Dissolved Oxygen: Jordan River
CVEEN 7920: Water Resources Planning
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Abstract

The Jordan River located in the state of Utah spreads across a 51-mile stretch flowing from Utah Lake to the Great Salt Lake. According to the Division of Water Quality the river is heavily impaired. The lower stretch of the river does not meet the dissolved oxygen standards of the state. An analysis was conducted in Stockholm Environment Institute's Water Evaluation and Planning (WEAP) model using climate change scenarios while also taking into consideration a management alternative for the biological oxygen demand (BOD) discharge of Central Valley Reclamation Facility. The two climate scenarios that were observed are the RCP 2.6 and 8.5 under each scenario; iterations were run to determine the optimum effluent concentration of the wastewater treatment plant to aid in the rehabilitation of the Jordan River. The current BOD effluent standard is at 25 mg/L, for the purposes of the analysis a standard of both 25 mg/L and 15 mg/L were considered in the WEAP model. Data was collected from multiple sources and used in WEAP to generate water temperatures, BOD and DO. The results of the WEAP model indicated a slight differentiation between the climate change scenarios, however indicated a minimal effect of 0.3 mg/L BOD and 0.1 mg/L DO.

Table of Contents

Introduction

The Jordan River is a heavily contaminated body of water that has been listed as impaired by Utah's Division of Water Quality. In 2005, the Utah Department of Environmental Quality hired Cirrus Ecological Solutions to conduct a Total Maximum Daily Load (TMDL) water quality study to analyze the levels of Dissolved Oxygen (DO), Total Dissolved Solids (TD), Escherichia coliform (E. coli), and water temperature (Temperature) in the Jordan River in Utah [1]. The levels of these constituents violate water quality regulations that have been set by the state of Utah. The impairment of the river is solely due to the contaminants in the river due to point and nonpoint sources.

This project will evaluate point sources, taking into consideration climate change and the BOD effluent discharge from a wastewater treatment plant into to the Jordan River. Central Valley Water Reclamation Facility (Central Valley), located near Mill Creek, will be the focus of an extended analysis of the TMDL. This was done by creating a model for DO in the Jordan River in WEAP. The project consisted of two different climate change scenarios and a sub-scenario for each climate change scenario with a proposed BOD effluent standard for Central Valley. The purpose of this project is to determine the standard for BOD effluent from Central Valley that would increase DO levels in the Jordan River. The main performance indicator used in this analysis is the concentration of DO in the Jordan River.

Background

The Jordan River is considered home to thousands of individuals and inhabitants; the river flows north from Utah Lake to the wetlands of the Great Salt Lake. The river has approximately 51 miles stretch across three counties: Salt Lake, Utah and Davis [1][2]. The river is used for multiple purposes including agriculture, irrigation, municipal, industrial and recreational uses[3]. Currently the Jordan River is heavily contaminated with toxic metal and considered impaired according to EPA standards. Regulating contamination levels in the Jordan River becomes a complex issue due to the location of the river and multiple bodies of water diverging into the Jordan River such as: City Creek, Little Cottonwood, Big Cottonwood, Parleys, and Mill Creek. Other sources that discharge into the river include both point sources and nonpoint sources. The point sources include the wastewater municipalities, industrial discharge and failing septic systems while non-point sources include storm water runoff, public pollution, illegal dumping, and agricultural runoff[3]. The Division of Environmental Quality(DEQ) is currently trying to restore the Jordan River to it's "Natural Conditions". Contamination and water quality issues of the Jordan River include: metals, total dissolved solids, E. coli, high water temperatures, high levels of ammonia and low dissolved oxygen[3].

“The DEQ's mission is to safeguard public health and our quality of life by protecting and enhancing the environment. We implement State and federal environmental laws and work with individuals, community groups, and businesses to protect the quality of our air, land and water”

The TMDL for the Jordan River was approved by the EPA in June 2013. The report’s major concerns for the Jordan River are associated with the organic matter and the DO levels of the river. Violations for temperature and total dissolved solids also exist, however this is solely due to natural causes. The model they used for their study showed a strong relationship between Total Organic Matter (OM) and DO. The only section of the Jordan River listed as impaired for DO is downstream of the surplus canal, which is north of 2100 south in Salt Lake City. DO deficits occur year round, but are generally greatest in late summer and early fall. The sources of OM pollution they examined included point sources and nonpoint sources. They also projected future OM loads, which were based mainly on population growth. The DWQ has specified the beneficial water uses for the Jordan River as follows in Table 1.

Table 1. Classification of Beneficial Uses[4]

Classification	Description
Class 1C	Protected for domestic purposes with prior treatment by treatment processes as required by the Utah Division of Drinking Water
Class 2B	Protected for secondary contact recreation such as boating, wading, or similar uses
Class 3A	Protected for cold-water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
Class 3B	Protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain
Class 3C	Protected for nongame fish and other aquatic life, included the necessary aquatic organisms in their food chain.
Class 3D	Protected for waterfowl, shore birds and other water-oriented wildlife not included in classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain
Class 4	Protected for agricultural uses including irrigation of crops and stock watering

The Jordan River was divided into eight water quality segments referred to as DWQ segments. Figure 1 shows the layout of the segments as well as the constituents that violate water quality regulations. From the Jordan River TMDL, Table 2 includes more detail of how these constituents affect the DWQ segments along the river. Dissolved oxygen affect Class 3B and 3C activities for DWQ segments 1 and 2.

