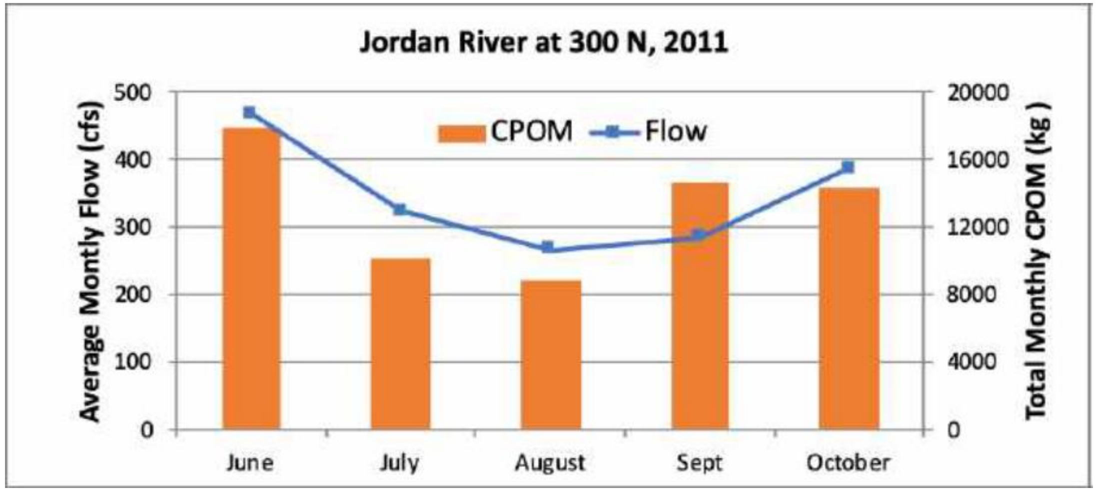


Figure 3-1a

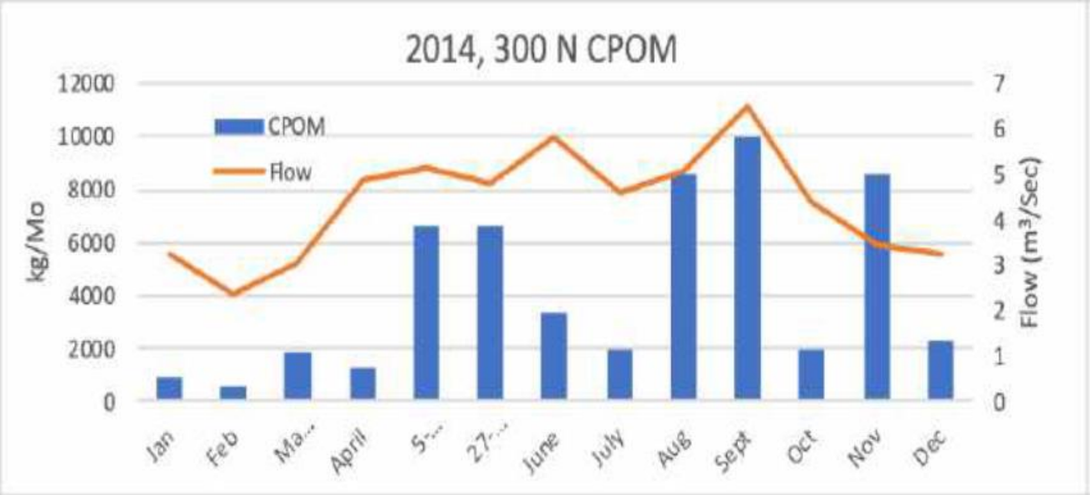


Figure 3-1b

Miller (2019c)

- CPOM measured most months (2010-2014) from major tributaries and Jordan River.
- Loading influenced by year, location, flow management.
- Large differences (2-5 times) between studies
- Potential for high variability among samples, methods, and events.

Table 3-1. Comparison of CPOM measurements collected during a wet year (2011) and a dry year (2013) by Miller (2019c) and during 2013 by Epstein et al. (2014).

Site	2011 - WFWQC		2013 - WFWQC		2013 - Epstein and Baker
	AFDM (kg)	C (kg)	AFDM (kg)	C (kg)	C (kg)
1700 South	218,712	72,175	33,954	11,205	6,023
300 North	62,119	20,499	139,433	46,013	8,592[a]
Legacy Nature Preserve	74,836	24,696	121,547	40,110	14,373[b]

[a] Sample collected at 500 North.

