Waller Creek Tunnel LA-Qual (v 9.05) Dissolved Oxygen Model for Recirculation Operations
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Abstract

The City of Austin is constructing a stormwater bypass tunnel in lower Waller Creek. Water must be recirculated from Lady Bird Lake through the tunnel during non-storm conditions to prevent water in the tunnel from becoming anoxic. LA-Qual (version 9.05) steady-state models were used to identify optimum tunnel recirculation flow rates under three seasonal conditions and during summer months immediately following storm events in order to maintain dissolved oxygen in the tunnel near 4 mg/L. Model predictions were applied to measured Waller Creek flow data from 1994 to 2009 to estimate the total recirculation withdrawal from Lady Bird Lake for comparison to the maximum allowed under a Firm Water Contract with the Lower Colorado River Authority. Predicted Lady Bird Lake withdrawal for recirculation varies from 1 to 4 ft^3/s during non-storm conditions depending on season, with 4th Street and 8th Street side inlet tunnel flows less than 0.5 ft^3/s. Post-storm recirculation rates are predicted to optimally be 35 ft^3/s, although the actual maximum pump capacity is 28 ft^3/s. Operating the Waller Creek immediately following storm events at 28 ft3/s will not maintain DO in the tunnel above 4 mg/L, but should be sufficient with cascade aeration prior to discharge to Waller Creek to maintain aquatic life use standards. Operation of the Waller Creek Tunnel under these recirculation flow conditions are not anticipated to exceed the annual maximum withdrawal from Lady Bird Lake allowed by the Lower Colorado River Authority.

Introduction

The City of Austin is constructing a stormwater bypass tunnel in lower Waller Creek to remove some land from the Waller Creek floodplain (http://www.austintexas.gov/department/waller-creek). During non-storm conditions, water from Lady Bird Lake will be pumped into the Waller Creek Tunnel (WCT) from the outlet structure on Lady Bird Lake north (upstream) towards the inlet structure in Waterloo Park (Figure 1) to maintain dissolved oxygen (DO) concentrations. Other than the inlet and outlet lagoons, the WCT will not be open to the atmosphere such that DO reaeration would occur. If the WCT became anoxic there would be negative aesthetic impacts from associated odors and the discharge of the large volume of anoxic water in the main tunnel (approximately 21,000,000 gallons) to Waller Creek would have severe adverse impacts on aquatic life in Waller Creek.

The WCT will generally be operated in two recirculation modes during non-flood operation. Immediately following storm events, a high turnover of any stormwater remaining in the WCT is desired requiring higher recirculation pump rates. Once remaining stormwater in the WCT has been pumped out of the tunnel, recirculation pump rates may be reduced to conserve water and electricity. The operating range of the pumps is reported to be 3 to 28 ft^3/s with a firm capacity of 17 ft^3/s.

Recirculation flow on exit from the tunnel will be comingled with existing Waller Creek ambient flow and some portion will be allowed to flow downstream to Lady Bird Lake. Water will be oxygenated before exiting from the WCT to Waller Creek by cascade aeration with an estimated 65% efficiency based on design specifications. There are two side inlets located at 4th Street and 8th Street which connect laterally to the main WCT with approximate lengths of 225 ft and 50 ft, respectively. Some inflow during non-storm flow conditions to the 17 ft diameter side inlet connecting tunnels will be necessary to maintain DO in the side connections, as advective dispersion or molecular diffusion of DO from the main WCT would likely be insufficient to prevent the entire length of the side tunnels from becoming anoxic. Diffusion or dispersion of DO from the main tunnel to the side inlet connecting tunnels (assuming no inflow to the side inlets) is limited because the pressure head from Lady Bird Lake works in opposition to side inlet connecting tunnel slope, because the area of interface between the side inlet connecting tunnel and main WCT is small relative to the length of the side inlet connecting tunnel, and because the relative small volumetric flow rates (see Results) are unlikely to generate substantial turbulent mixing.

The Lower Colorado River Authority (LCRA) has entered into a firm water contract with the City of Austin to provide recirculation water supply from Lady Bird Lake to the WCT. The LCRA firm water contract currently limits the total annual diversion from Lady Bird Lake for recirculation flow to 7,240 ac-ft/year.

