

LOWER JORDAN RIVER: PHASE 2 REPORT

DISSOLVED OXYGEN RESPONSE TO FLOW CHANGE (2011-2016)

Prepared for:

Jordan River Commission

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March 22, 2016

INTRODUCTION AND BACKGROUND

In 2014, the Jordan River Commission completed the first phase of a study investigating the use of flow manipulation as a potential mechanism for increasing dissolved oxygen (DO) during the late summer season in the Lower Jordan River (LJR). The resulting report, *Lower Jordan River: Phase 1* (SWCA 2014), assessed data collected in 2013 and 2014 to evaluate the basic relationship between flow and DO in the LJR. The report went on to incorporate output from a water quality model (QUAL2Kw) developed during the Jordan River TMDL process to further assess the role of flow in increasing DO in the LJR.

The model output indicated that increasing flow in the LJR resulted in higher DO concentrations due to increased aeration at diversion structures, increased surface disturbance, and reduced retention time in the river. The TMDL process also identified linkages between DO levels and other river processes, some of which are directly or indirectly influenced by flow.

On the basis of the data review and model output, the report recommended empirical studies to definitively answer two key questions:

- (1) Is there a defined, positive correlation between flow and DO, and
- (2) Is there a minimum flow threshold that will support DO levels above chronic conditions in the late summer months?

Acting on that recommendation, the Jordan River Commission contracted Cirrus Ecological Solutions, LC (Cirrus) to conduct a flow experiment on the lower Jordan River in 2016/2017. The intent is to manipulate flows and monitor the resulting effects on DO in the problematic reach. Acquiring sufficient water rights has slowed implementation of the study.

Water availability and water rights drive the distribution of flow in the LJR during the summer and early fall seasons when flows are split between the Surplus Canal and the LJR. During the winter and spring seasons, flows are managed according to needs for storage or flood control. The Jordan River Commission and collaborating agencies have worked with water rights holders to secure water, and the experiment is slated to move forward in the summer of 2017.

In the interim, our focus has turned to analysis of existing instantaneous flow and DO data collected from 2010 through 2016. Results of this analysis will supplement the pending flow/DO experiment and will help refine the proposed 2017 flow releases to make the best use of available water. This report summarizes that analysis.

METHODS

Using the cited, existing data, we examined the relationship between flow at the 2100 South diversion structure and DO downstream in the LJR. The QUAL2Kw model predicted that higher flow would increase velocity and reaeration at gate structures along the river, increase surface disturbance, and reduce water retention in the LJR. The model sensitivity analysis suggested that increasing flows into the LJR should result in measurably higher DO concentrations. If other influences were constant, this combination of changes would theoretically increase the base DO and reduce the potential for oxygen depletion from biological oxygen demand (BOD) and sediment oxygen demand (SOD).

The 2100 South diversion diverts flow into the LJR. Flow data reflecting changes in the amount of water diverted is available from the USGS gage at 1700 South. Review of that flow data indicated that adjustments of the gate occur over a very short time (< 1 hour) followed by a period of uniform flow. Once representative flow changes clearly associated with changes at the 2100 South diversion were

identified, we looked at the available instantaneous DO data collected from each downstream LJR monitoring location.

We paired flow data with DO data from the instantaneous sondes located at four locations in the LJR: 2100 South downstream from the diversion, 300 North, Cudahy Lane, and Burnham Dam. Measurements in both the flow and DO data sets are collected at 15-minute intervals. We adjusted the DO data record to account for travel time between the diversion and each DO sonde, using the Salt Lake County HEC-RAS model to estimate travel time from the 2100 South. Travel times were estimated for flows ranging from 50 to 250 cfs (Table 1). The travel time between the 2100 South diversion and the 1700 South gage is approximately 45 minutes, and this was accounted for when flow at 1700 South and DO data records were paired.

Once all the data sets were paired, we calculated average DO for 24 and 48 hours before each flow change as well as 24, 48, and 72 hours after a flow change. Data records were limited at some monitoring locations and could not be included in the analysis.

The precision of the sondes from which the DO data was derived was assumed to be +/- 0.2 mg/L. Average DO concentration for the 24-, 48-, and 72-hour intervals was compared to 24-hour average DO prior to the flow change (Table 2). This allowed us to look at the net change in average DO over a full diurnal cycle for the 24-, 48-, and 72-hour time step in response to a change in flow at each site. The average net change in DO is labeled 24 (Period 1), 48 (Period 2), and 72 (Period 3) hours in Table 3 and represents the average change in DO for that period of time. Individual values of net change in DO for each flow event and station are found in Table 2.

Flow changes were also separated by season. Spring flows were defined as the runoff period, April through June. Summer months were defined as the heating period of July through September. No flow changes were identified during the fall and winter seasons.

In terms of data analysis and interpretation, the range of variables affecting DO in the LJR, coupled with limitations on the quality and quantity of data available for review, make establishing a causal relationship impossible. As a result, our focus was redirected to DO changes correlated with rather than caused by flow changes. Beyond that, limited data availability, and thus small N sizes, precluded any meaningful statistical comparison of mean differences among DO changes. We report means and standard deviations in order to characterize variability in the data.

RESULTS

Sixteen flow changes were analyzed at the four monitoring locations in the LJR. As data was not available for all flow changes at all locations, this yielded a total of 45 events in the analysis (Table 2). Six additional flow changes were disqualified for a variety of reasons including intermittent or questionable DO measurements and measurable rain events that occurred near the flow change or within the period of analysis.

The average flow change at the 2100 South diversion was an increase of approximately 30 cfs, ranging from a 65 cfs increase to a 26.2 cfs decrease. The majority of the flow change events were increases within a narrow range of 25–35 cfs. Only three events involved flow decreases (the same 26.2 cfs decrease reviewed at three separate DO monitoring sites).

The DO response associated with these flow changes were mixed. Some flow changes produced very little (<0.1 mg/L) or no change in DO. The majority of DO changes ranged between -0.5–0.5 mg/L. Some events were influenced by storm events that occurred near the same time as a flow change and these events are identified in the discussion below. In regard to the flow changes that were considered, overall

DO response ranged from -1.9 mg/L during Period 3 at 300 North to 1.0 mg/L in Period 2 at the Cudahy and Burnham sites. In general, negative DO responses were less frequent but of greater magnitude compared to positive DO responses across all flow events and sites.

It is interesting to note the high variability of change in average DO for each 24-hour period in response to similar changes in flow.

Separating the flow changes by season identified two flow-change events during the summer season at three sites. Both July and August 2015 events showed a positive change in average DO at 2100 South, Cudahy, and Burnham Dam, for all periods measured (Table 2). However, spring events showed mixed results in terms of DO response.

Overall, 36 percent of the net changes in DO reported in Table 2 were less than the 0.2 mg/L accuracy assumed for the DO sondes. However, these reflect mean changes, reflecting measurements every 15 minutes across each period at each site. As an indication of variability, standard deviations were greater than the means for all 12 sites and periods (i.e., four sites and three periods, indicated in the bolded rows in Table 2).