[b] Sample collected at Cudahy Lane.

Source: Miller (2019c) Table 4.

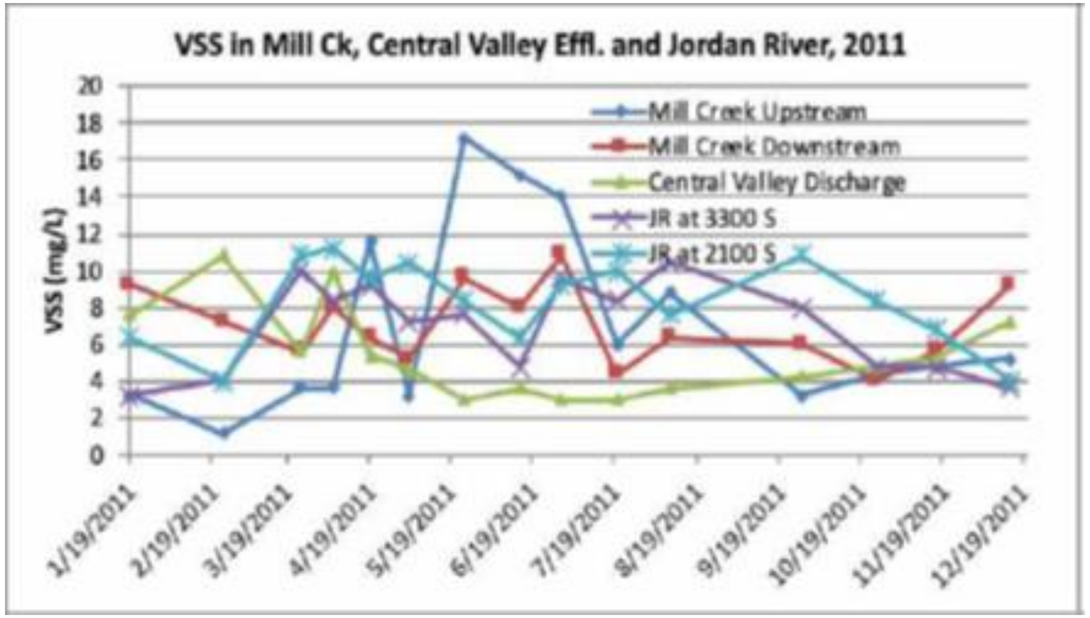
FPOM and DOM Monitoring

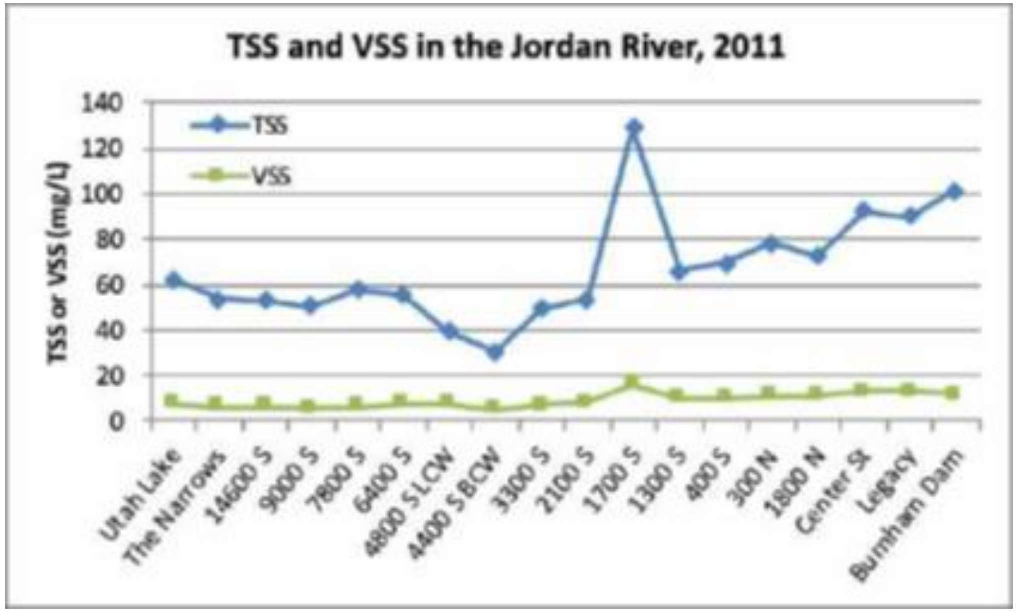
Miller (2019b)

- Monthly sampling 2009-2012
- Annual average concentrations of VSS 2010-11 showed little variation.
- Seasonal assessment (2012) showed differences above 2100 S. and little dilution from BCC and LCC.
- Monthly values show some variation.