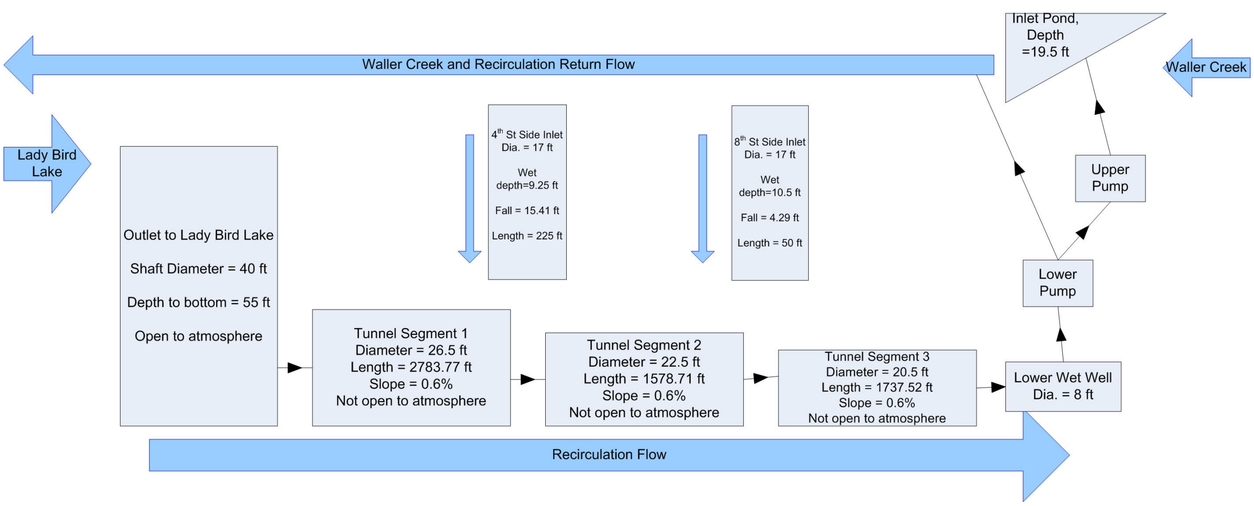

Figure 1. Conceptual model of Waller Creek Tunnel operations during non-storm flow conditions. Elements not to scale. Blue arrows indicate water flow direction through elements.

This modeling effort was undertaken to estimate the range of recirculation rates that would be necessary to maintain minimum DO levels in the WCT during recirculation operations. Optimization of pump rates to maintain DO while minimizing the pump rate is useful in ensuring not only that the LCRA firm water contract withdrawal amount is not exceeded, but also to minimize the cost of running the pumps.

Minimizing recirculation return flow to Waller Creek would additionally mimic existing hydrology, as Waller Creek currently maintains relatively low non-storm flow (Figure 2).

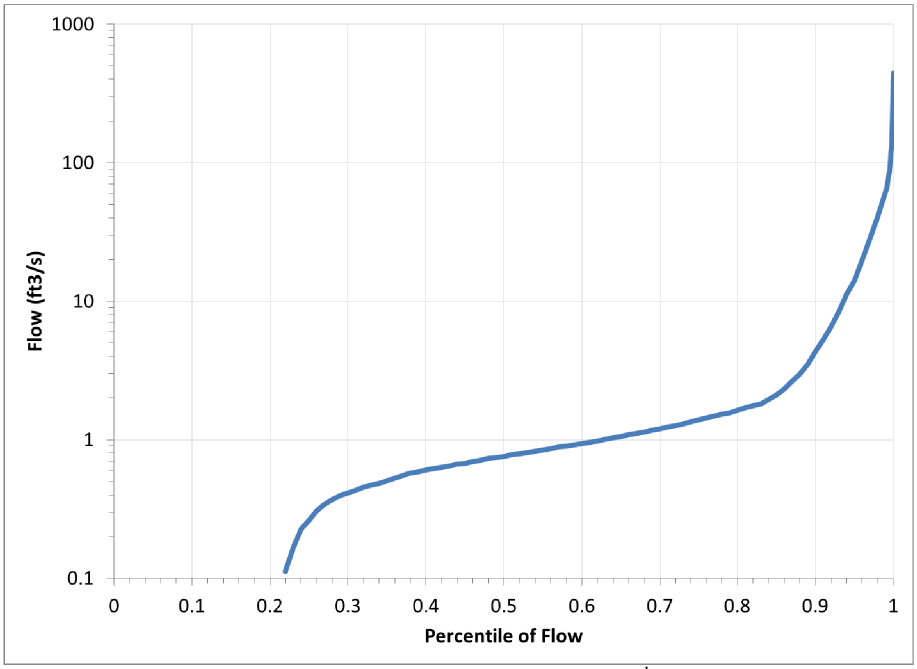

Figure 2. Flow duration curve for Waller Creek at 23rd Street from City of Austin sub-daily monitoring, 1993-2010.

