City of Austin WATERSHED PROTECTION

Creation of a multi-metric index for describing the environmental integrity of Austin-area lakes.

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Abstract

The Austin Lake Index (ALI) was designed to provide a yearly assessment of the environmental integrity of Lake Austin, Lady Bird Lake, and Lake Long. Sub-indices used to compute the ALI include representative measures of water quality, sediment quality, habitat quality, diversity/cover/% exotic aquatic vegetation, aquatic life health, and degree of eutrophication. The water quality and sediment indices are reliable metrics also used in Environmental Integrity Index (EII) calculations for Austin streams. The calculations of habitat and aquatic life scores from the EII were modified to better explain the biological integrity of the lentic (lake) rather than lotic (stream) habitat. The aquatic vegetation sub-index and the eutrophication sub-index use survey data describing measures of the plant and algal communities on each lake. Samples are collected throughout the year at several locations within each lake in order to obtain a more accurate representation of the lake in a given year. First year results of the ALI showed no differences in the overall health of the lakes. The individual sub-indices showed much greater variability between the lakes. Lake Austin obtained the highest score in the water quality sub-index. Sediment, habitat, and aquatic vegetation sub-indices were highest in Lake Long, while the aquatic life and eutrophication sub-indices were highest in Lady Bird Lake. The ALI was developed from the local data available for Lake Austin, Lady Bird Lake and Lake Long; therefore, it should provide the City a comprehensive regional assessment tool for detection and communication of environmental change in these lakes. It should also allow for prioritization of water quality needs on each lake and provide an easily understood representation of each lake to the general public.

Introduction

One of the main goals of the City of Austin's Watershed Protection Department (WPD) is to maintain and improve the water quality in Austin area watersheds. Austin creeks have been monitored for years through the Environmental Integrity Index (EII) which assesses the ecological integrity and degree of impairment to Austin streams (COA 2002). However, the three lakes located in Austin do not have a method of assessment comparable to the EII monitoring program. Lady Bird Lake (Town Lake), Lake Austin, and Lake Walter E. Long are part of the aesthetic beauty of Austin and are widely used by citizens of Austin for recreational purposes. Lake Austin and Lady Bird Lake are run-of-the-river reservoirs on the Colorado River; therefore, they both have some riverine characteristics. The greenbelts and waters of both lakes are used recreationally by Austin citizens. In addition, the Ulrich and Davis drinking water treatment plants withdraw water from Lake Austin and serve as the municipal drinking water source for the Austin area. Degraded water quality could require more costly treatment processes for the two water treatment plants on Lake Austin. Lake Long is a man-made lake on the northeast side of Austin. It was built as an impoundment on Decker Creek to cool the Decker Creek Power Plant. The capacity of the lake is 33,940 acre-feet and on average 16,156 acre-feet/year is pumped into Lake Long from the Colorado River, downstream from where the Austin Water Utility Walnut Creek wastewater treatment plant discharges to the river. Austin Energy also releases 500 gallons/minute from the lake into the lower portion of Decker Creek to maintain circulatory flow within the lake. Degraded water quality in Lake Long may necessitate a more costly screening process to remove solids and protect power plant equipment.

Another Department goal of WPD is to decrease property loss from erosion and increase beneficial uses of waterways. This is an important goal for Lady Bird Lake and Lake Austin as large amounts of valuable public and private property along the banks could be affected by erosion. Promotion of healthy riparian zones can help protect these properties from erosion and property loss. Accurate assessment of the lakes is of great utility in addressing current areas of degradation and planning for projects, programs, and regulations to maintain and improve current environmental health.

The ALI was developed on the basis of the best available science to produce a quantifiable method to assess chemical, biological, and physical conditions in the Austin lakes. If implemented consistently, the ALI will provide a tool to evaluate the conditions of Lady Bird Lake, Lake Austin, and Lake Long over time. Water chemistry measurements may provide a snapshot of information on conditions such as instantaneous nutrient concentrations in the water, but they are not sufficient to classify impairments to water bodies especially when degradation is caused by nonpoint source impacts (Woodley et. al. 1993, Davis and Simon 1995, Karr 1991). A more robust index was needed that incorporates biological, physical, chemical, and toxicity data, similar to the EII. To achieve this, six sub-index components were incorporated into the index including the Water Quality Index, Sediment Quality Index, Habitat Quality Index, Aquatic Life Index, Vegetation Index, and Eutrophication Index.