Detailed results for each monitoring station are presented below. Keep in mind that all reported changes in DO values are relative to the values recorded 24 hours before the flow change.

2100 SOUTH MONITORING STATION

The 15 observations analyzed at the 2100 South monitoring station include 14 flow increases and one flow reduction. Eight flow increases resulted in a reduction in DO within the first 24-hour period (Period 1) after the flow change occurred. Five flow increases were associated with a positive change in DO in Period 1, and one event had no net change. The one flow reduction produced a negative net change in DO (Table 2).

Interestingly, the largest flow increase (76 cfs) at 2100 South decreased DO by 0.04 mg/L in Period 1 (Table 2, Figure 1), while the largest increase in DO in Period 1, 0.77 mg/L, occurred after a 34.66 cfs flow increase (Figure 2). Overall, the data suggests that change in DO in the first 24 hours is highly variable.

The average change in DO at 2100 South during Period 1 was a reduction of 0.04 mg/L (Table 3). This decrease in DO may not be a significant change, but it does not support the hypothesis that increased aeration from turbulence associated with flow increases through the diversion structure results in higher DO concentrations.

Thirteen paired observations were reviewed for Period 2. Nine of the 13 showed an increase in DO values. The average change in DO was a 0.13 mg/L increase, suggesting a slight rebound after Period 1.

Twelve observations were reviewed for Period 3. Eight of the 12 showed an increase, however all DO samples combined average 0.06 mg/L.

These results suggest a small initial drop in DO, followed by a rebound to above pre-flow-change observations, followed by a minor increase in DO out to 72 hours (Figure 2).

Comparing DO at 2100 South by season identified two flow change events during the summer. Flow increases were 18.3 cfs and 29.7 cfs in the two events occurring in July and August of 2015 (Figures 3 and 4). Change in DO in Period 1 for these two events was an increase of 0.01 and 0.1 mg/L, respectively. Change in DO during Period 2 increased for both events by 0.25 mg/L and 0.44 mg/L, respectively. DO

remained relatively stable during Period 3 for both events, maintaining 0.22 mg/L and 0.42 mg/L over concentrations prior to the flow changes (Table 2).

300 NORTH MONITORING STATION

Nine monitoring events were analyzed at the 300 North monitoring station for the period of available data. One reading (May 21, 2013) was removed from the analysis due to a spike in DO concentration prior to the flow change (Table 2, Figure 1). This spike was not observed at other monitoring stations, and it would have significantly affected the average change in DO during all periods. It was considered an anomaly and dropped from the analysis.

The remaining eight events included seven increases and one decrease in flow (Figure 5). The singular event with a drop in flow resulted in a decrease in DO. Corresponding monitoring data showed a change in DO during Period 1 that ranged between a decrease of 0.64 mg/L and an increase of 0.62 mg/L, to flow increases of 31.3 and 34.6 cfs respectively (Table 2).

The average change in DO for Period 1 was a decrease of 0.12 mg/L (Table 3) from pre-release concentration. Period 2 DO was reduced by 0.14 mg/L and Period 3 DO was reduced by 0.33 mg/L relative to the pre-release concentration.

These results indicate the overall trend in DO at the 300 North station is slightly downward over time in response to a change in flow (Figure 5). This pattern of continued decrease over the three periods is unique to the 300 site.

CUDAHY MONITORING STATION

Eight events were reviewed at the Cudahy monitoring station. Flow changes were all increases, ranging from 18.3 to 76.5 cfs. Two events were excluded from the results summarized in Table 3 due to rain events that occurred after the initial flow change. One event had immeasurable rainfall, while the other had rainfall during Period 2. These events represented two of the greatest DO reductions in the analysis (Figures 6-7). However, DO concentrations rebounded significantly after the initial drop on the same day as the rain event in March 2015 (Figure 7).

Four of the remaining events at the Cudahy site showed a positive DO response to increased flow, while the remaining two events showed a reduction (Figure 8). The average change in DO in Period 1 was an increase of 0.19 mg/L (Table 3). During Period 2 the average change in DO was an increase of 0.29 mg/L, and during Period 3 the average change was a 0.09 mg/L increase over concentrations prior to the flow change. These results suggest an increase in DO at Cudahy Lane when flows are increased to the LJR at 2100 South.

Summer events in July and August 2015 at Cudahy showed increased DO in all three periods during each of the 18.3 cfs and 29.7 cfs flow changes. During Period 1 DO increased by 0.2 mg/L and 0.1 mg/L respectively. During Period 2, DO increased by 0.34 mg/L and 0.3 mg/L, and during Period 3 DO increased by 0.26 mg/L and 0.22 mg/L respectively (Table 2). The pattern of increased DO concentration in response to an increase in flow follows a pattern similar to 2100 South during these same two events.

BURNHAM DAM MONITORING STATION

Thirteen events were reviewed at Burnham Dam. Flow changes ranged from a reduction of 26.2 cfs to an increase of 76.5 cfs. DO concentrations for six of the 13 events responded to flow changes in a negative manner, including one event with a flow reduction (June 4, 2016). The remaining seven events showed an increase in DO concentrations in response to a flow increase (Table 2).

One of the 13 events had a high 24-hour average DO concentration prior to a change in flow, which skewed the remaining values to a negative DO response (Figure 9). We removed this event from the results shown in Table 3, and average change in DO concentration across all flow changes for Period 1 was 0.03 mg/L. Change in average DO concentration for Period 2 and Period 3 remained positive at 0.20 mg/L and 0.12 mg/L, respectively.

Change in DO at Burnham Dam in response to summer season flow changes followed the positive trend observed at 2100 South and Cudahy during the 18.3 cfs and 29.7 cfs flow increases. In response to the 18.3 cfs change, DO during Period 1 increased by 0.41 mg/L, while the 29.7 cfs flow change resulted in a DO increase of only 0.1 mg/L. The change in DO concentration during Period 2 and Period 3 were respectively, 0.33 mg/L and 0.48 mg/L for the 18.3 cfs flow change, and respectively 0.30 mg/L and 0.49 mg/L for the 29.7 cfs flow change.

The Burnham Dam results show an increase in DO concentration across all three periods following a flow increase. This trend is similar to the Cudahy site. Seasonal patterns are also similar between these sites; i.e. an initial dip or no response in DO occurs during flow changes in the spring, and positive increases in DO were observed for all measurement periods during the summer (Table 2, Figure 10).

DISCUSSION

The initial hypothesis derived from previous data collection and the QUAL2Kw model was that increased flow would increase DO due to additional aeration at gate structures, increased turbulence in the surface waters, and reduced retention time of the water column in the river. This overall increase in DO could potentially reduce DO violations primarily seen during summer months on the LJR.

Results were mixed over the 45 flow-change events reviewed at the four LJR locations. All three events involving the flow reduction were correlated with DO reductions across sites and time periods. In Period 1, 22 flow-increase events were associated with a decrease in DO, while the remaining 20 indicated an increase. Downstream segments in the LJR (DWQ segments 1 and 2, downstream of North Temple) had 64 percent (16) of the events with a negative DO response to a flow change compared to upstream segments in the LJR (DWQ segment 3, upstream of North Temple). The monitoring station at 300 North had the greatest net negative response to flow increases, where six of the nine events were negative (Table 2). DO in Period 1 showed an average increase of 0.04 mg/L over the four LJR sites (Table 3).