Methods

The minimum DO target set for the WCT was 2 mg/L. Because conditions in Lady Bird Lake can be highly variable, a 100% safety factor was applied such that the target minimum DO in the WCT for estimating recirculation rates by modeling was at or near 4 mg/L. Reaeration of WCT recirculation water will occur prior to discharge to Waller Creek by cascade aeration with an estimated 65% efficiency, and thus consideration of recirculation return flow DO concentrations to Waller Creek was not considered in this analysis. The Texas Commission on Environmental Quality (TCEQ) has established the aquatic life use for lower Waller Creek to be high based on presumed flow type, with a corresponding DO standard of a diel DO average greater than or equal to 5 mg/L and diel minimum greater than or equal to 3 mg/L.

The LA-Qual (version 9.05, 20 May 2010) model was used to evaluate WCT recirculation rate impact on DO. The LA-Qual model is widely used by Texas and Louisiana to evaluate waste load impacts on DO in streams, and has been used by City of Austin staff in evaluation of wasteload impacts to area streams previously (Herrington, 2008a; Herrington, 2008b). The LA-Qual is a steady-state one dimensional model utilizing the Streeter-Phelps (Chapra, 1997) model to evaluate decomposition of organic matter and reaeration on DO concentrations. DO, carbonaceous 5-day biochemical oxygen demand (BOD), nitrogen, phosphorus and phytoplankton were simulated. Although the tunnel will not be open to sunlight, respiration and decomposition of phytoplankton from Lady Bird Lake will exert an additional oxygen demand within the tunnel.

LA-Qual Texas program defaults were generally used for rates, constants and temperature correction coefficients except where values existed from Austin-area calibrated Water Quality Analysis Simulation Program (WASP) models for Lady Bird Lake (City of Austin, 2004) or Lake Creek (Richter, 2012), an urbanized Edwards Plateau stream in Austin. Phytoplankton carbon content was set to LA-Qual default, but all other phytoplankton model parameters were set to Lake Creek WASP model values. Nutrient transformation rates were selected from a combination of previous modeling efforts and area direct measurement (Table 1). Wind velocity was set to zero, daily photoperiod was set to zero, and total daily radiation set to zero to reflect the closed, lightless conditions of the WCT.

Table 1. Nutrient transformation/release rates used in the model.

Parameter	Unit	Value
Organic N decay rate	per day	0.03
Organic N settling rate	m/day	0
Settled organic N available as sediment NH3 source	fraction	0.5
Ammonia decay rate	per day	0.3
Background sediment ammonia nitrogen source rate	$g/m^2/day$	0
Background sediment inorganic phosphorus source rate	$g/m^2/day$	0.01
Denitrification rate	per day	0.22
Organic phosphorus hydrolysis rate	per day	0.16
Organic phosphorus settling rate	m/day	0.1
Settled organic phosphorus available as sediment inorganic phosphorus source	fraction	0.5

The WCT was modeled in 7 segments with 2,228 total computational elements over 6,423 ft of total length (Table 2). The "Width and Depth" hydraulic calculation option was selected to fix constant tunnel dimensions. No slope was considered for the main WCT segments as slope is in opposition to recirculation flow direction; slope most directly affects reaeration calculations but there is no reaeration in full pipe flow. Manning's n was set to 0.013 for all segments (Johnnie Price, City of Austin Watershed Protection Department, personal communication). Only headwater inputs were considered for the outlet, 4th Street side inlet, and 8th Street side inlet; no incremental inflows, nonpoint source loads or wasteloads were used. The total pump operation flow rate would be the sum of the Lady Bird Lake inflow plus the side inlets. The side inlets were modeled at the same flow rate, but could be varied if necessary for additional scenario evaluation. WCT tunnel turnover was estimated for each tunnel segment by dividing the volume by the flow rate.