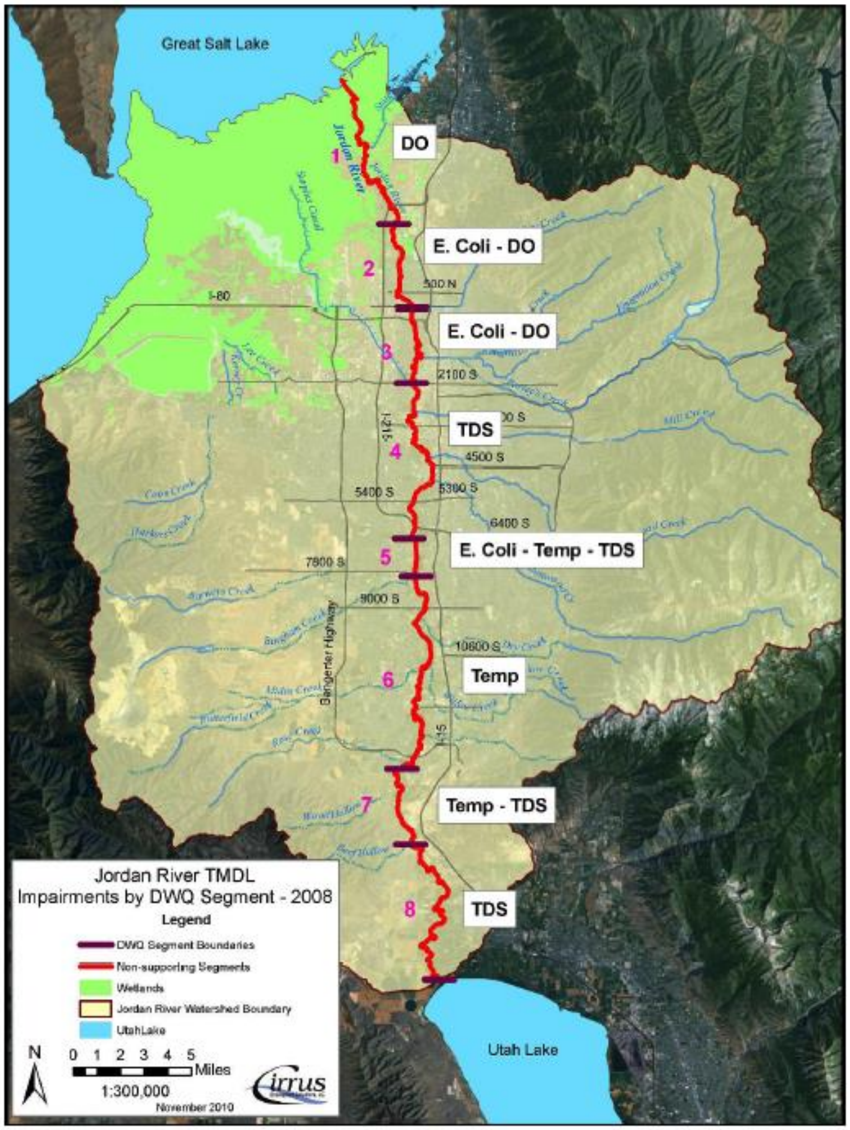

Figure 1. Location of DWQ segments and corresponding pollutant of concern

Table 2. WQ segments of Jordan River with corresponding impaired beneficial uses [1]

Table 1.1. DWQ segments of the Jordan River included on the Utah 2008 303(d) List (Utah DWQ 2008a).

DWQ Segment	Beneficial Use and Support Status [1]							(Beneficial Use) Pollutant of Concern	Standard or Pollution Indicator Level [2] for Pollutant of Concern
	River Mileage	1C	2B	3A	3B	3C	4		
1	0–6.9				NS	NS		(3B) Benthic Macro Impairment[2] (3B) Organic Enrichment/Low DO (3C) Organic Enrichment/Low DO	(3B) O/E ratio[3] >0.74 or >0.54 per sample size (3B) Min: Aug–Apr = 4 mg/L, May–Jul = 4.5 mg/L (3C) 30-day avg DO = 5 mg/L
2	6.9–11.4		NS		NS			(2B) *E. coli* (3B) Benthic Macro Impairment (3B) Organic Enrichment/Low DO	(2B) Max=940 col/100 mL, Geo. Mean=206 col/100 mL (3B) O/E ratio >0.74 or >0.54 per sample size (3B) Aug–Apr = 4 mg/L, May–Jul = 4.5 mg/L
3	11.4–15.9		NS		NS			(2B) *E. coli* (3B) Organic Enrichment/Low DO (3B) Total Phosphorus	(2B) Max=940 col/100 mL, Geo. Mean=206 col/100 mL (3B) Aug–Apr = 4 mg/L, May–Jul = 4.5 mg/L (3B) 0.05 mg/L (pollutant indicator level)
4	15.9–24.7			[4]			NS	(4) Salinity/TDS/Chlorides	(4) 1,200 mg/L
5	24.7–26.4		NS	NS			NS	(2B) *E. coli* (3A) Temperature (4) Salinity/TDS/Chlorides	(2B) Max=940 col/100 mL, Geo. Mean=206 col/100 mL (3A) Max = 20°C (4) 1,200 mg/L
6	26.4–37.6			NS				(3A) Benthic Macro Impairment (3A) Temperature	(3A) O/E ratio >0.74 or >0.54 per sample size (3A) Max = 20°C
7	37.6–41.8			NS			NS	(3A) Benthic Macro Impairment (3A) Temperature (4) Salinity/TDS/Chlorides	(3A) O/E ratio >0.74 or >0.54 per sample size (3A) Max = 20°C (4) 1,200 mg/L
8	41.8–51.4	[1]		NS			NS	(3A) Benthic Macro Impairment (3A) Temperature (4) Salinity/TDS/Chlorides	(3A) O/E ratio >0.74 or >0.54 per sample size (3A) Max = 20°C (4) 1,200 mg/L

[1] Shaded cells indicate beneficial uses assigned to each DWQ segment. NS indicates non-support of the assigned beneficial use.
[2] Benthic macroinvertebrate impairment is based on pollution indicator values.
[3] O/E ratio – the measured ratio of observed macroinvertebrate species to expected macroinvertebrate species (Utah DWQ 2008b).
[4] Beneficial use class 3A applies to DWQ Segment 4 above the confluence with Little Cottonwood Creek.

Methods

For the purposes of this project, the Stockholm Environment Institute's Water Evaluation and Planning (WEAP) model was chosen for a water quality analysis of the Jordan River. To begin the modeling process, data was collected from various sources to input into WEAP. This data was managed in two different scenarios: historical and projected. The collection implementation, and calculation of the data is discussed further in the following sections.

Data Collection

Catchment Areas

The catchments are used to determine how much runoff from the precipitation data is contributed to the streamflow of the river. Areas for each catchment were developed using the online USGS Streamstats program. Headflows for each stream were derived from data available on the Salt Lake County Flood Control website, where average monthly flows are available. Figure 2 shows the locations of the stations were data is available. Including headflows for each stream in the model helped to reduce the number of errors WEAP was generating. These headflows are shown in Table 3. Crop coefficients are listed in Table 4.