Dupont et al. (2018)

- DOM measurements discussed with stormwater.





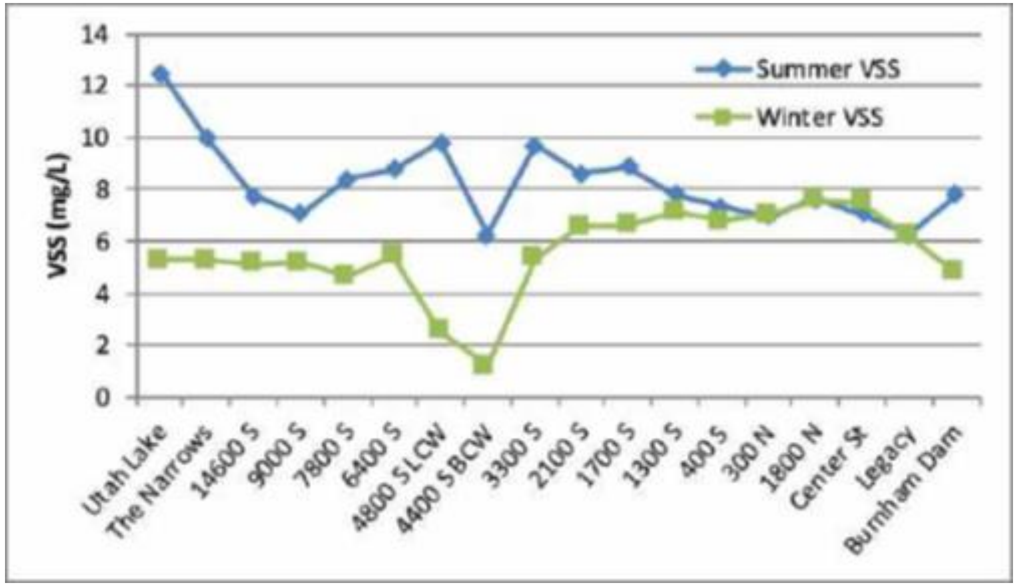


Figure 3-2

Emission-excitation matrix analysis

Fluorescence Index (FI) → DOM

Follstad Shah et al. (2017), Follstad Shah et al. (2019b)

- Lower FI values = plant material, Higher FI values = stormwater, wastewater.
    - Potential urban influence
- Jordan River FI values very high (2.2 – 2.4) compared to other aquatic systems; microbes may comprise significant part of OM.
- Elevated FI below WRF suggests effluent may influence OM composition.
- Elevated FI during fall season suggests limited natural terrestrial OM.