In general, DO rebounded during Period 2 at three of the four monitoring locations where 24 of 41 events were associated with an increase in DO. The only site showing a continued decline in DO was 300 North. Across all monitoring stations, average change in DO was a 0.13 mg/L increase for Period 2.

Relative to Period 2, Period 3 DO for three stations moved toward pre-release values (Table 3). Period 3 DO at 300 North continued to steadily decline, but the three other stations maintained DO levels above pre-release concentrations. Across all four monitoring stations, average change in DO was a 0.01 mg/L decrease for Period 3. Results suggest a positive DO change from flow increases without 300 North, comparable to summer season results.

Summer season flow increases were associated with positive changes in DO at the 2100 South, Cudahy, and Burnham sites. No summer data was available for the 300 North site. Observations were limited to two dates and represent six of the 45 events reviewed. On average, flow increases produced positive DO results across all periods (Table 4), with a river-wide average increase in DO of 0.15 mg/L (Period 1), 0.36 mg/L (Period 2), and 0.32 mg/L (Period 3). These gains are important given the fact that the Cudahy and Burnham sites typically see more DO violations on the river than any other sites monitored.

The observed decrease in average DO at 300 North following flow changes is different from the relationship observed at the other monitoring stations. We speculate that changes in river dynamics are driving the continued depression of DO at this location, including velocity, scour, and resuspension of sediments. This station had the fewest sites with available data which could also influence the results.

To validly interpret these results, we need to consider the small mean differences in DO before and following flow changes, the narrow (i.e., 25–35 cfs) range of flow changes available for the study period, and the seasonal differences observed. As noted above under methods, we knew that the limited data and flow range would not support the rigorous statistical analysis.

Nevertheless, this review does suggest some correlation between flow increases and DO concentrations at three of the four monitoring stations – a small change in the first 24 hours, an increase over the next 24 hours, followed by stability or slight decrease. In summary, the review suggests that flow increases may be more effective in increasing DO at some sites than others and may be more effective during the critical summer period. The weak correlation may be explained in part by:

- The small magnitude and narrow range of flow changes available to review.
- Interaction with other natural or anthropogenic factors affecting DO in the LJR, as identified in the TMDL.

Potential causes for the DO dip in the first 24 hours may be:

- Build-up of sediments around the 2100 South structure.
- Increased influence of erosion above the structure.
- Changes in river dynamics (e.g., increases in velocities and scouring influences).

Potential causes for seasonal variation in average DO change:

- Magnitude of flow change in regard to existing flow.
- Influence of snowpack runoff from tributaries.
- Thermal differences in water from tributaries and mixing.
- Sediment load from tributaries.
- Greater bedload scour.

In conclusion flow could play a role in reducing potential DO violations. However, positive responses could be delayed, and the potential to depress DO levels in the LJR in response to flow change during critical times may exist. The two summer season flow changes showed a gain at the 2100 South, Cudahy, and Burnham sites and a similar response at different flows. This increase and consistency could indicate positive benefits in response to increasing summertime flows. Moderate flow increases may be a management tool to reduce potential DO violations during the summer.

To build on these speculative conclusions, we recommend:

- More empirical experiments with higher, more stable and sustained flow changes (as proposed in the current study plan).
- Further investigation into the causes of the initial drop in DO and other factors affecting DO response variability.
- If resources are limited, a research focus on flow effects during late summer.

Table 1. Travel time in hours from USGS gaging station at 1700 South.

Hours_t from USGS Gage to DO Station					
	50 CFS	100 CFS	150 CFS	200 CFS	250 CFS
2100 S.	-0.9	-0.8	-0.7	-0.6	-0.6
300 N.	6.9	5.7	4.7	4.3	4.0
Cudahy	17.2	14.8	13.2	12.0	11.3
Burnham	22.6	19.8	17.5	16.0	15.1

¹ Negative values indicate travel times between an upstream monitoring site (i.e. 2100 S) and the USGS gage at 1700 S.

Table 2. Data analyzed from flow changes and DO stations in the Lower Jordan River.

DO mg/L Before		DO mg/L After				Net Change in DO mg/L			Flow
Date	48 hr	24hr	24hr	48hr	72hr	24hr	48hr	72hr	Diff
2100 South									
22-Jun-11		8.24	8.15			-0.09			31.2
23-Jun-11		8.15	8.22	8.33	8.29	0.07	0.18	0.14	21.38
28-Jun-11		8.24	8.05			-0.19			32.36
29-Jun-11		8.02	7.98	8.25	8.21	-0.04	0.23	0.19	29.7
22-Apr-13	9.37	10.22	10.39	10.89	10.81	0.17	0.67	0.59	36.82
1-May-13	8.75	9.18	9.95	9.91	9.44	0.77	0.73	0.26	34.66
21-May-13	7.38	7.94	7.9	7.7	7.9	-0.04	-0.24	-0.04	76.5
21-Mar-14	9.52	9.46	9.63	9.33	7.86	0.17	-0.13	-1.6	38
23-Jun-14	5.99	6.43	6.36	6.2	6.5	-0.07	-0.23	0.07	29
23-Mar-15	9.61	9.63	8.9	9.78	10.35	-0.73	0.15	0.72	65
17-Jul-15	7.52	7.53	7.63	7.97	7.95	0.1	0.44	0.42	29.7
12-Aug-15	7.37	7.15	7.15	7.4	7.37	0	0.25	0.22	18.3
2-Jun-16		10.06	10.01	10.16	9.82	-0.05	0.1	-0.24	34
4-Jun-16	9.93	10.41	9.85	9.76		-0.56	-0.65		-26.2
6-Jun-16	9.82	9.73	9.6	9.88	9.71	-0.13	0.15	-0.02	32.6
Average	8.53	8.69	8.65	8.89	8.68	-0.04	0.13	0.06	
Standard Dev	1.36	1.21	1.20	1.35	1.31	0.33	0.38	0.59	
300 North									
22-Apr-13	8.94	9.26	9.44	9.9	9.79	0.18	0.64	0.53	36.82
1-May-13	8.38	8.9	9.52	9.26	8.75	0.62	0.36	-0.15	34.66
21-May-13	7.75	9.1	7.37	7.41	7.71	-1.73	-1.69	-1.39	76.5
21-Mar-14	9.63	9.55	9.01	8.17	7.65	-0.54	-1.38	-1.9	38
23-Jun-14	5.56	5.79	5.58	5.57	5.19	-0.21	-0.22	-0.6	29
17-Mar-16	9.96	10.23	9.59	10.11	10.23	-0.64	-0.12	0	31.3
2-Jun-16		9.19	9.09	9.15	8.95	-0.1	-0.04	-0.24	34
4-Jun-16	8.95	9.22	9.05	8.79		-0.17	-0.43		-26.2
6-Jun-16	8.95	8.71	8.59	8.78	8.77	-0.12	0.07	0.06	32.6
Average	8.52	8.88	8.58	8.57	8.38	-0.12	-0.14	-0.33	

Table 2. Data analyzed from flow changes and DO stations in the Lower Jordan River.