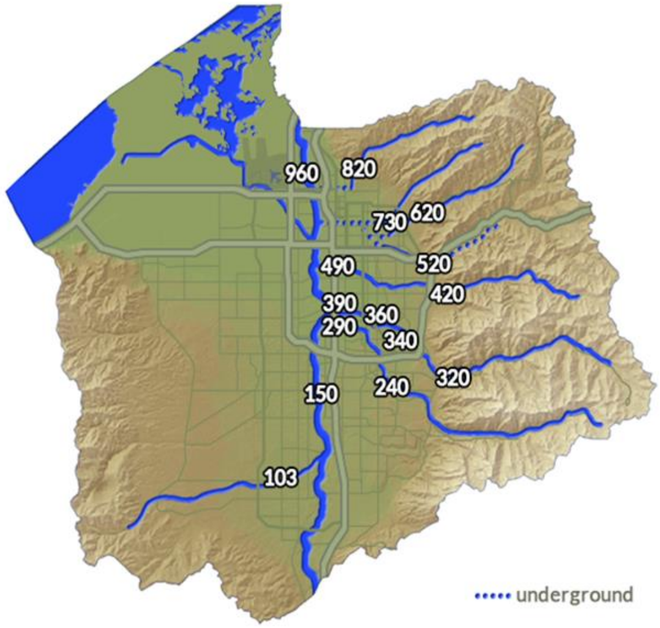

Figure 2: Average Monthly Flows

Table 3: Headflows

Headflows (cfs)								
	City Creek	Dell Creek	Lambs Creek	Parleys Creek	Mill Creek	Little Cottonwood	Big Cottonwood	Jordan River
January	12.4	2.4	2.4	-	9.4	3.0	5.0	91.2
February	16.8	2.0	2.0	-	8.5	3.0	5.5	36.9
March	17.3	5.6	5.6	-	8.9	3.1	5.0	31.8
April	22.3	5.7	5.7	-	11.0	11.5	32.0	27.6
May	55.5	6.9	6.9	-	18.8	44.3	87.7	853
June	75.3	11.9	11.9	-	31.6	296	280	660
July	21.8	3.5	3.5	-	15.5	25.7	31.2	283
August	15.9	2.2	2.2	-	12.9	5.8	5.2	202
September	15.6	1.8	1.8	-	10.6	3.3	5.2	160
October	15.0	2.2	2.2	-	10.5	3.4	9.0	115
November	14.6	2.7	2.7	-	9.7	4.2	5.0	127
December	9.5	2.9	2.9	-	6.2	3.0	5.0	100

Table 4: Crop Coefficients

Crop Coefficients (Kc)								
	City Creek	Dell Creek	Lambs Creek	Parleys Creek	Mill Creek	Little Cottonwood	Big Cottonwood	Jordan River
January	0.9	1.0	1.0	1.0	1.1	1.1	1.1	0.9
February	0.9	1.0	1.0	1.0	1.1	1.1	1.1	0.9
March	1.0	1.2	1.1	1.2	1.2	1.2	1.2	1.0
April	1.1	1.2	1.1	1.2	1.3	1.3	1.3	1.1
May	1.4	1.5	1.4	1.5	1.6	1.6	1.6	1.4
June	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.1
July	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.1
August	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.1
September	0.9	1.0	1.0	1.0	1.1	1.1	1.1	0.9
October	0.9	1.0	1.0	1.0	1.1	1.1	1.1	0.9
November	0.9	1.0	1.0	1.0	1.1	1.1	1.1	0.9
December	0.9	1.0	1.0	1.0	1.1	1.1	1.1	0.9

Streams

A shapefile was imported into WEAP from GIS to accurately portray the lengths and confluences of each stream. The eight streams that were modeled and their defining factors are listed in Table 5 below.

Table 5: Stream Data

Reach	Reach Length	Catchment Area	Effective Precipitation
	km	km^2	%
City Creek	11.7	46.1	85%
Emigration Creek	22.9	55.2	85%
Dell Creek	12.2	44.0	85%
Lambs Creek	9.0	55.7	85%
Parleys Creek	28.5	147.4	85%
Mill Creek	32.6	95.1	85%
Little Cottonwood	36.2	104.6	85%
Big Cottonwood	40.7	211.1	85%
Jordan River	69.4	2049.0	85%

Channel Geometry

Water quality modeling in WEAP requires a description of the channel geometry. The standard format for this data in WEAP is a flow-depth-width curve. These curves were developed using channel cross sections from UDOT bridge inspections. The latest available cross section was used for each stream where data was available and the program hydraulic toolbox was used to generate the curves using an assumed slope of 0.5% in most cases. Total reach lengths were calculated using ArcGIS, along with stream data downloaded from the Utah Automated Geographic Reference Center (AGRC).

AWQMS

The historical Jordan River quality data was obtained through the Ambient Water Monitoring System (AWQMS). The AWQMS is compiled by the DEQ and is a public system specifically designed for water quality data. BOD values were pulled across the stretch of the Jordan River from the database. The data was then sort through using an R script that took the latitudes and longitudes of the data and plotted it on Google Earth; refer to Figure 3, below.

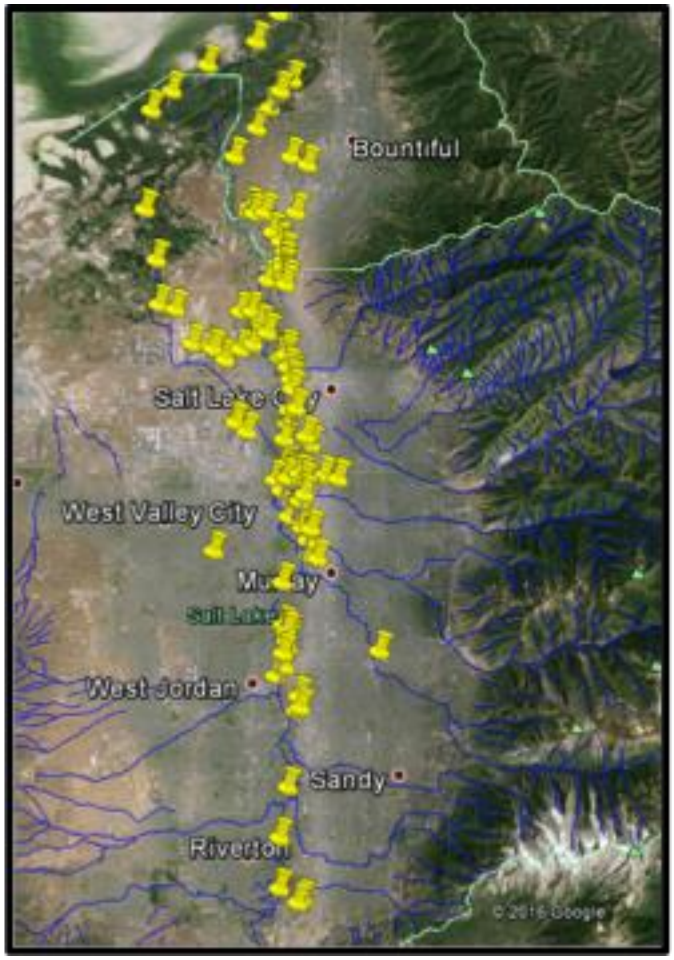

Figure 3: AWQMS BOD data points

Table 6 below is a summary of the BOD data collected from the AWQMS. These data points were entered as BOD headflow concentrations in WEAP.

Table 6: AWQMS BOD Data

BOD (mg/l)								
	City Creek	Dell Creek	Lambs Creek	Parleys Creek	Mill Creek	Little Cottonwood	Big Cottonwood	Jordan River
January	2	4	4	4	4	2	2	3
February	2	5	5	5	6	1	1	4
March	3	5	5	5	12	3	3	4
April	3	5	5	5	5	1	1	5
May	3	4	4	4	4	2	2	2
June	3.36	7.5	7.5	7.5	7.5	1	1	2
July	4.15	8	8	8	5	2	2	3
August	5.72	5	5	5	8	2	2	6
September	4	5	5	5	5	1	1	4
October	3	5	5	5	5	1	1	3
November	2	3	3	3	3	3	3	2
December	2	3.25	3.25	3.25	3.25	1	1	2

Projected Data

In order to analyze climate change scenarios using WEAP, projected data from the Intergovernmental Panel on Climate Change (IPCC) were used in the model. The IPCC developed four different Representative Concentration Pathway (RCP) scenarios in order to address the varying effects of greenhouse gas emissions as shown in Figure 4. The IPCC came up with four main RCP scenarios, RCP8.5, RCP6, RCP4.5 and RCP2.6. “The RCP are based on assumptions about economic activity, energy sources, population growth and other socio-economic factors” [12].For the purposes of the WEAP analysis only RCP2.6 and RCP8.5 were considered. RCP2.6 assumes a minimal amount of climate change (temperature < 2ºC) while RCP8.5 is an extreme of global climate change (temperature > 4.9ºC).