Water Quality Index: This sub-index is essentially a water chemistry measure. As such it is only a snapshot of the level of pollutants in the water column at the time of sampling. It is still useful; however, in providing an instantaneous view of the condition of the water column.

Sediment Quality Index: Measures of sediment chemistry provide a longer term view of pollutant accumulation. Some toxic chemicals adsorb to the sediment and are slowly released into the water column as time passes. Knowing the concentration of sediment pollutants and summarizing these constituents in a sub-index score provides a gauge of potential toxicity to the lake ecosystems.

Habitat Quality Index: Physical changes in aquatic and riparian habitat can lead to changes in the biological communities, vegetation, and trophic status of the lake through erosion and nutrient loading. The Habitat Quality Index assesses the physical changes on the lakes providing information that will help the Water Resources Evaluation (WRE) staff interpret other biological scores of the ALI and act as a reference to which lakes could be candidates for habitat restoration.

Aquatic Life Index: Biological communities have become common indicators for environmental assessment of water bodies. Benthic macroinvertebrate communities respond to long-term environmental stresses in water, sediment, and habitat quality and are thus great tools for long-term assessment of environmental integrity (EPA 2011). The Aquatic Life Index incorporates the community structure of benthic macroinvertebrates on the lakes.

Vegetation Index: Aquatic vegetation provides habitat for waterfowl, fish, and macroinvertebrates However, high levels of vegetative cover can become a nuisance to recreational users of the lakes. In addition, invasive species that rapidly replace diverse vegetation coverage with a thick monoculture can be detrimental to a healthy aquatic ecosystem. Dense rapid growth of hydrilla has been problematic in Lake Austin for water treatment plant intakes, flooding, recreation, lakeside homeowner uses, and potentially property values. The Vegetation Index incorporates the amount and type of aquatic vegetation present on each lake to assess problem areas throughout the lakes.

Eutrophication Index: This sub-index incorporates algal biomass and nuisance algae species. High levels of certain groups of algae can affect aesthetic appeal, cost of drinking water treatment, and dissolved oxygen levels (EPA 2011). Interactions of algae and weather can also cause rapid drops in dissolved oxygen that can result in fish kills.

Similar to the EII scoring the ALI numerical scoring is categorized into eight levels of environmental quality using the following ranges: very bad (0-12), bad (13-25), poor (26-37), marginal (38-50), fair (51-62), good (63-75), very good (76-87), and excellent (88-100). Since each subcomponent was determined to be equally important to the Lake Index, no weighting factors were used in calculating the overall index score. Therefore, the ALI is calculated as the simple arithmetic mean of the lake sub-index components. While the sub-index components can be calculated on a site by site basis, the overall ALI cannot be calculated on such a small scale because the sites for some sub-index components are not located the same way. For example, sediment and water quality date are only collected at three discrete downstream locations near the dams, whereas habitat, algae, and benthic macroinvertebrate data are collected at a larger subset of sites within the lakes. The ALI was calculated for data collected in 2010, but further evaluation of the index should be done in the upcoming years in order to refine the index if necessary and ALI scores should be calculated annually. The specifications by WRE staff for this project were designed to meet the following objectives:

- Employ cost effective monitoring protocols and methods that can be implemented within current WRE budget and other resources.
- Use indicators that are sensitive to early signs of degradation and environmental changes.
- Use monitoring and assessment protocols that are scientifically sound, technically feasible, and appropriate to Central Texas Ecoregions
- Provide a method for relative prioritization of environmental needs for planning purposes.
- Provide a communication tool that may be represented visually and may be easily understood by the public.
- Provides feedback for City Council, City Management, and multiple City departments including WPD on environmental quality of each lake so that the appropriate programs, BMPs, regulations, and policies can be chosen based on the best available science and community goals for each water body.

Meeting these objectives allows the City of Austin to obtain the data necessary to monitor the environmental integrity of the Austin lakes in the most cost efficient manner. This report describes the ALI methodology and the results of the first year of monitoring.