DO mg/L Before		DO mg/L After			Net Change in DO mg/L			Flow	
Date	48 hr	24hr	24hr	48hr	72hr	24hr	48hr	72hr	Diff
Standard Dev	1.37	1.24	1.31	1.39	1.57	0.65	0.76	0.81	
Cudahy									
22-Apr-13	8.92	8.84	9.49	9.87	9.53	0.65	1.03	0.69	36.82
1-May-13	8.22	8.88	9.35	9.07	8.4	0.47	0.19	-0.48	34.66
21-May-13	7.37	7.47	7.47	7.58	7.92	0	0.11	0.45	76.5
21-Mar-14	10.19	10.2	8.98	7.36	7.16	-1.22	-2.84	-3.04	38
23-Jun-14	5.72	5.63	5.35	5.41	4.99	-0.28	-0.22	-0.64	29
23-Mar-15	12.79	11.07	8.25	9.52		-2.82	-1.55		65
17-Jul-15	5.48	5.55	5.65	5.85	5.77	0.1	0.3	0.22	29.7
12-Aug-15	6.09	5.46	5.66	5.8	5.72	0.2	0.34	0.26	18.3
Average	8.10	7.89	7.53	7.56	7.07	0.19	0.29	0.08	
Standard Dev	2.51	2.20	1.76	1.78	1.65	0.33	0.41	0.53	
Burnham Dam									
22-Jun-11		8.32	8.19			-0.13			31.2
23-Jun-11		8.23	7.92	8.15	8.24	-0.31	-0.08	0.01	21.38
28-Jun-11		8.05	7.66			-0.39			32.36
29-Jun-11		7.53	7.61	7.84	7.82	0.08	0.31	0.29	29.7
22-Apr-13	8.52	8.63	9.33	9.66	9.22	0.7	1.03	0.59	36.82
1-May-13	8.05	8.8	9.19	8.9	8.28	0.39	0.1	-0.52	34.66
21-May-13	7.32	7.56	7.63	7.8	8.01	0.07	0.24	0.45	76.5
23-Jun-14	5.47	5.33	5.18	5.31	4.98	-0.15	-0.02	-0.35	29
17-Jul-15	5.71	5.7	5.8	6.03	6	0.1	0.33	0.3	29.7
12-Aug-15	6.33	5.57	5.98	6.05	6.06	0.41	0.48	0.49	18.3
17-Mar-16	9.06	10.42	9.09	8.95	9.14	-1.33	-1.47	-1.28	31.3
4-Jun-16	8.49	8.63	8.53	8.19		-0.1	-0.44		-26.2
6-Jun-16	8.43	8.06	7.8	8.07	7.87	-0.26	0.01	-0.19	32.6
Average	7.36	7.51	7.40	7.41	7.19	0.03	0.20	0.12	
Standard Dev	1.37	1.83	1.56	1.41	1.51	0.33	0.39	0.40	

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

	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

Table 4. Averaged Net Change in DO (mg/L) during two summer flow change events occurring on July 17, 2015 and August 12, 2015. Net Change in DO is determined at 24, 48, and 72 hours after the change in flow.

	N	Period 1	Period 2	Period 3
2100 S	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

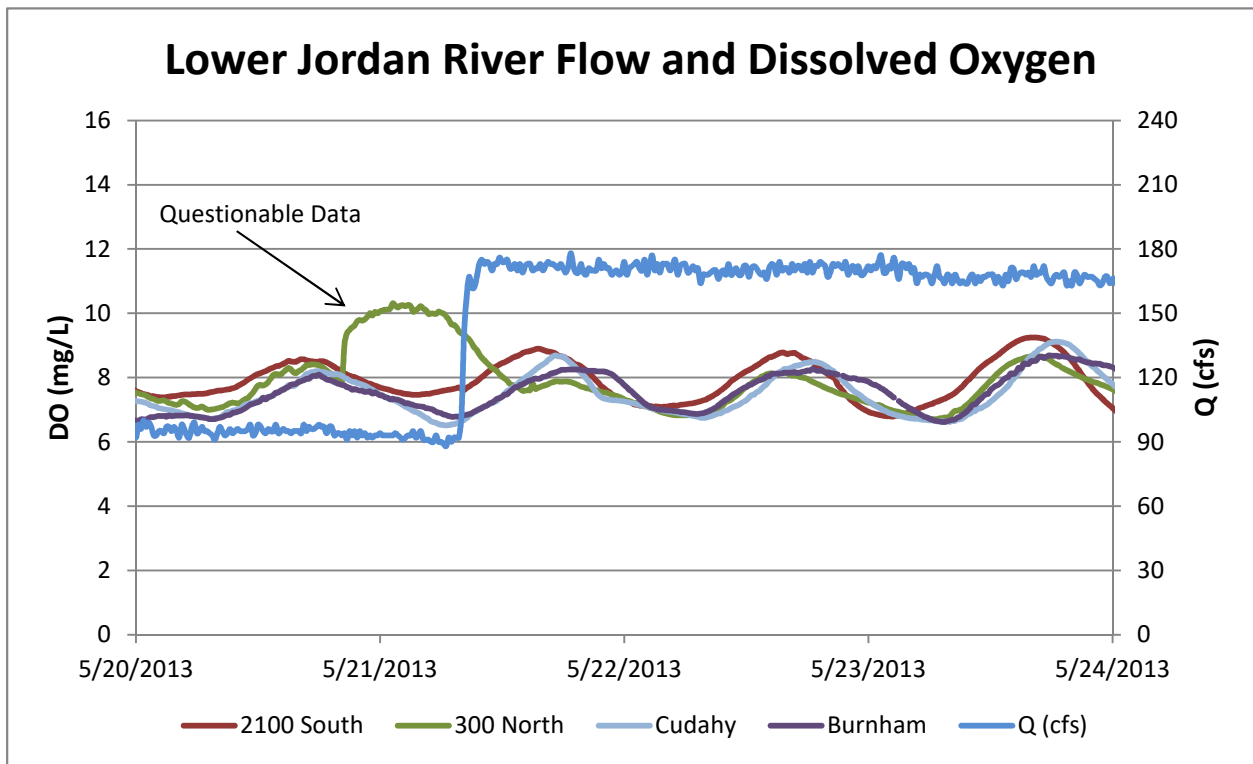


Figure 1. Largest flow change (76.5 cfs) observed in the LJR with paired DO data.