The climate data needed for the WEAP model included air temperature, wind speed, precipitation, and relative humidity. Average monthly data was downloaded from the downscaled CMIP5 climate and hydrology projections website, and sorted using an R script. Data was obtained for two locations, Parleys and the Salt Lake City Airport. The climate data from Salt Lake City Airport was used for the Jordan River and City Creek, and the data for Parleys was used for the rest of the mountainous streams.

The downloaded data included minimum air temperature, maximum air temperature, wind speed, and precipitation. The average air temperature was calculated between the minimum and maximum, and the relative humidity was calculated using the August-Roche-Magnus approximation [7]. The datasets were converted to csv files with a format compatible with WEAP.

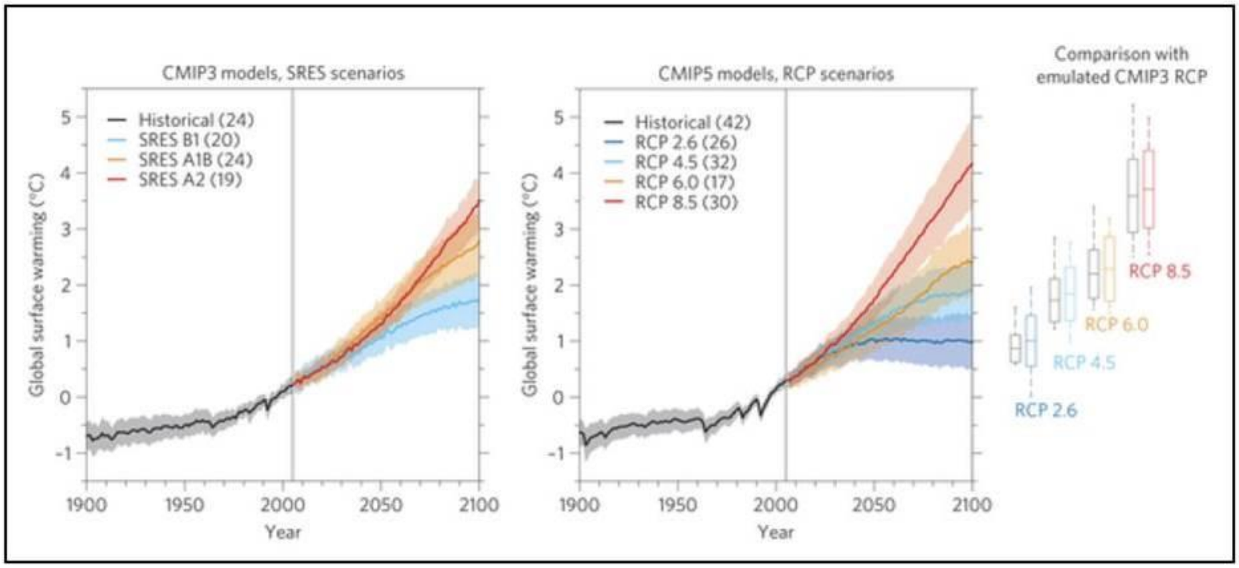

Figure 4: RCP Scenarios

WEAP Model

Calculations

The water quality constituents BOD, DO, and water temperature were modeled in all of the streams. The BOD and DO model require water temperature to have data inputted or modeled in WEAP. To model in WEAP, wind speed, air temperature, and humidity needed to be added into the model. Once added, the water temperature was calculated using simple mixing, a weighted average of water temperature of all flows such as groundwater, return flows, tributaries, and flows from upstream. If no temperature data is provided, it is calculated with the WEAP Temperature Model defined by Equation 1. The equation is repeated and defined in Appendix: Equations.

Equation 1: Water Temperature [6]

$$\frac{dT}{dt} = \frac{Q_i}{V}T_i + \frac{R_n}{\rho C_p H} + \left(\frac{\sigma(T_{air} + 273)^4 a\sqrt{e_{air}}}{\rho C_p H}\right) - \frac{Q_i}{V}T_{i+1} - \frac{\varepsilon\sigma(T_{i+1} + 273)^4}{\rho C_p H} - \frac{\varepsilon\sigma(T_{i+1} + 273)^4}{\rho C_p H} - \frac{f(u)(T_{i+1} - T_{air})}{\rho C_p H} - \frac{g(u)D}{\rho C_p H}$$

With water temperature, BOD and DO were modeled within the program using Equation 2 and 3. The following equations are repeated and defined in Appendix: Equations. Equation 2 is used to find the oxygen saturation for each segment which is estimated based on a function of water temperature. The Streeter-Phelps model, Equation 3 is used to calculate the oxygen concentrations from point source loads of BOD. In general, the Streeter-Phelps model for DO is more sensitive to changes in temperature than it is to changes in BOD.

Equation 1: Water Temperature[6]

$$OS = 14.54 - (0.39T) + (0.01T^2)$$

Equation 3: Streeter-Phelps Model [6]

$$O = OS - \left(\frac{k_a}{k_a - k_r}\right)\left(exp^{-k_r\left(\frac{L}{U}\right)} - exp^{-k_a\left(\frac{L}{U}\right)}\right)BOD_{IN} - \left((OS - O_{IN})exp^{-ka\left(\frac{L}{U}\right)}\right)$$

BOD removal and the BOD removal rate are calculated in Equations 4 and 5. These equations are repeated and defined in Appendix: Equations.

Equation 4: BOD Removal [6]

$$BOD = BOD_{IN}\left(exp^{-k_{rBOD}\left(\frac{L}{U}\right)}\right)$$

Equation 5: BOD Removal Rate [6]

$$k_{rBOD} = k_{d20}{}^{\left(1.04T\,(T-20)\right)} + \frac{v_s}{H}$$

Schematic

The Jordan River Basin has been simplified to streamline the water quality modeling in WEAP. The basic structure of the model was developed using a shapefile of the major streams in Salt Lake County. This base model included eight catchments, eight rivers, one demand node and one wastewater treatment plant as shown in Figure 5.