Table 2. Model segments and dimensions.

Segment #	Segment Name	Length (ft)	Diameter/Depth (ft)	Slope (%)
1	Outlet shaft at Lady Bird Lake	40	55	0
2	Outlet to 4th Street	2783.77	26.5	0
3	4th Street Side Inlet	225	17	2.54
4	4th Street to 8th Street	1578.71	22.5	0
5	8th Street Side Inlet	50	17	2.54
6	8th Street to Lower Wet Well	1737.52	20.5	0
7	Lower Wet Well	8	4	0

Reaeration rates were set to zero for all model segments except the outlet at Lady Bird Lake, for which reaeration was calculated using the Texas equation as a function of the velocity and depth of the segment. The aerobic BOD (BOD1) decay rate was set to the WASP model default of 0.4/day. The BOD settling rate was set to 0.05/day. The BOD settling rate was evaluated with sensitivity analysis to check influence on DO predictions and found to be not influential. A 50% decrease in BOD settling rates changed minimum DO levels by only 0.1% (0.01 mg/L). The anerobic BOD (BOD1) decay rate set to 0.05/day. Barometric pressure was set to 999 milibars, the regional average.

Sediment Oxygen Demand (SOD) was set to 0.35 g/m^2/day. SOD values were evaluated with sensitivity analysis and found to have minimal impact on predicted DO levels as 50% change in SOD resulted in only 8.3% change (+/- 0.3 mg/L) in minimum DO levels. The fraction of organic matter settled that is converted to SOD was set to 0.5 based on the assumption that 50% of algal biomass is carbon and algal biomass would be the predominant source of settlable organic matter during recirculation operations.

Lady Bird Lake input concentrations were derived from City of Austin long-term monitoring data at 1st Street bridge (the closest monitoring site) (City of Austin Field Sampling Database) except for BOD, which also included observations from the Lady Bird Lake Basin (City of Austin Field Sampling Database) to increase the number of BOD samples available (Table 3). Side inlet input concentrations were set to be a mixture of modeled tunnel concentrations at the inlet-end of the tunnel mixed volumetrically with Waller Creek upstream input concentrations by conservation of mass. This would not account for any addition or attenuation that may occur in reality in Waller Creek from 12th Street to 8th Street although given the relatively short distance the assumption of no change from 8th to 12th streets is reasonable. The model was run iteratively to convergence for DO and BOD (change in concentration < 0.01 mg/L) because of the dependence of predicted concentration in the WCT at the inlet and side inlet input concentrations. Waller Creek upstream data input was derived from City of Austin long-term monitoring data averages during non-storm conditions (City of Austin Field Sampling Database) and the worst case of average grab samples (City of Austin Field Sampling Database) or stormwater event mean concentrations derived from City of Austin targeted stormwater monitoring data in Waller Creek at 23rd Street (Roger Glick, City of Austin Watershed Protection Department, personal communication).

Temperature strongly influences DO saturation (Chapra, 1997). Evaluation of Lady Bird Lake water surface temperature data from the 1st Street bridge monitoring site suggests three separate seasonal groups: summer (July-August), Spring/Fall (March-June, November) and Winter (December-February). Three temperature conditions were used to evaluate non-storm recirculation rates for the model.

Table 3. Non-storm input concentrations used in the model by seasonal group.

		Waller Creek			**Lady Bird Lake**		
		Summer	**Spring/Fall**	**Winter**	**Summer**	**Spring/Fall**	**Winter**
Parameter	**Unit**	**(7,8,9,10)**	**(3,4,5,6,11)**	**(1, 2, 12)**	**(7,8,9,10)**	**(3,4,5,6,11)**	**(1, 2, 12)**
Water Temperature	C	26.4	21.8	13.3	24.6	19.5	14.8
Salinity	ppt	0.32	0.39	0.49	0.25	0.3	0.35
Dissolved Oxygen	mg/L	7.2	8	9.6	7.4	8.9	9.5
Ammonia as N	mg/L	0.111	0.107	0.116	0.046	0.033	0.038
Nitrate as N	mg/L	0.46	0.81	0.73	0.184	0.316	0.409
PO4 as P	mg/L	0.1	0.0965	0.054	0.014	0.013	0.001
Phytoplankton chlorophyll-a	µg/L	6.6	1.2	1.2	9.9	6.2	1.9
Carbonaceous 5-day BOD	mg/L	4.6	4.6	4.6	0.71	0.71	0.71
Organic Nitrogen as N	mg/L	0.671	0.446	0.914	0.304	0.317	0.292
Orthophosphorus as P	mg/L	0.2	0.193	0.108	0.016	0.027	0.021
Total Phosphorus as P	mg/L	0.189	0.151	0.106	0.03	0.04	0.02
Total Kjeldahl Nitrogen as N	mg/L	0.782	0.553	1.03	0.35	0.35	0.33
E. coli	mpn/dL	1332	2137	738	90	80	41