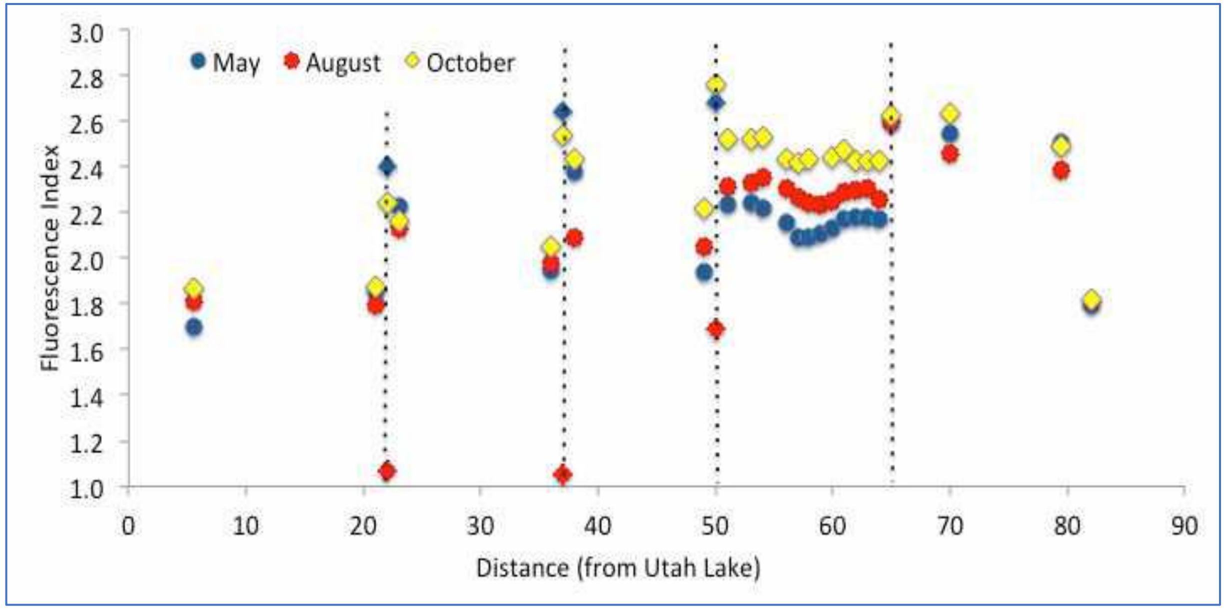


Figure 3-3