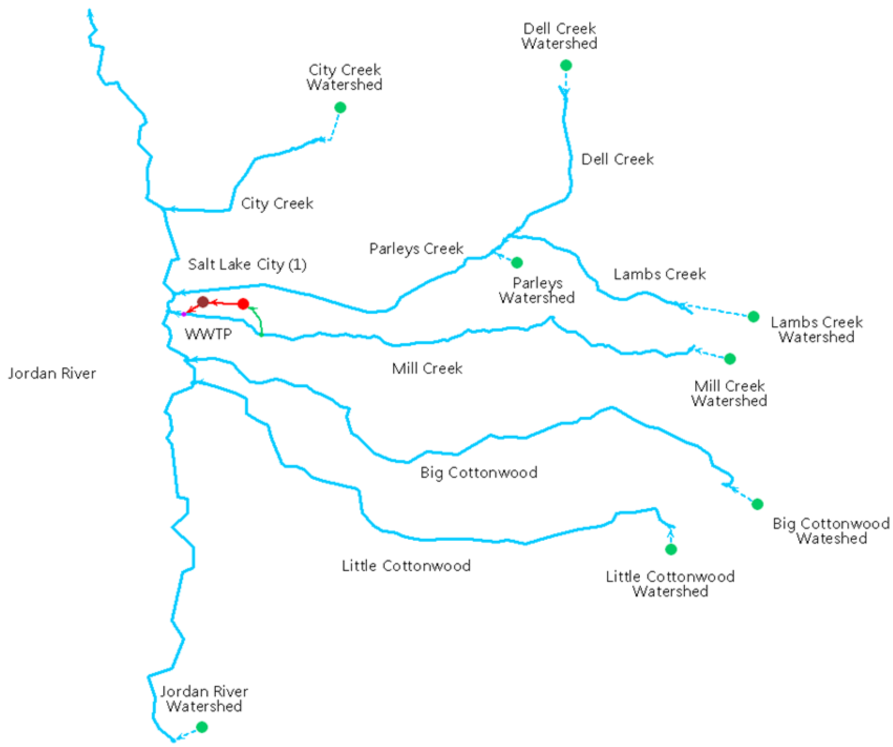

Figure 5: WEAP Schematic

Assumptions were made based on the scope of the problem to allow for these modifications to create the structure. Central Valley is located at the downstream end of Mill Creek. This effluent is the only point source in this analysis. To account for the other point sources within the basin, the historical BOD data was applied as headflow concentrations for each reach. This would allow for the climate change scenarios to effect the BOD model calculations for the entire reach.

The two main reservoirs in Parleys Canyon, Mountain Dell and Little Dell, were not included in the model to facilitate basic water quality modeling in the streams. To accommodate this change, the demand node consumed 0% of the water. This allowed for maximum capacity of flow into the wastewater treatment plant, creating a worst case scenario of BOD concentration. Without the reservoirs, the diversion was unnecessary and removed from the model.

Current Account and Scenarios

The Current Account scenario was set to the year 1980. This year was the earliest year of the climate change data that was acquired. All of the physical properties and historical data were applied to this scenario. Physical attributes such as reach length, flow-width-depth curves, catchment area, etc. were carried over to the main scenarios, RCP 2.6 and RCP 8.5. Historical data included average monthly headflows, BOD concentrations at headflows, average climate data for the basin, and precipitation data for catchments.

The two main climate scenarios as discussed were RCP 2.6 and RCP 8.5. The main changes to these scenarios relative to the Current Account scenario are the addition of the projected climate data: precipitation, air temperature, wind speed, and relative humidity. From these data points, the water quality is calculated using WEAP's Temperature Model, BOD Model, and DO Model. These models calculated the temperature, BOD and DO along each of the streams.

Sub-scenarios were created under each RCP scenario. These sub-scenarios had the changes in the BOD effluent standard for the wastewater treatment plant. After multiple iterations, it was determined that the analysis would be a comparison between the current BOD effluent standard of 25 mg/L and the proposed BOD effluent standard of 15 mg/L.

Results

After running the model, the results were reviewed in detail. It was determined that to better show the effects that climate change has on the Jordan River, the data was plotted every 10 years. In addition, August was chosen as the main month of consideration due to it being a late summer month. As the TMDL depicted, DO deficits are generally greatest in the late summer and early fall.

Figure 6 and Figure 7 represents the BOD and DO levels in the Jordan River just downstream of the confluence with Mill Creek. This region was chosen as the BOD concentration will be at its peak near the effluent of the wastewater treatment plant.