Immediately following a storm event, the WCT will be filled in part or in whole (depending on storm magnitude) with Waller Creek stormwater. This stormwater is likely to be turbid and high in BOD, and will need to be displaced with less contaminated Lady Bird Lake water. Lady Bird Lake is likely to still be influenced by stormwater runoff in this end-of-storm scenario as would upstream Waller Creek. Initial conditions during post-storm recirculation in the WCT were set to Waller Creek at 23rd Street stormwater event mean concentrations (from Roger Glick, City of Austin Watershed Protection Department, personal communication). Lady Bird Lake storm-influenced samples during summer months were used to represent WCT inflow during post-storm recirculation (Table 4). Storm conditions are highly variable, dependent on storm size, intensity and antecedent moisture conditions. As such, only the average summer storm was modeled to evaluate post-storm recirculation operations. This is assumed to be a conservative approach, as spring/fall and winter storms are likely to have lower water temperatures and not expected to be substantially different in stormwater BOD.

Table 4. Post-storm input concentrations used in the model.

Parameter	Unit	Waller Creek	Lady Bird Lake
Water Temperature	C	24.4	24.5
Salinity	ppt	0.32	0.25
Dissolved Oxygen	mg/L	7.2	6.2
Ammonia as N	mg/L	0.248	0.043
Nitrate as N	mg/L	0.92	0.212
PO4 as P	mg/L	0.337	0.021
Phytoplankton chlorophyll-a	ug/L	0.8	11
Carbonaceous 5-day BOD	mg/L	13.3	1.1
Organic Nitrogen as N	mg/L	2.032	0.347
Orthophosphorus as P	mg/L	0.382	0.025
Total Phosphorus as P	mg/L	0.719	0.046
Total Kjeldahl Nitrogen as N	mg/L	2.28	0.39
E. coli	mpn/dL	4814	6351

Total annual Lady Bird Lake withdrawal for recirculation operations can be estimated by applying selected optimum model results to measured mean daily Waller Creek flows from the City of Austin flow gauge located at 23rd Street. Flow data from 1994 thru 2009 were evaluated annually. Season was determined by month of the year. Post-storm recirculation flow rates were applied to any day with an increase in flow over the previous day. Total withdrawals by year were summed, and compared to maximum withdrawal allowable under the LCRA Firm Water Contract. This would most likely overestimate withdrawals from Lady Bird Lake as there is no allowance for the storm flow operation of the WCT in which no withdrawal occurs because stormwater is moving from the inlet downstream to the outlet.

Results for optimum recirculation rates were determined regardless of actual recirculation pump capacity. Optimum pump rates were compared to the actual pump range (3-28 ft^3/s), and to firm pump capacity (17 ft^3/s).

Results

As anticipated, side inlet connecting tunnels are predicted by LA-Qual to go completely anoxic without some input flow. The volume of water is likely too large in reality for advective diffusion of DO from the main WCT to substantially occur so some inflow into the side inlets will always be necessary (Ben Hodges, University of Texas at Austin, personal communication).

Different recirculation pump flow rates were evaluated for each seasonal scenario and for post-storm operations to identify pumping necessary to maintain DO at 4 mg/L. LA-Qual was run iteratively to convergence to resolve dependence of side inlet inflow concentration on end of tunnel predicted concentrations at the WCT inlet. This was done for every model scenario (non-storm summer, non-storm fall/spring, non-storm winter, post-storm summer).