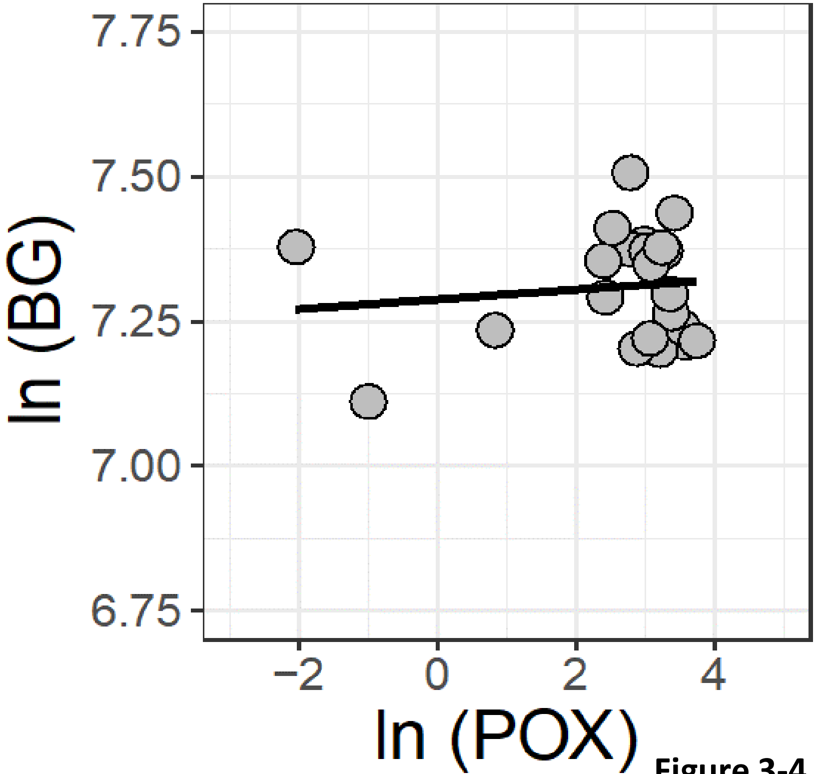
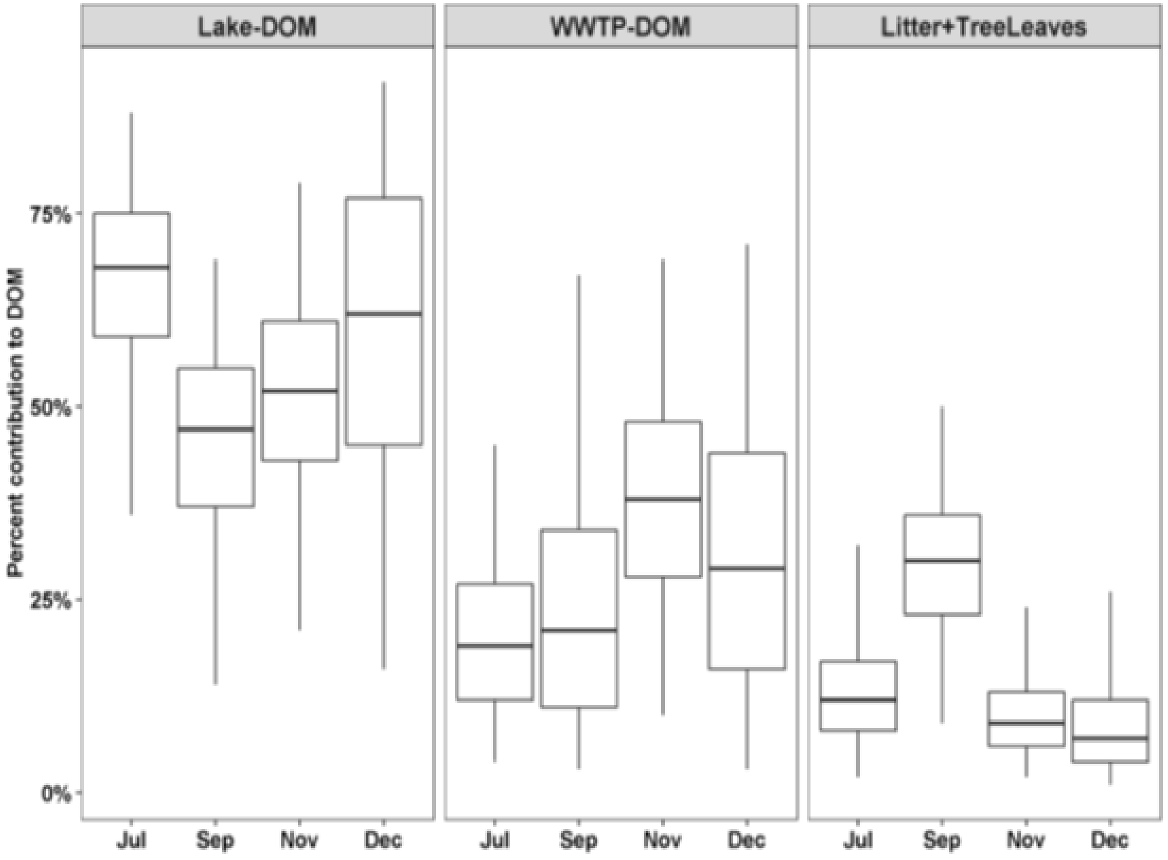