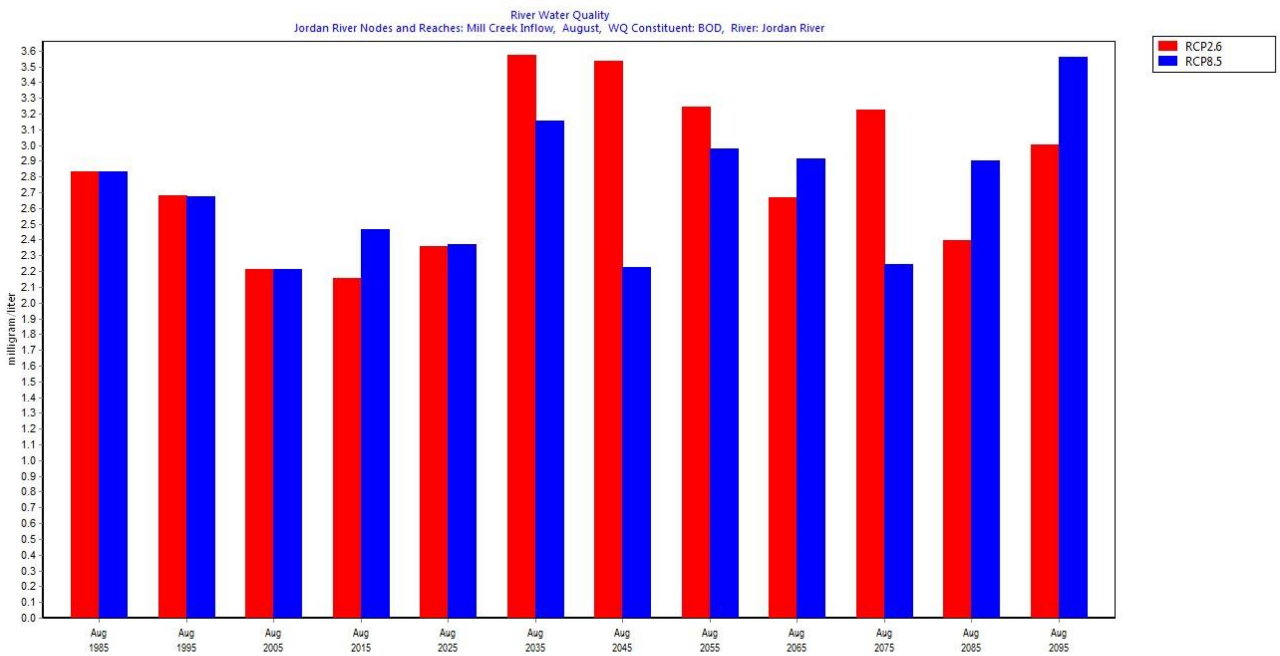

Figure 6: BOD in the Jordan River: RCP2.6 vs. RCP8.5

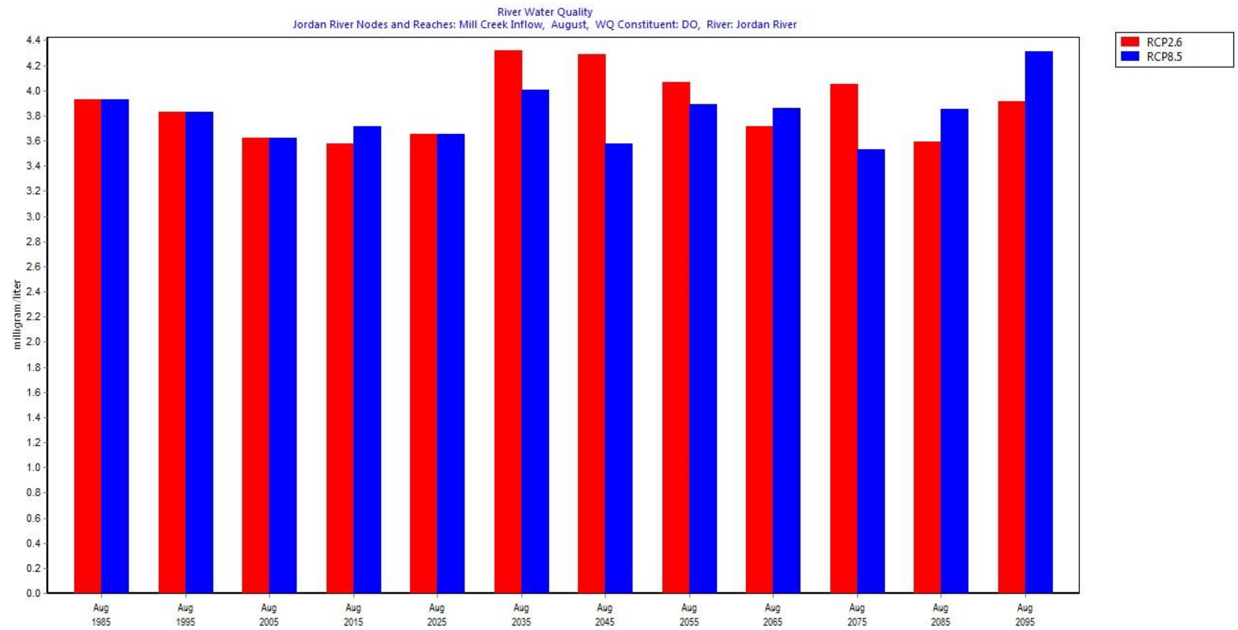

Figure 7: DO in the Jordan River: RCP2.6 vs. RCP8.5

The remaining results are listed in the Appendix: Additional Results. These results include comparing the BOD and DO levels between RCP scenarios to their sub scenario that has the adjusted BOD effluent concentration standard changed. In addition, DO and BOD levels between the RCP 2.6 and RCP 8.5 was plotted to display the impact that climate change has on the Jordan River.

Discussion

To showcase the effects of the climate change scenario had on the Jordan River, Figure 8 was created. This relative comparison of water temperature between RCP 2.6 (top) and RCP 8.5 (bottom) shows how RCP 2.6 peaks and starts to decline while the RCP 8.5 scenario is steadily increasing.

The analyses of the results were separated to compare each individual scenario to their corresponding BOD effluent change scenario. Figure 9 is a graph of BOD concentration in the Jordan River based on the two scenarios RCP 2.6 and 2.6 BOD 15. This graph shows how the effluent change of 15 mg/L decreases the BOD in the Jordan River near the effluent by approximately 0.3 mg/L across the time frame. This result is also reciprocated in Figure 10, a graph of RCP 8.5 and 8.5 BOD 15.

Though the BOD decreases in the Jordan River, Figure 11 and Figure 12 show minimal change in the DO concentration in the Jordan River for RCP 2.6/2.6BOD 15 and RCP 8.5/8.5 BOD 15 respectively. This can be attributed to how WEAP calculates DO. As discussed earlier, DO is more reliant on water temperature than BOD. Since BOD was the only change between RCP 2.6 and 2.6 BOD 15, and similarly with RCP 8.5, the changes are insignificant.

Conclusion

The goal of this analysis was to determine if a new BOD effluent standard for Central Valley would increase the dissolved oxygen levels in the Jordan River. With an effluent standard of 15 mg/l, the BOD levels near the confluence of Mill Creek and the Jordan River decreased by 0.3 mg/L but the DO levels only increased by 0.1 mg/l. Due to the calculation methods of WEAP, water temperature has a greater impact on DO levels than the concentration of BOD in a stream. These results show that no change in the BOD effluent standard is recommended.

Further analysis should be conducted to validate this finding. The analysis can be extended further to include a more complex model that incorporates more point sources, nonpoint sources, and to account for the growth of Salt Lake City's population and water demand.

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Appendix

Equations

Equation 1: Water Temperature[6]

$$\frac{dT}{dt} = \frac{Q_i}{V}T_i + \frac{R_n}{\rho C_p H} + \left(\frac{\sigma(T_{air}+273)^4 a\sqrt{e_{air}}}{\rho C_p H}\right) - \frac{Q_i}{V}T_{i+1} - \frac{\varepsilon\sigma(T_{i+1}+273)^4}{\rho C_p H} - \frac{\varepsilon\sigma(T_{i+1}+273)^4}{\rho C_p H} - \frac{f(u)(T_{i+1}-T_{air})}{\rho C_p H} - \frac{g(u)D}{\rho C_p H}$$

The first term on the right-hand side is the upstream heat input to the stream segment with constant volume, V (m^3), flow Qi (m^3/time), and temperature, T_i at the upstream node. The second term is the net radiation input, Rn, to the control volume with density rho, and C_p the specific heat of water and H (m), the mean water depth of the stream segment. The third term is the atmospheric long-wave radiation into the control volume, with the Stefan-Boltzmann constant, Tair the air temperature (C), a, a coefficient to account for atmospheric attenuation and reflection and the air vapor pressure, e_{air}. The fourth term is the heat leaving the control volume, while the fifth term is the long-wave radiation of the water that leaves the control. The sixth and seventh terms are the conduction of heat to the air and the removal of heat from the stream due to evaporation. The terms f(u) and g(u) are wind functions, and D is the vapor pressure deficit. The temperature, T_{i+1} is solved for the downstream node with a fourth-order Runge-Kutta and is the boundary condition temperature for the next reach.

Equation 2: Oxygen Saturation[6]

$$OS = 14.54 - (0.39T) + (0.01T^2)$$

Equation 3: Streeter-Phelps Model[6]

$$O = OS - \left(\frac{k_a}{k_a - k_r}\right)\left(exp^{-k_r\left(\frac{L}{U}\right)} - exp^{-k_a\left(\frac{L}{U}\right)}\right)BOD_{IN} - \left((OS - O_{IN})exp^{-ka\left(\frac{L}{U}\right)}\right)$$

Where in Equation [2] and [3] OS is Oxygen Saturation and T is water temperature. Constants in Equation [3] are k_d = 0.4, k_a = 0.95, and k_r = 0.4 which represent decomposition, the reaction, and the re-aeration rates respectively in units (1/day). L is the reach length (m), U the velocity of the water in the reach, O is the oxygen concentration (mg/l) at the top of the reach and BOD_{IN} is the concentration of the pollutant loading (mg/l) at the top of the reach.