Water Quality Index (WQI)

Introduction

For planning and prioritization of watersheds and sub-watersheds for WPD activities, WRE staff previously constructed a water quality component for the Environmental Integrity Index (EII), for creeks (COA 2002). The basis of the index is similar to the system constructed by the National Sanitation

Foundation (NSF) which transforms water chemistry values to quality values (q-values) using a conversion curve. To form a more region specific index we developed a median method protocol that used historical data to create the quality value curves. The EII water quality component has been shown to effectively convert water chemistry data into a single region specific score for a watershed, thus the method for calculating the water quality component has not been altered in the ALI.

Parameters

Parameters used in the water quality portion of the ALI were chosen to be equivalent to the parameters used in the EII water quality so that the water quality components in each index could be comparable (Table 1). Parameters were previously chosen because they are important constituents that contribute to nonpoint source pollution, they are affordable to analyze, and they are reliable indicators for the effects of urban runoff (COA 2002). As the goal of the ALI water quality component is similar to the goal of the EII water quality component, it is logical to use equivalent parameters to calculate each index. These parameters are also useful regardless of the water bodies being more lentic (lake) than lotic (running stream).

Table 1: Parameters used in the Water Quality Index.

Parameter	**Method**
Ammonia as N	SM 4500-NH3 D
Nitrate as N	SM 4500-NO3H
Orthophosphorus as P	EPA 300
Total Suspended Solids	SM 2540 D
E coli	Colilert
Conductivity	Hydrolab or Quanta

Sampling Protocol

Water quality is sampled at three sites on each lake (Table 2). Lake Austin sites were chosen by the Lower Colorado River Authority (LCRA) which conducts water quality monitoring of Lake Austin, while sites for Lady Bird Lake and Lake Long were chosen based on observed water quality differences in sections of each lake (COA 2007, COA 2010) and are monitored by COA. Multiple water quality samples are collected through the year in non-storm conditions to compensate for variability induced by seasonal changes and dam releases (Table 2). Sample collection methods were the same for all lakes and matched those of the LCRA. Nutrients are collected at each site 0.2 m from the surface and 0.2 m from the bottom of the lake. Total suspended solids and *E. coli* fecal indicator bacteria are collected only at the surface while conductivity is collected along a depth profile (0.2 m from the surface to 0.2 m from the bottom and every 1 meter interval between). Samples are then taken to the LCRA Environmental Lab Services for analysis.

Table 2: Number of water quality samples and site locations for each lake.

	Lake Austin	**Lake Long**	**Lady Bird Lake**
Number of Samples	6/yr	3/yr	4/yr
Collection Entity	LCRA	WRE	WRE
Sites	560 Mansfield Dam	4344 Dam	1 Basin
	561 Tom Miller Dam	4345 East Arm	2 1st Street
	573 Emma Long	4346 West Arm	5 Red Bud Isle

Median Method and Q-values

Water chemistry data is converted into a quality value (0 to 100) using a q-value curve for each parameter. Q-value curves were originally generated following the median method protocol we developed in order to have q-curves based on the region. The first step of the median method protocol is to find the site median, maximum, and minimum for each parameter at every site used in the analysis. In the calculation of the EII q-value curves, sampling sites in each watershed with three or more data points for a given parameter were used in the analysis. Next the site values are grouped together by watershed. Median values are calculated for the site medians, site maximums, and site minimums (watershed medians). The watershed medians are then grouped and the overall regional medians of medians, medians of maximums, and medians of minimums are calculated. Table 3 contains the medians of the medians, medians of the maximums, and medians of the minimums for each parameter and the q-value to which each is assigned.

Table 3: Q-values developed for each parameter in the Water Quality Index.