Figure 3-4

- Ecoenzyme activity rates from Jordan River indicate labile nature of OM.
- BG ecoenzyme activity is associated with acquisition of labile carbon.
- BG is 2 orders of magnitude greater than POX indicating labile C substrate.

OM Source / Stable Isotope Analysis

- Kelso (2018)
- C ($\delta^{13}C$), N ($\delta^{15}N$), and H ($\delta^{2}H$) measured at 9 sites during (2014-2015).
- Mixing models used to determine most likely source of OM for three OM size classes.
- Five source types evaluated for each OM size class including terrestrial, aquatic, benthic OM (BOM), WRF effluent, and Utah Lake.



CPOM

- Leaf litter is the most dominant source of CPOM except during the summer months when macrophytes contribute equally.
- BOM was least likely source of CPOM; more contributions in spring and summer.

FPOM

- Variation across all months.
- Terrestrial sources higher in fall, BOM and Utah Lake higher in summer.
- WRF contributions increased in September and continued through November

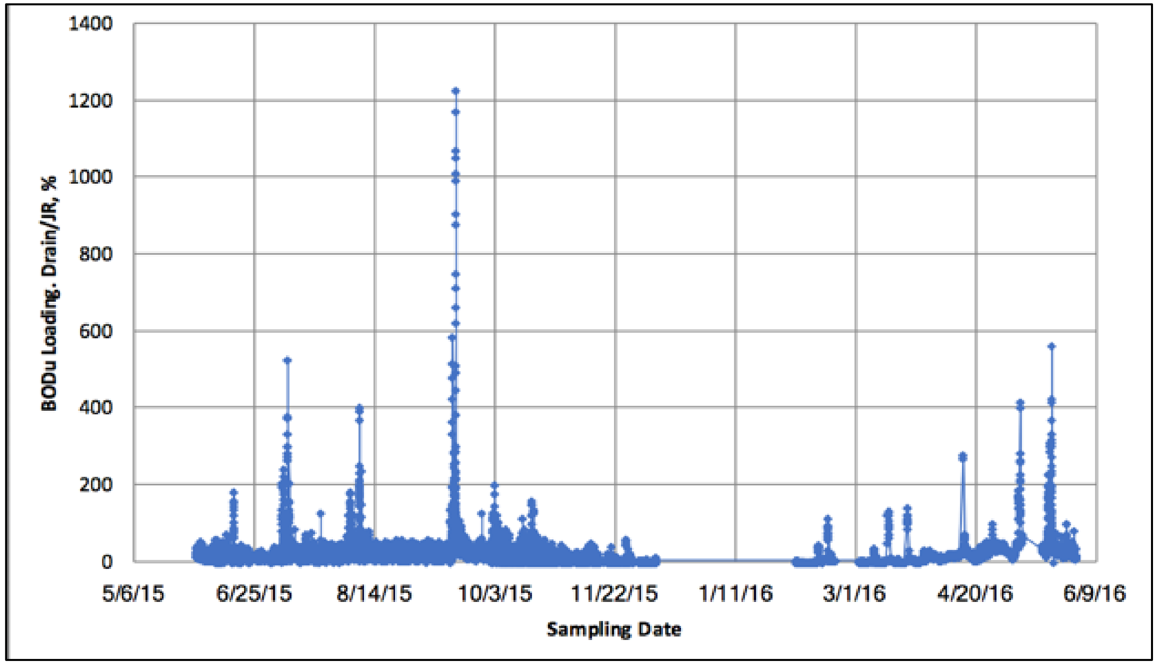
DOM

- Utah Lake: mean=57%, median range=48%-70%.
- WRF: mean=27 %, median range 20%-33%.
- Terrestrial: mean = 16%.

Stormwater OM

Dupont et al. (2018)

- Continuous flow and WQ June 1, 2015 – June 30, 2016
- Automated sampling during storm events (DOC, BOD_5, BODu)
- Flow comparison: Annual mean outfall discharge is 6% of Jordan flow, 20% in summer and >150% during extreme storm events.
- Mean outfall fDOM loads are 3.2% of Jordan load at 1700 South, frequently >30% during storm events and >180% during a storm in September 2015.
- Stormwater OM is much less stable than Jordan OM based on BODu/fDOM ratio.
- BODu loading from stormwater is > 1,200% of Jordan when degradability of DOC is accounted for.



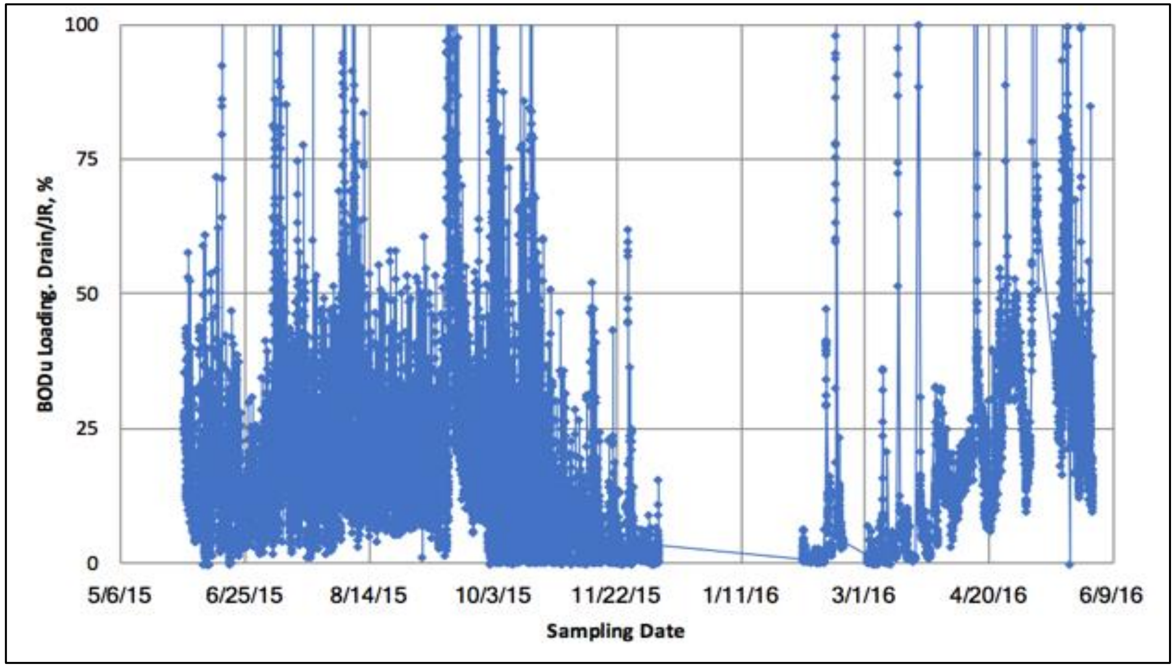


Figure 3-9

Future change in loading

Khatri et al. 2019

Table 3-2. Projected future change in streamflow and sediment concentration under three climate change scenarios including minimum downscaled climate change projections, moderate greenhouse gas emissions (RCP6), and maximum downscaled climate change projections.