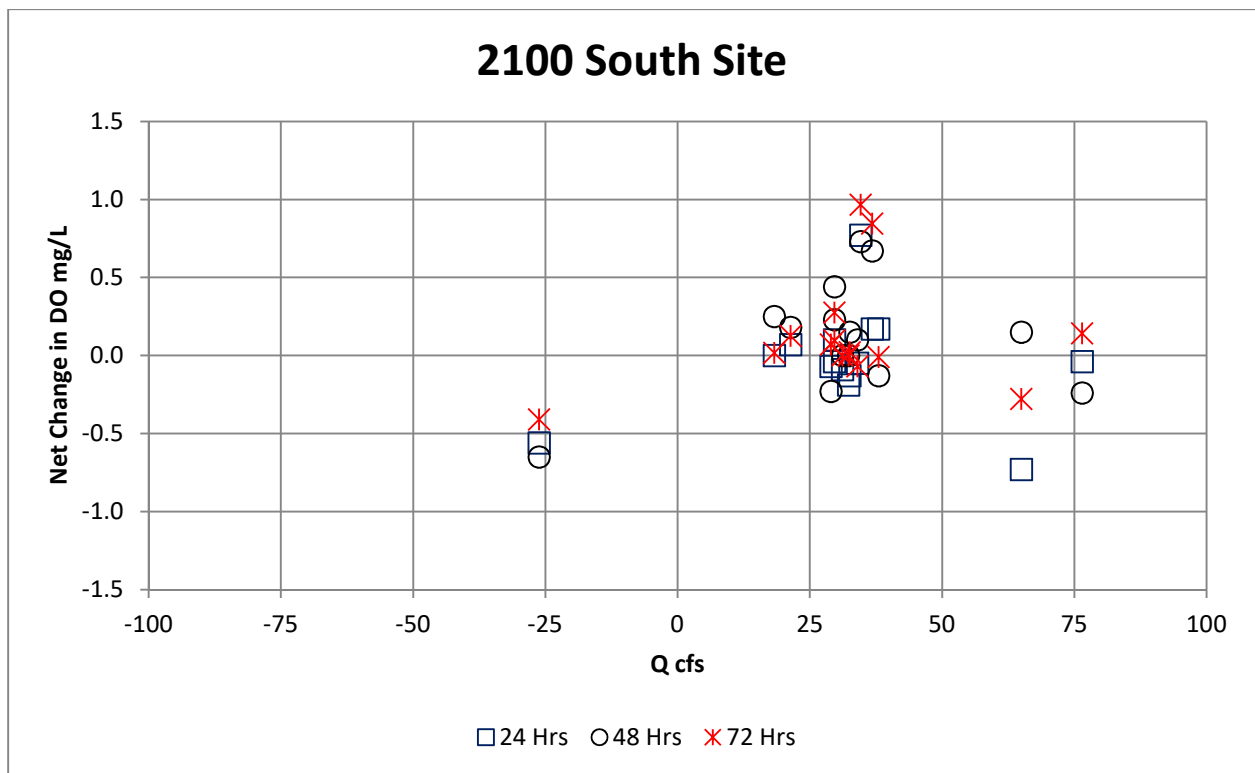


Figure 2. Net change in DO after 24, 48, and 72 hours plotted against net change in flow at 2100 South.

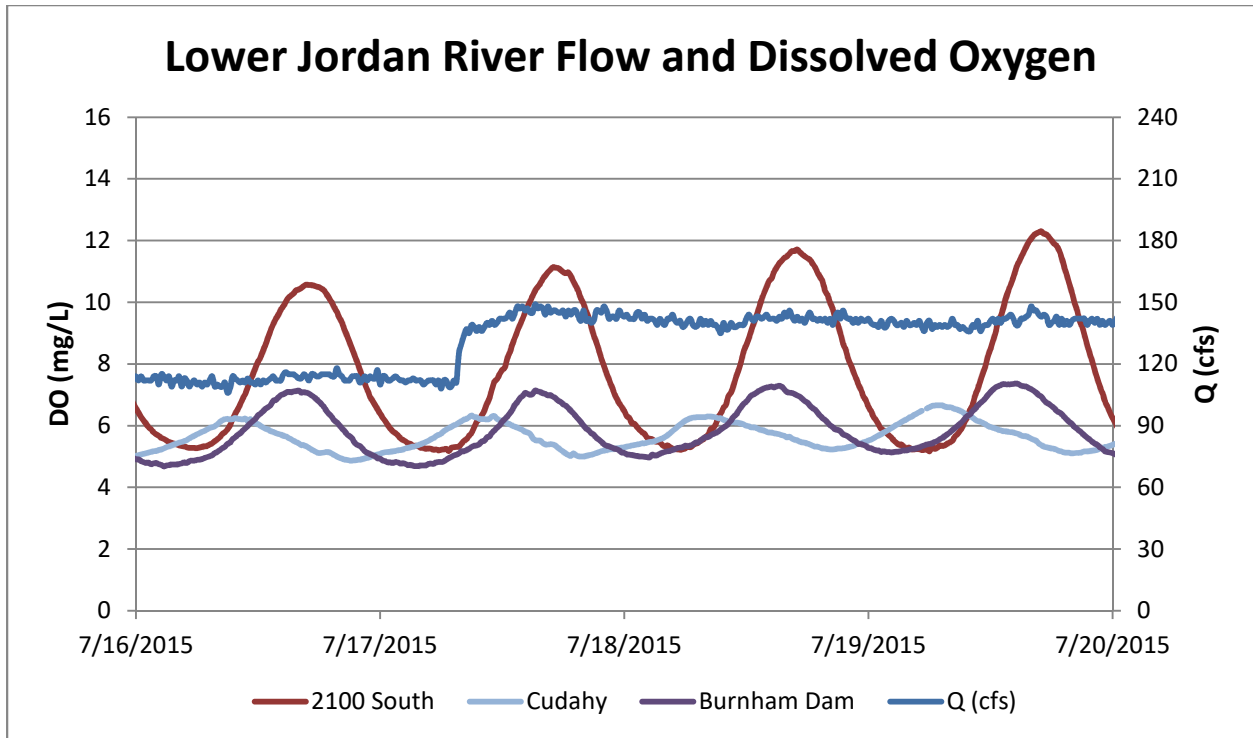


Figure 3. Flow change (29.7 cfs) occurring in July 2015. This is the first of two flow events identified during the summer season.