	Ammonia as N	**Nitrate as N**	**Orthophosphorus as P**	**Total Suspended Solids**	**E. coli**	**Conductivity**	**Q-value**
Detection Limit or Zero	0.02	0.06	0.01	0.5	1	0	100
Median of all Minimums	0.025	0.1	0.02	1.1	41	537	75
Median of all Medians	0.03	0.3	0.05	1.7	72	674	50
Median of all Maximums	0.035	0.7	0.08	5.7	490	796	25
Highest Maximum Value	2.87	19.5	3.1	890	89460	2330	0

Water Quality Index Calculation

Once the water chemistry data has been converted to a q-value via the q-curve, it is weighted by the following percentages:

Ammonia as N	10%
Nitrate as N	20%
Orthophosphorus as P	10%
Total Suspended Solids	20%
E. coli	20%
Conductivity	20%

The weighting factor was constructed to reflect the importance of each parameter in the eutrophication process which is a major factor in the degradation of Central Texas creeks. Historical data for ammonia and orthophosphorus indicated low concentrations in Central Texas streams. In addition, these parameters can be rapidly taken out of solution through chemical reactions and biomass uptake, thus they are weighted at 10 percent. The remaining four parameters were shown vary significantly in base flow and contribute to algae growth and water clarity problems; therefore, they are weighted at 20 percent each. The weighted q-values for each parameter are then summed at each site to give an event water quality score. Event water quality scores are averaged to obtain a site water quality score and finally, the site water quality scores are averaged to obtain a watershed, or lake, score.

Sediment Quality Index

Introduction

Similar to the water quality component of the ALI, calculations for the sediment quality component were taken from the Environmental Integrity Index previously constructed for use in the WPD Masterplan (COA 2002). Some contaminants that may be harmful to both human and biological health may preferentially adsorb to the sediment and leach into the water column under certain conditions. Thus, it is important to measure and track concentrations in the sediment to fully represent all sources of contamination within a watershed. The sediment quality component in the EII has been shown to successfully track parameters concerning human and biological health, so the calculation of the sediment quality component was not altered for use in the ALI.

Parameters
Parameters included in the sediment quality component include arsenic, cadmium, copper, lead, mercury, zinc, PCBs, DDE, DDT, DDD, chlordane, and PAHs. In addition to being common pollutants associated with nonpoint source pollution, these parameters were selected for monitoring because they have documented biological effect levels. Effect levels include the no observable effects level (NOEL), effects range-low (ER-L), effects range-median (ER-M), and apparent effects threshold (AET). Effect levels were originally obtained from the National Oceanic & Atmospheric Administration (NOAA) Technical Memorandum NOS OMA 52.

Sampling Protocols
One sediment sample is collected a year on both Lake Austin and Lake Long, while two sediment samples are collected on Lady Bird Lake (Table 4). As Lake Austin and Lady Bird Lake are run-of-the-river lakes and could be described as lotic (running water) habitats during part of the year, sites are selected to be more downstream so that the sediment is representative of the entire lake. Lake Long has a much longer retention time as it is more of a lentic (standing water) habitat where no true downstream site exists. Sediment is collected at site #4344 Lake Long @ Dam because previous analysis showed that sediment contaminants had higher concentrations at this site in the lake (COA 2010).

Table 4: Number of sediment samples and site locations for each lake.

	Lake Austin	**Lake Long**	**Lady Bird Lake**
Number of samples	1/yr	1/yr	2/yr
Collection Entity	WRE	WRE	WRE
Sites	561 - Tom Miller Dam	4344 - Dam	1 - Basin

Sediment is collected from the bottom of the lake as three grab samples using a Ponar Dredge. Samples are composited in a large glass bowl. A Teflon scoop is used to transfer the composite sample into a large glass jar with a Teflon lid. Anoxic sediments are avoided. Samples are preserved on ice until they are delivered to DHL for analysis.

Q-values
Similar to the water quality component, sediment data was converted to a quality value using q-curves developed for each parameter. Instead of creating thresholds using the median method, the biological effect level of each parameter was assigned an index value to be used in the q-curve (Table 5).

Table 5: Specific Effects Level and corresponding Q-values.

Parameter Specific Effects Level	**Index Value**
None	100
No Observable Effects Level (NOEL)	75
Effects Range-Low (ER-L)	50
Effects Range-Median (ER-M)	25
Apparent Effects Threshold (AET)	0

Since the inception of the EII process, the Environmental Protection Agency (EPA) revised the effect levels developed by NOAA with additional data (EPA 1997). Current biological effect levels used in the EII calculation and the ALI have been set to coincide with the levels set by the EPA (Table 6). If there was no documented NOEL for a particular parameter then the NOEL was omitted.