		Minimum		RCP6		Maximum	
Climate Change Scenarios/parameters	Historical 2000s	2040s	2090s	2040s	2090s	2040s	2090s
Streamflow and sediment concentration for Big Cottonwood Creek at canyon mouth.							
A-Streamflow (m^3/s)							
Mean	2.1	1.8	2.0	2.4	2.3	2.1	2.6
Minimum	0.7	0.6	0.7	0.7	0.6	0.6	0.7
Maximum	9.5	8.2	8.7	7.5	9.4	9.0	9.3
Standard deviation	2.1	1.9	2.0	1.9	1.6	2.0	2.2
B-Sediment concentration (mg/L)							
Mean	3.4	3.3	3.4	4.5	6.2	5.0	6.3
Minimum	1.5	1.5	1.5	1.5	1.4	1.5	1.6
Maximum	24.9	47.0	33.4	41.5	106.7	62.6	60.4
Standard deviation	3.5	3.9	3.8	4.7	9.5	9.5	8.2
Streamflow and sediment concentration for Jordan River above Surplus Canal.							
A-Streamflow (m^3/s)							
Mean	13.8	14.1	14.7	15.8	15.9	15.5	15.9
Minimum	6.8	7.8	8.1	8.0	8.1	7.9	8.1
Maximum	32.8	27.8	30.3	30.6	32.7	36.3	32.8
Standard deviation	6.0	5.0	5.2	5.9	5.3	6.0	5.3
B-Sediment concentration (mg/L)							
Mean	28.7	28.8	28.2	27.6	29.7	29.1	29.3
Minimum	1.4	0.6	0.6	0.6	0.5	0.7	0.8
Maximum	72.8	62.7	62.2	91.9	160.6	95.4	99.9
Standard deviation	18.2	16.4	16.0	15.7	18.8	16.8	16.9

Source: Khatri et al. (2019) Table 2 (Big Cottonwood Creek) and Table 4 (Jordan River).

- Potential changes in magnitude and timing of streamflow and sediment yield
  - 2040s: Year 2035-2044
  - 2090S: Year 2085-2094
- Locations
  - Jordan River at 2100 South
  - Big Cottonwood Creek at Canyon mouth
- Land use scenarios
  - Continue existing Land Use Land Cover
  - Business as Usual Growth
  - Centers Oriented Growth
  - No significant difference in model output under the 3 scenarios
- Climate scenarios
  - Minimum downscaled climate change
  - RCP6 – moderate green-house gas emission
  - Maximum downscaled climate change

Channel Restoration

Improved WQ and reduced loading

- Salt Lake County (2018)
- Restoration work on Jordan River from 5100 South to 4800 South (~3,600 lineal feet)
- Natural channel design (e.g. toe wood structures)
- Before-after channel cross-section measurements indicate improvements to deeper, narrower channel.
- Changes to riparian area will increase resilience to flood events, improve DO and temperature and filter sediment and nutrients before reaching the river.
- Pebble counts show movement of fines from thalweg to floodplain or being moved downsteam by increased velocity in the deeper thalweg

Channel migration – Jordan River near 4800 S.

Critical aspect of LJR restoration is to increase baseflow conditions and promoting a more natural hydrograph where possible.

Other suggested modifications include redesign of 2100 South diversion to provide a top-release of water that would eliminate capture of bedload OM.

Questions

Oxygen Demand in Water Column and Sediment

Conclusions

Key points that help to:

- Recommend parameter of concern linking OM, DO, and pollutant sources,
- Recommend options for quantifying differences in lability among OM sources, and
- Recommend methods for quantifying relative contributions of OM sources to sediment oxygen demand (SOD).

Summarize results of the first (2017) and second (2020) research synthesis with implications for Phase 2 TMDL.