Equation 4: BOD Removal[6]

$$BOD = BOD_{IN}\left(exp^{-k_{rBOD}\left(\frac{L}{U}\right)}\right)$$

Where k_{rBOD} is represented in **Equation 5: Removal Rate [6].**

$$k_{rBOD} = k_{d20}^{\left(1.04T\left(T-20\right)\right)} + \frac{v_s}{H}$$

The removal rate is influenced by multiple factors: temperature (T), settling velocity of the particles (s), and water depth (H).

Additional Results

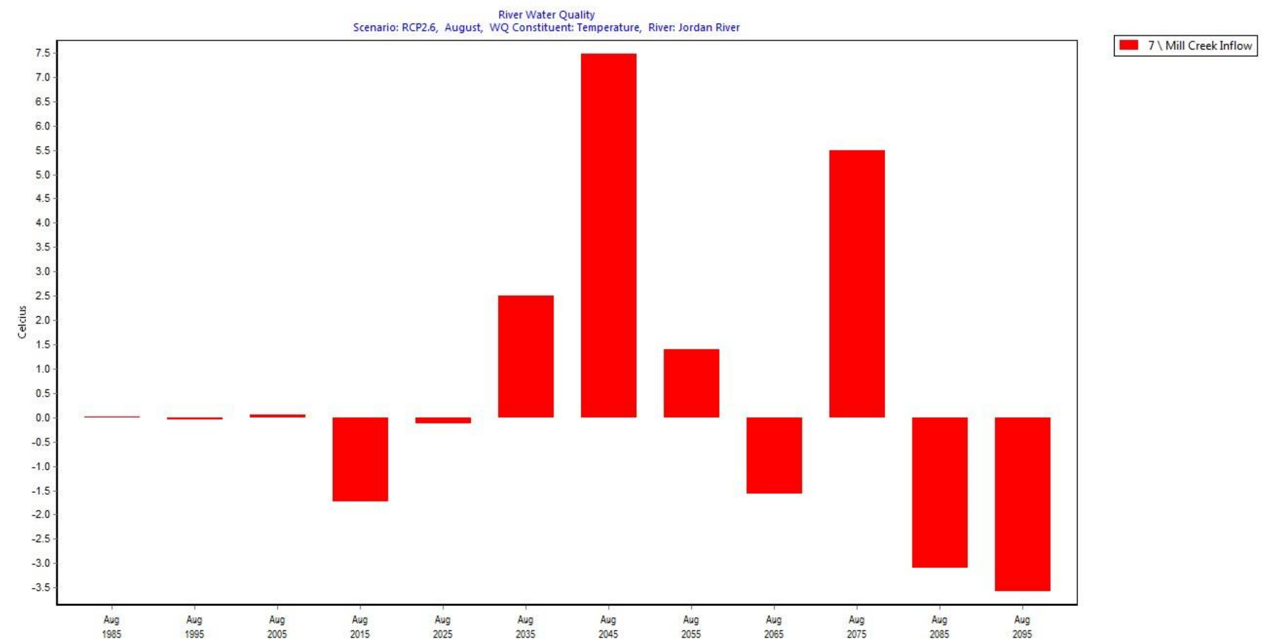