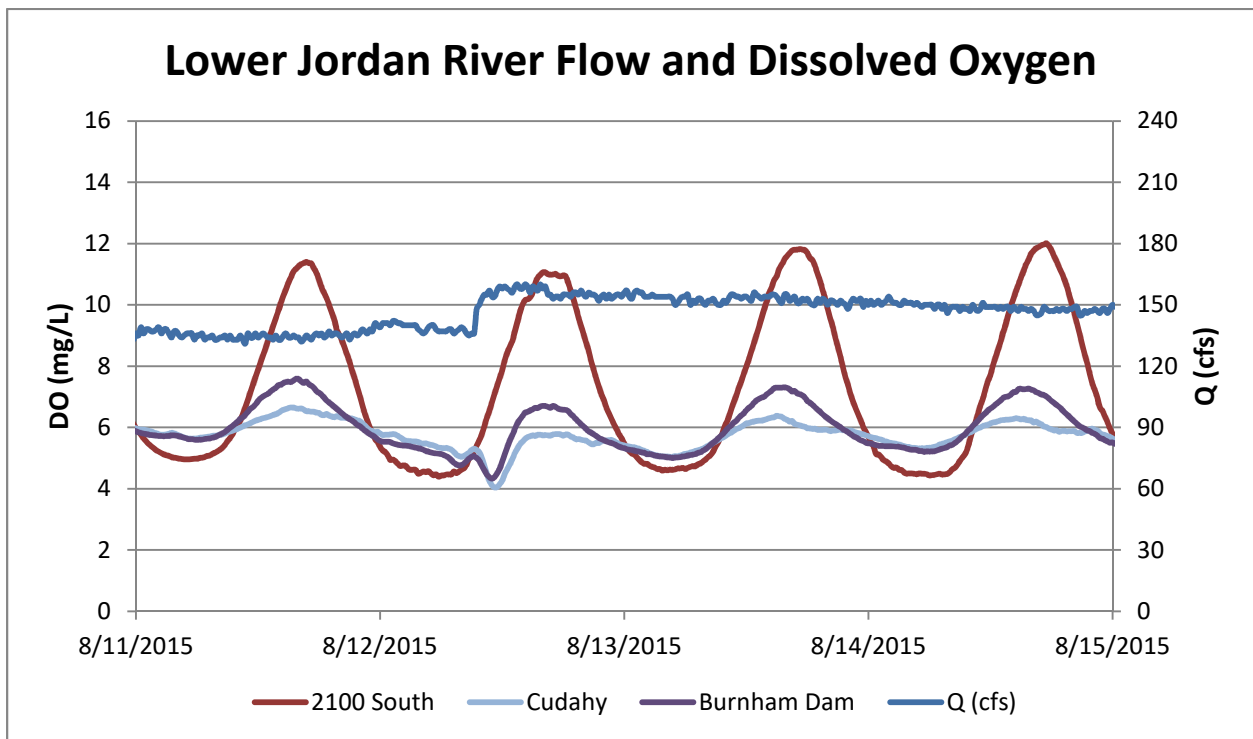


Figure 4. Flow change (18.3 cfs) occurring in August 2015. This is the second of two flow events identified during the summer season.

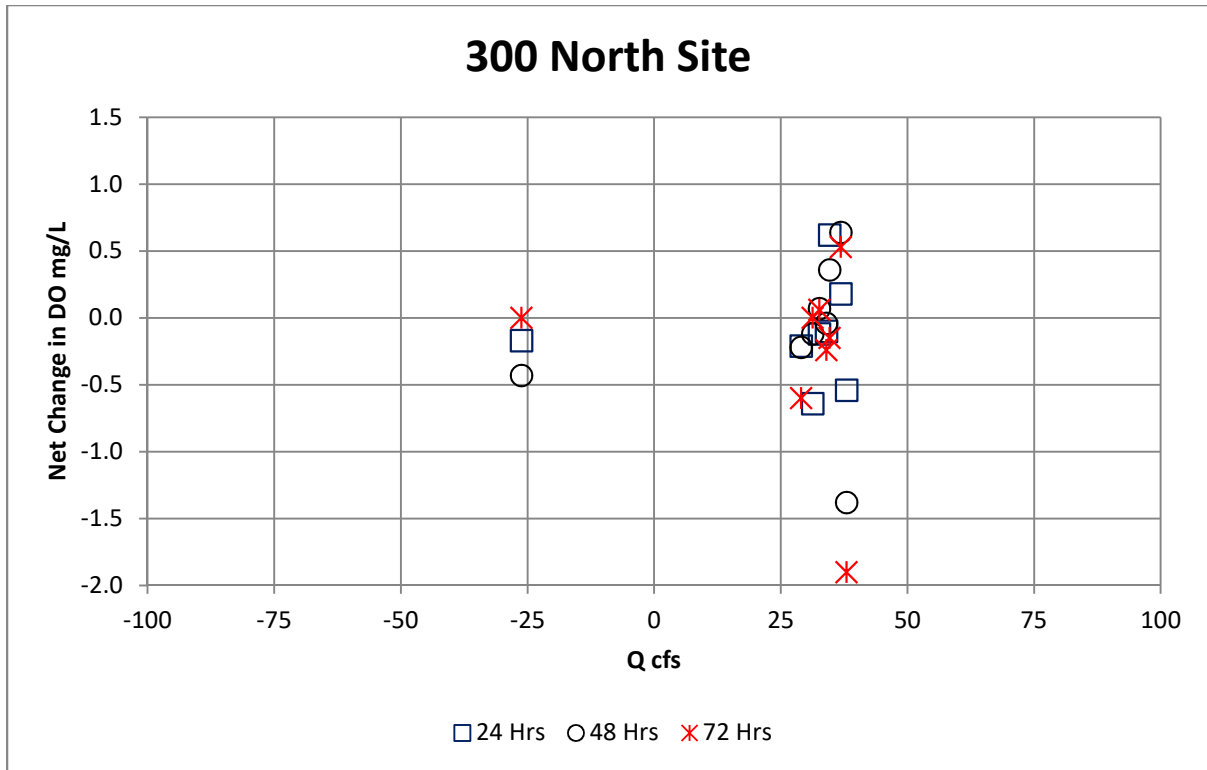


Figure 5. Net change in DO after 24, 48, and 72 hours plotted against net change in flow at 300 North.