Maximum tunnel flow rates during non-storm recirculation operations were necessary during the warm temperature summer season to maintain DO (Table 5). A total pump flow rate of 4.5 ft^3/s with 0.25 ft^3/s inflow to each side inlet is necessary during summer. This would allow for at least 3.5 ft^3/s of surface flow in Waller Creek downstream of 4th Street. Total pump rates could be reduced to 2.5 ft^3/s during the spring/fall season, and to 1.5 ft^3/s during winter months as lower temperatures and reduced Lady Bird Lake phytoplankton reduce oxygen demand in the WCT.

Table 5. Model output during non-storm recirculation operations by season. Flow rate from Lady Bird Lake and each side inlet with resulting total tunnel turnover time as well as minimum DO in critical tunnel segments are presented. Yellow highlight indicates optimal recirculation rate.

Season	Flow Rate (ft^3/s)			Dissolved Oxygen (mg/L)			Turnover (days)
	Lady Bird Lake	Side Inlet, each	*Total Pump Rate*	Inlet Lower Wet Well	4th St Side Inlet	8th St Side Inlet	
Summer	4	0.5	*5*	3.97	4.44	4.95	7.6
	3	1	*5*	3.85	4.75	5.04	9.3
	4	0.25	*4.5*	3.9	3.94	4.76	7.8
	3	0.5	*4*	3.64	4.34	5.2	9.9
	2	0.5	*3*	3.16	4.25	4.93	14.4
	1	0.5	*2*	2.17	4.03	4.93	26.7
Spring/Fall	3	0.25	*3.5*	5.43	4.11	5.36	10.3
	2	0.5	*3*	4.59	4.46	5.34	14.4
	2	0.25	*2.5*	4.73	3.6	5.1	15.2
	1.5	0.5	*2.5*	4.07	4.41	5.38	18.7
	1	0.5	*2*	3.26	4.32	5.41	26.7
	0.5	0.5	*1.5*	1.91	4.17	5.46	48.8
Winter	2	0.25	*2.5*	6	5.03	6.39	15.2
	1	0.25	*1.5*	4.32	3.68	5.5	28.8
	0.5	0.25	*1*	1.93	2.56	4.76	53.5
	1	0.5	*2*	3.89	4.31	5.31	26.7

Post-storm recirculation rates are significantly higher, with a total pump flow rate of 45 ft^3/s required to maintain DO (Table 6). Turnover in the WCT at this flow would occur in approximately 0.9 days.

Table 6. Model output during <u>post-storm</u> recirculation operations in the summer season. Flow rate from Lady Bird Lake and each side inlet with resulting total tunnel turnover time as well as minimum DO in critical tunnel segments are presented. Yellow highlight indicates optimal recirculation rate.

Season	Flow Rate (ft3/s)			Dissolved Oxygen (mg/L)			Turnover (days)
	Lady Bird Lake	Side Inlet, each	*Total Pump Rate*	Inlet Lower Wet Well	4th St Side Inlet	8th St Side Inlet	
	40	4	*48*	4.27	3.5	5.52	0.8
	35	5	*45*	3.95	4.01	5.63	0.9
	35	4	*43*	4.01	3.5	5.51	0.9
	35	3	*41*	4.09	2.66	5.32	0.9
	30	4	*38*	3.66	3.49	5.5	1.0
Summer	20	4	*28*	2.52	3.48	5.45	1.5

Evaluation of non-storm recirculation rate model results suggest two potential operation strategies (Table 5). Side inlet flow can be minimized in order to maximize the volume of water in Waller Creek, particularly downstream of the 4th Street side inlet. This would result in potentially higher withdrawals from Lady Bird Lake. Conversely, Lady Bird Lake withdrawals can be minimized by increasing side inlet flow although this may result in reduced surface flow in Waller Creek. As long as total Lady Bird Lake withdrawal rates do not exceed the maximum allowable rate set by the LCRA Firm Water Contract, allowing some flow downstream of 4th Street is preferred to maintain habitat for aquatic life and connectivity between Waller Creek and Lady Bird Lake during non-storm conditions.