Key Points – Oxygen Demand

- Algal Photosynthesis and Respiration
  - Sufficient light and nutrients to support benthic algae at depth; lack of benthos due to erratic flow and unstable substrate.
  - No clear pattern of nutrient influence on algal growth based on annual averages. Closer look may identify patterns.
  - Odd shift in peak DO; UJR productivity sets minimum DO in LJR.
- Aerobic Decomposition in Water Column
  - Microbial growth is N-limited. DOM fuels net heterotrophy and DO consumption. Low DO during dry-weather is influenced by factors that produce protein-rich DOM substrates. Identify DOM sources and monitoring parameter.
- Macroinvertebrates
  - Literature values and density estimates indicate potential for filtering Jordan River with possible water quality impacts. Net DO benefit would require turbidity reduction and growth of benthic algae.

Key Points – Oxygen Demand

- Hydrology and Oxygen Demand
- Isotope tracing indicates LJR water sources vary temporally. Total WRF flow comprises 63% of total LJR flow in fall and large seasonal influence. Results could help with load allocations.
- Dry weather flow increases yield positive DO increase during summer.
- Sediment Nutrient Flux
- Measurements indicate dominance of denitrification over nitrification.
- Microbial activity in sediments is limited by C and/or P during during certain times of year.

Key Points – Total OM and Pollutant Sources

- CPOM loads from major Jordan River tributaries is estimated at 200,000 kg/yr during normal to high years and less than half this during low runoff years.
- Measurements collected by Miller (2019 c or d) are ~ 2-5 times more than reported by Epstein et al. (2016). CPOM measurements have high variability. Review of original data is needed to determine pollutant sources that may contribute to measured SOD levels.
- Microbes may comprise a significant portion of DOM in the water column. Resources that influence microbe activity could play a significant role in DO demand and OM decomposition.
- FI values increase below WRF effluent during all seasons, suggesting effluent on Jordan OM composition. FI values indicate limited DOM from leaves/litter in the fall, suggesting aquatic DOM and nutrients could contribute to chronic DO in the fall.
- Jordan River OM comprised of labile C including dissolved and particulate OM forms.

Key Points – Total OM and Pollutant Sources

- Stable isotopes indicate Jordan River CPOM is mostly terrestrial except in summer when macrophytes contribute equal amounts. FPOM is primarily terrestrial and WRF sources in Fall and BOM and Utah Lake in Summer. DOM is from Utah Lake with major contributions from WRFs. This assessment does not consider periodic stormwater contributions.
- Stormwater is a significant and on-going intermittent source of oxygen demand based on fDOM:BODu analysis of stormwater and Jordan River.
- Climate change is projected to move median flows forward in Jordan River and tributaries by 4 weeks in 2040s and 8 weeks in 2090s.
- Based on past success, Jordan River restoration has the potential to restore features that could reduce pollutant loading in support of beneficial uses.

Data Gaps – Oxygen Demand

- Oxygen demand in the water column and sediment should be defined as part of an oxygen budget accounting for season, wet and dry years, and other scenarios that capture external and internal influences on DO demand in the LJR.
- More information would be helpful to quantify spatial variability of SOD regarding changes in substrate and sediment OM content in the LJR before these measurements can be extrapolated to the scale of river segments.
- Additional research and analysis are needed to determine if microbial activity in the water column and sediment can be regulated through pollutant source management, particularly regarding protein-rich DOM during periods of low DO in low flow periods.
- Research is needed to identify what factors are suppressing and modifying primary production in the LJR where peak DO concentration occurs outside the photoperiod.
- Additional analysis is needed to compare phytoplankton concentration with benthic algae biomass to determine dominant drivers of photosynthetic production in the UJR and LJR.

Data Gaps – Total OM and Pollutant Sources

- Future OM load increases and timing should be calculated based on estimates of future changes to flow and sediment delivery. This effort must capture or attempt to capture the changes expected in urban stormwater runoff.
- How OM loading contributes to SOD (i.e., how does SOD accumulate) should be quantified, and a method to allocate contributions between pollutant sources should be identified.
- Additional OM budget assessments should be completed to identify particle size contributions during a wet year.
- Oxygen demand by season generated by microbial consumption of DOM should be quantified.
- The accuracy of EEM analysis in urban streams settings and potential sources of interference should be validated.

Questions

Conclusions