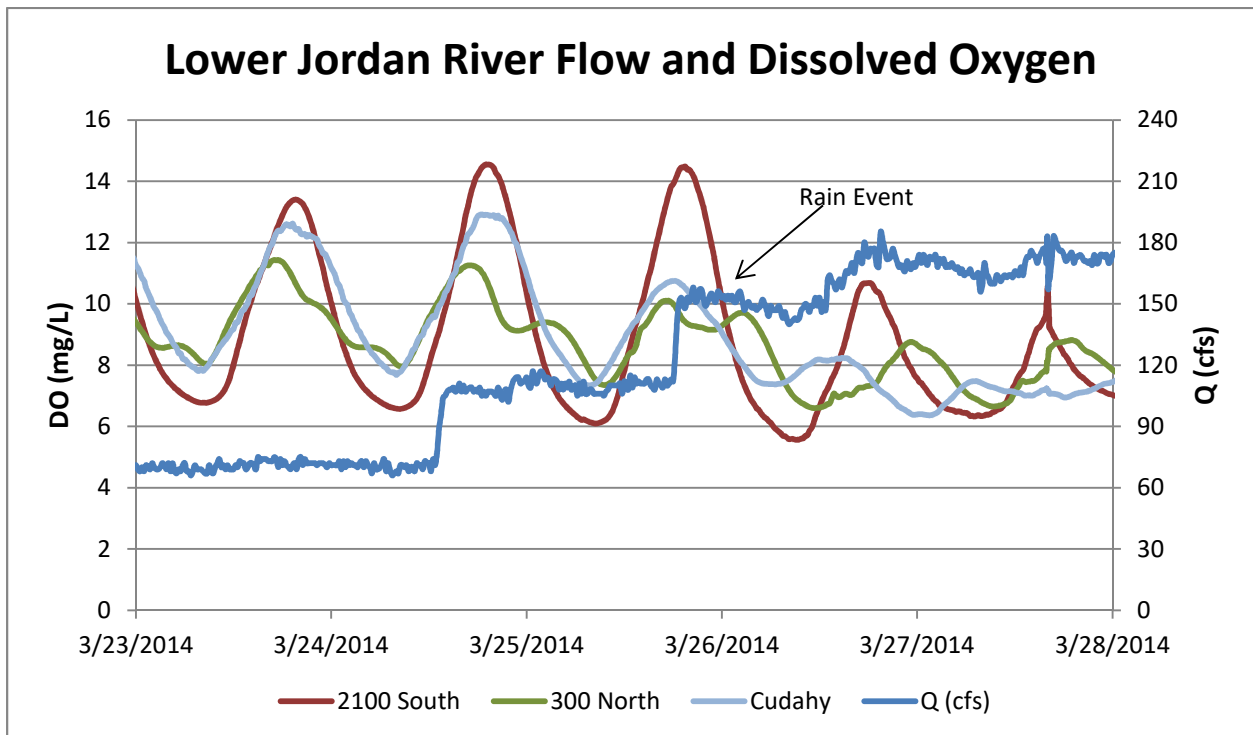


Figure 6. An example of the greatest reduction in DO following a flow change (38 cfs). DO concentrations were further depressed after the flow change by a precipitation event.

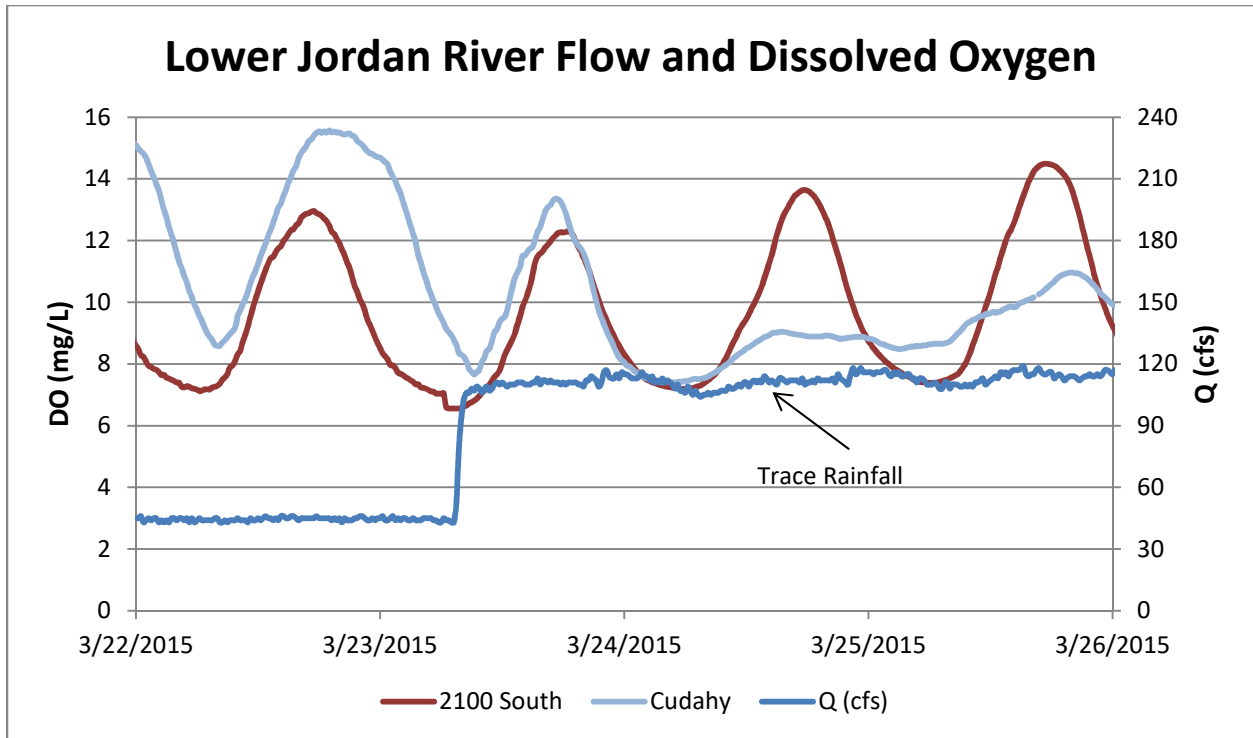


Figure 7. An example of an initial drop in DO from a flow change (65 cfs) followed by a precipitation event Cudahy.

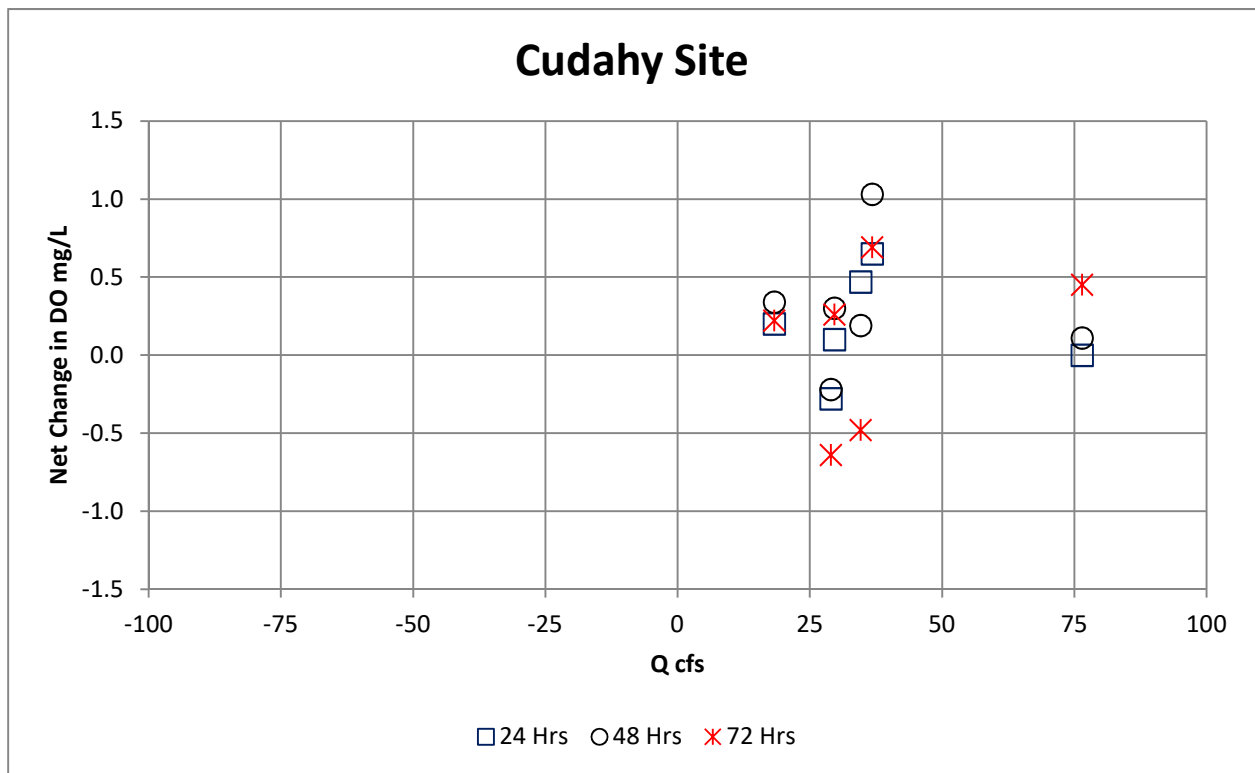


Figure 8. Net change in DO after 24, 48, and 72 hours plotted against net change in flow at Cudahy.