In comparison to actual pump capacity, the Fall/Spring and Winter scenarios yield optimum pump results less than the 3 ft^3/s actual pump capacity. Thus, recirculation operations during these conditions would yield even higher DO concentrations that the target minimums specified in this analysis. During post-storm operations, the optimum pump rate of 45 ft^3/s exceeds the actual firm pump capacity (17 ft^3/s) and the actual full pump capacity (28 ft^3/s). Maximizing Lady Bird Lake inflow to the tunnel enables more rapid clearing of post-storm water in the tunnel, although DO in the side inlets must be maintained at sufficient levels (Table 7). It is not possible to maintain 4 mg/L DO in the lower wet well and the side inlets at a pump capacity of 28 ft^3/s. However, it is possible to maintain tunnel and side inlet DO above 2 mg/L at the full pump capacity of 28 ft^3/s. With cascade aeration, recirculation flow of 28 ft^3/s should maintain Waller Creek DO concentrations when water from WCT is discharged to Waller Creek above the TCEQ-assigned aquatic life use standard.

In case of equipment failure, the firm recirculation pump capacity of WCT is 17 ft^3/s. At this operational rate, it is not possible to maintain DO in the WCT above 2 mg/L (Table 7). With cascade aeration, it is possible to maintain DO of WCT recirculation water discharged to Waller Creek above the TCEQ-assigned aquatic life use but with only a 0.46 mg/L margin of safety.

Table 7. Model output during post-storm recirculation operations in the summer season accounting for maximum pump rate of 28 ft^3/s and firm capacity of 17 ft^3/s. Flow rate from Lady Bird Lake and each side inlet with resulting total tunnel turnover time as well as minimum DO in critical tunnel segments are presented. Yellow highlight indicates optimal recirculation rate.

Season	Flow Rate (ft3/s)			Dissolved Oxygen (mg/L)			Turnover (days)
	Lady Bird Lake	Side Inlet, each	*Total Pump Rate*	Inlet Lower Wet Well	4th St Side Inlet	8th St Side Inlet	
Full Capacity (28 ft^3/s)	20	4	*28*	2.52	3.48	5.45	1.47
	22	3	*28*	2.94	2.65	5.27	1.37
	24	2	*28*	3.38	1.30	4.90	1.29
Firm Capacity (17 ft^3/s)	11	3	*17*	0.86	2.62	5.16	2.60
	13	2	*17*	1.46	1.28	4.82	2.30
	14	1.5	*17*	1.94	0.66	4.46	2.19

Total Lady Bird Lake withdrawal for recirculation operations were estimated by applying model results to measured daily Waller Creek flows from the City of Austin flow gauge located at 23rd Street from 1994 to 2009. The 3 ft^3/s minimum pump operation range was applied for Fall/Spring and Winter conditions instead of the optimum operation rates predicted by the model which were less than 3 ft^3/s. As WCT turnover during post-storm operations under the optimal scenario is approximately 1.37 days at full pump capacity, the entire day and one-third of the next day were assumed to be operated under post-storm, full pump capacity (28 ft^3/s) recirculation conditions.

Under the optimal summer, non-storm operation scenario in combination with the minimum 3 ft^3/s pump capacity non-storm Fall/Spring and Winter conditions and the 28 ft^3/s maximum post-storm conditions, the maximum annual recirculation withdrawal from Lady Bird Lake is predicted to be 5,341 ac-ft from 1994-2009 (Figure 3), or approximately 74% of the annual 7,240 ac-ft allowed under the LCRA Firm Water Contract. The maximum annual withdrawal occurs in 2004.