Figure 8: Relative graph of Water Temperature: RCP 2.6 vs. RCP 8.5

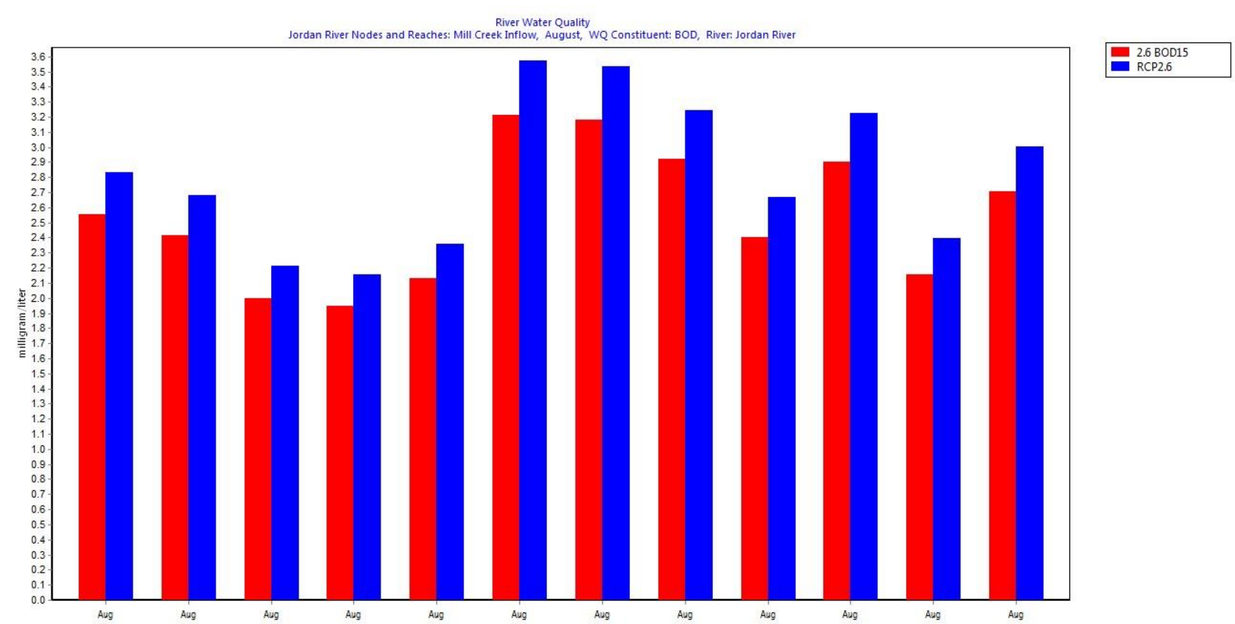

Figure 9: Graph of BOD: RCP 2.6 vs. 2.6 BOD 15

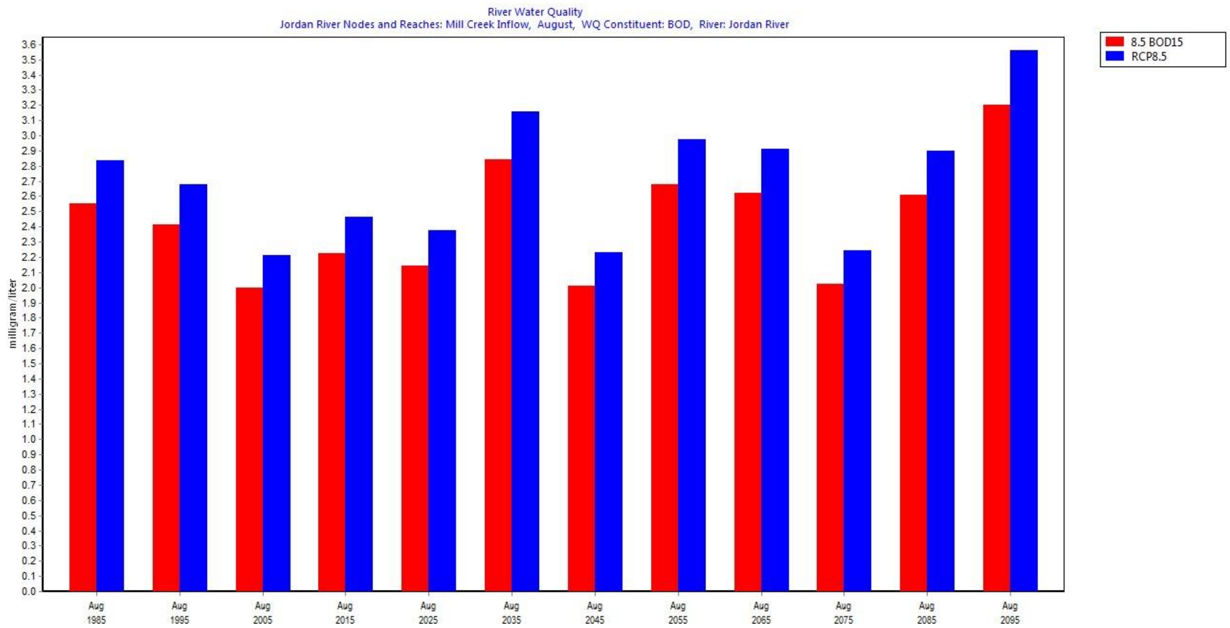

Figure 10: Graph of BOD: RCP8.5 vs. 8.5 BOD 15

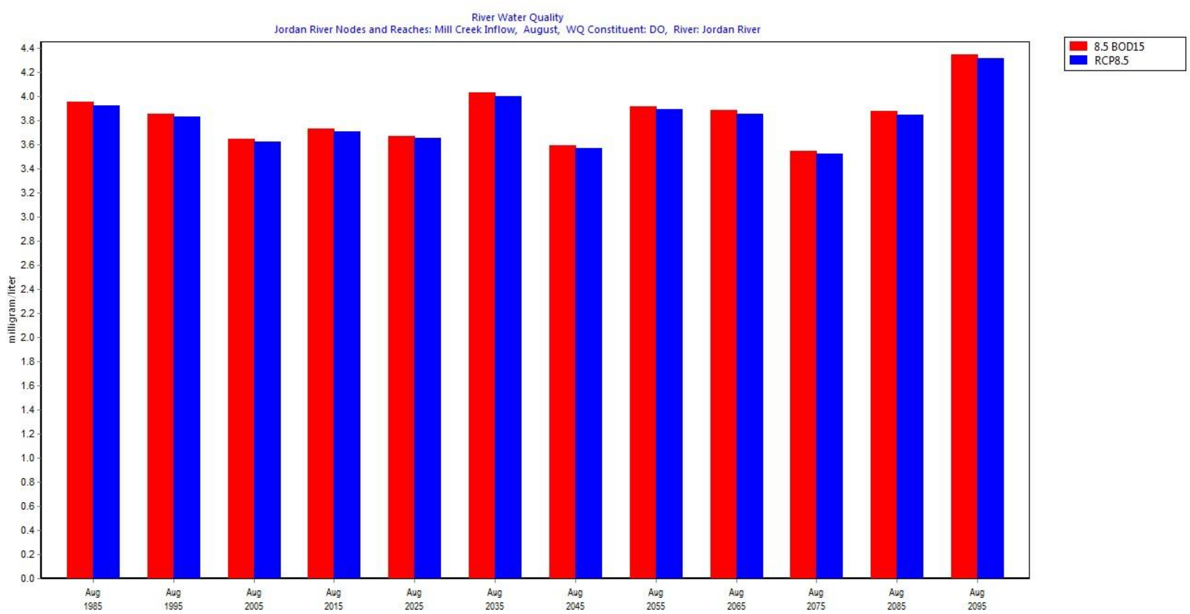

Figure 11: Graph of DO: RCP 2.6 vs. 2.6 BOD 15

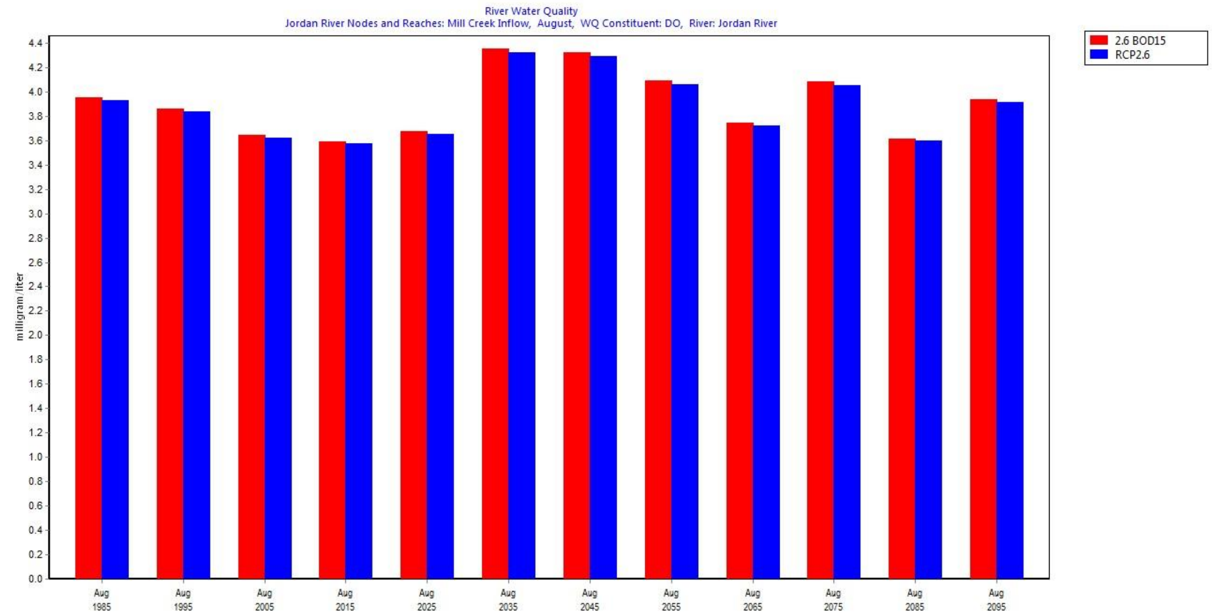

Figure 12: Graph of DO: RCP8.5 vs. 8.5 BOD 15