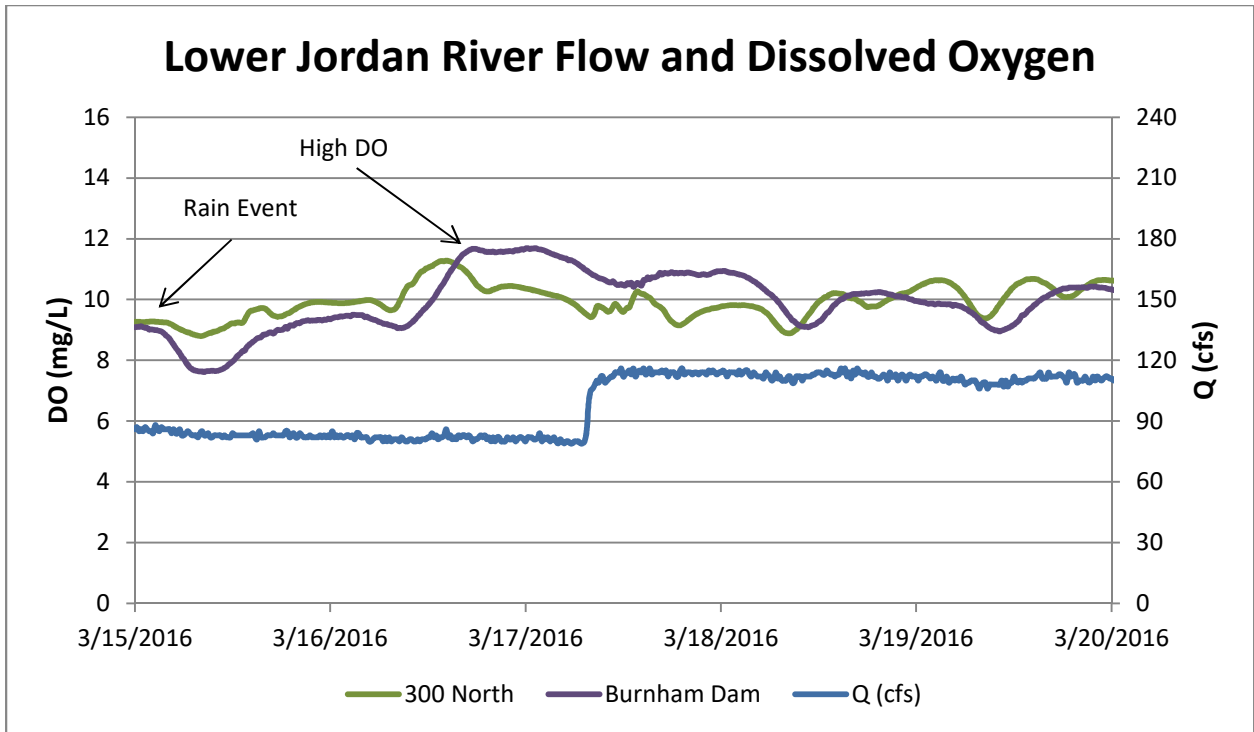


Figure 9. Paired DO and flow data for the Lower Jordan River illustrating the anomaly of high DO prior to a flow change (31.3 cfs) influencing the net change in DO.

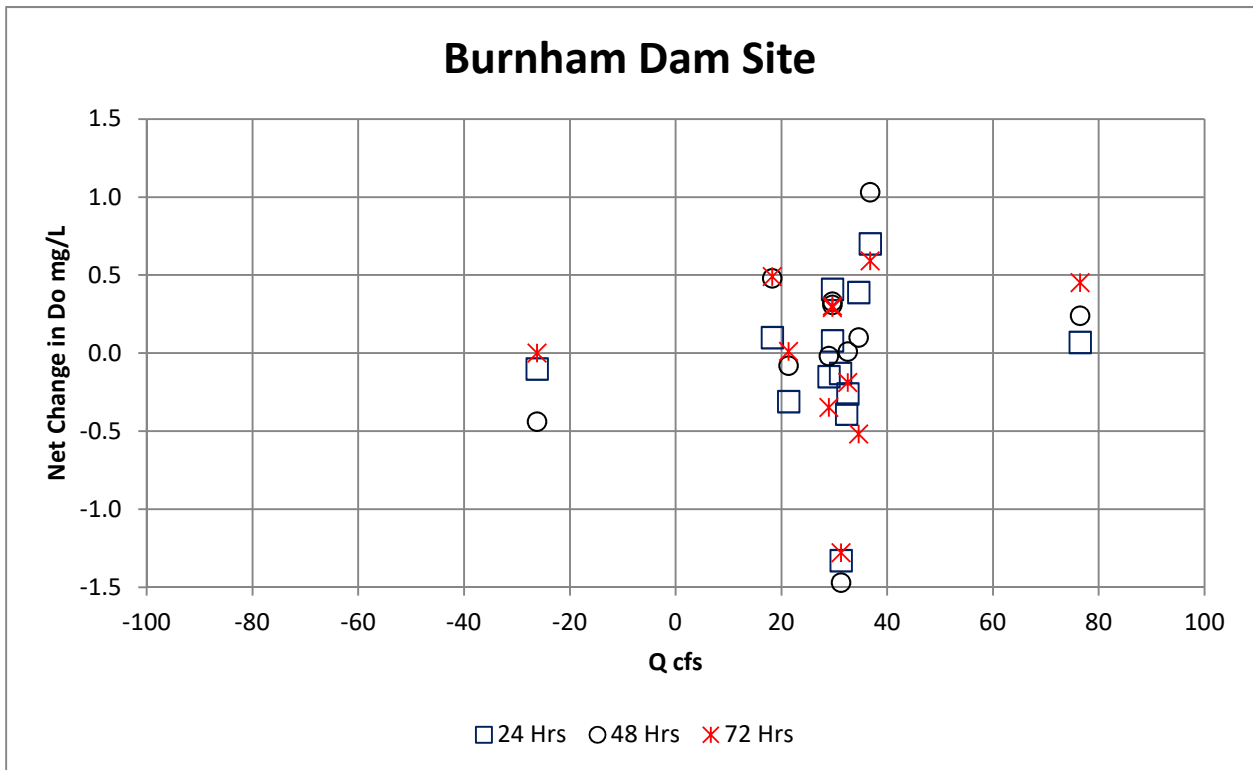


Figure 10. Net change in DO after 24, 48, and 72 hours plotted against net change in flow at Burnham Dam.