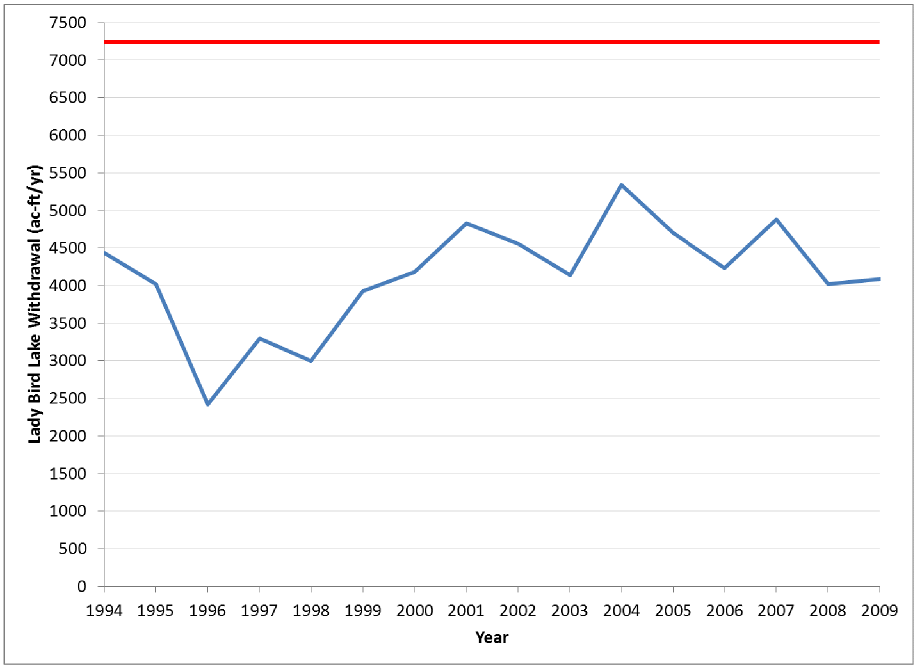

Figure 3. Maximum estimated annual Lady Bird Lake withdrawal for recirculation operations under the optimal scenarios identified in Table 5 and incorporating actual minimum and maximum pump capacity. The red horizontal line indicates the maximum allowable withdrawal of 7,240 ac-ft/yr under the LCRA Firm Water Contract.

Conclusions

Three seasonal conditions (summer, spring/fall, winter) were used to evaluate optimum non-storm recirculation operations for the Waller Creek Tunnel (WCT) in order to maintain a minimum dissolved oxygen (DO) at or near 4 mg/L (Table 7). Post-storm recirculation operations were evaluated during summer conditions when water temperatures are highest (Table 7). Operating the tunnel seasonally under these conditions during non-storm conditions is predicted to maintain adequate DO in the WCT. Total annual withdrawals from Lady Bird Lake for recirculation flow operations is not predicted to exceed the maximum 7,240 ac-ft/yr allowed under the LCRA Firm Water Contract.

Table 7. Predicted optimum Waller Creek Tunnel operation rates by season.

Condition	**Lady Bird Lake withdrawal, ft^3/s**	**Side Inlet flow, ft^3/s**
Summer, non-storm	4.0	0.25
Spring/Fall, non-storm	1.5*	0.50
Winter, non-storm	1.0*	0.25
Summer, post-storm	35.0**	5.00

*this value is less than the minimum operational range of the pumps (3 ft^3/s).
**this value is greater than the maximum operational range of the pumps (28 ft^3/s).

The maximum real capacity of the pumps is 28 ft^3/s. Operating the WCT at 28 ft^3/s post-storm will not maintain DO above 4 mg/L in the tunnel, but should be sufficient with cascade aeration prior to discharge to maintain Waller Creek aquatic life use standards. Operating the tunnel at firm pump capacity (17 ft^3/s) during post-storm recirculation may be sufficient to maintain Waller Creek aquatic life use standards with cascade aeration prior to discharge but with effectively no margin of safety.

Discussion

The LA-Qual is a steady-state one dimensional prediction of minimum DO in the Waller Creek Tunnel (WCT). Multiple scenarios were applied to measured flow data to more accurately estimate withdrawals from Lady Bird Lake across a seasonally and storm condition varying year. As the WCT is not yet constructed, direct calibration of model results is not possible.

While steady-state models are used to evaluate critical conditions for wasteload assimilation, protectiveness of steady-state water quality model predictions versus dynamic modeling approaches are dependent on variability in receiving stream wasteload assimilative capacity and accurate selection of critical conditions (Dilks and Pendergast, 2000).

Although sensitivity analysis was used to evaluate influence of unknown estimated input variables, predictions are highly dependent on input temperature and BOD values. Average conditions from relevant ambient monitoring within the identified seasons were used for input concentrations. Extreme event conditions, such as algae blooms during warm summer months with minimal flow through Lady Bird Lake, will occur and result in additional DO demand within the WCT. Substantial safety factors, including a 100% increase in minimum target DO in the critical WCT, will buffer against some variation in ambient conditions. Recirculation operation of the WCT during all normal conditions using recirculation flow rates derived from extreme conditions would lead to significant waste of energy, potentially exceed the LCRA Firm Water Contract, and would further alter the current flow regime of Waller Creek. However, should the WCT become anoxic discharging the anoxic water to Waller Creek would have significant, negative aquatic life impacts. DO and water temperature monitoring via conventional digital multi-probe instrumentation at the lower wet well should be used once the WCT goes into operation to validate or calibrate this model.

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