Table 6: Specific Effects Level for each parameter in the Sediment Quality Index.

PARAMETER	NOEL	ER-L	ER-M	AET
Metals (ug/kg)				
COPPER	16	31.6	149	390
LEAD	31	35.8	128	250
MERCURY	0.15	0.18	1.06	2
ARSENIC	5.9	9.79	33	85
CADMIUM	0.58	0.99	4.98	10
ZINC	98	121	459	820
PAHs (ug/kg)				
PYRENE	290	195	2200	16000
ACENAPHTHENE	22	150	650	2000
ANTHRACENE		57.2	960	13000
BENZO(A)ANTHRACENE	160	108	1600	5100
BENZO(A)PYRENE	230	150	2500	3000
CHRYSENE	220	166	2800	9200
DIBENZ(AH)ANTHRACENE	31	33	260	540
FLUORENE (9H-FLUORENE)	18	77.4	640	3600
FLUORANTHENE	380	432	3600	30000
PHENANTHRENE	140	204	1380	6900
NAPHTHALENE	130	176	2100	2400
2-METHYLNAPHTHALENE		65	670	1900
TOTAL_PAH	260	1610	22800	100000
Pesticides/PCBs (ug/kg)				
PCB	32	59.8	676	5300
4_4'-DDT	1	4.16	62.9	710
4_4'-DDE	1.42	3.16	31.3	190
4_4'-DDD	2	4.88	28	60
CHLORDANE	0.5	3.24	17.6	60

Sediment Quality Index Calculation

The Sediment Quality Index is calculated by averaging the group q-values (metals, pesticides/PCBs, and total PAHs). The group q-value for metals is calculated by assigning a q-value to each metal and averaging the six q-values together. The procedure is similar for the group q-value for pesticides/PCBs. The total PAH group q-value is determined by adding all individual PAH compound concentrations together and converting this into a q-value based on the total PAH curve. In the event that a parameter's concentration is less than the detection limit the following rules are applied to the score:

- If the detection limit is greater than the Effects Range-Low level, then the score for the parameter is not used.
- If the detection limit is less than the Effects Range-Low level, then half of the detection limit is used.

Habitat Quality Index

Introduction

Protection of the habitat surrounding any lake is vital to maintaining the environmental health of the lake itself. Changes in aquatic and riparian habitat can lead to changes in the biological communities (i.e. fish and benthic macroinvertebrates), vegetation, and trophic status of the lake through multiple avenues including erosion and nutrient loading. As such a large factor in determining the biological potential in a water body, it is essential to account for any potential shifts in habitat whether they are in the riparian zone or in the aquatic environment. The substrate, aquatic cover, shoreline characteristics, and riparian characteristics are monitored to represent habitat quality and can be used to examine potential changes to the aquatic life, vegetation, and eutrophication indices.

Sampling Protocol
Habitat surveys are collected once per year at 10 evenly spaced sites along each lake (Table 7). At each site a visual assessment is recorded for substrate and available cover in the littoral (near shore shallow water) zone, shoreline characteristics, and riparian zone characteristics. The site littoral zone assessment area is designated as 15 m in width and extends away from the shore for 10 m or until the depth of the water reaches 1 meter. The shoreline assessment area is 15 m wide and extends 1 m away from the edge of the water, while the riparian assessment area is 15 m wide and extends 15 m back from the edge of the water.

Table 7: Number of habitat samples and site locations on each lake.

	Lake Austin	**Lake Long**	**Lady Bird Lake**
Number of Samples	1/yr	1/yr	1/yr
Collection Entity	WRE	WRE	WRE
Sites	1051 LCRA Boat Ramp	4476 Dam South	4614 Holly Peninsula
	4534 DS Ullrich	4477 Intake South	4615 Gazebo
	4535 DS Bull Creek	4478 Intake North	4616 Edgecliff Terrace
	4536 Davenport Golf Course	4479 Opposite Boat Ramp	4617 Holiday Inn
	4537 DS Emma Long	4480 East Arm West	4618 West Bouldin
	4538 Across Emma Long	4481 Discharge South	4619 RR Bridge North
	4539 OPP Commons Ford Park	4482 Opposite Discharge	4620 Stratford Dr.
	4540 US Commons Ford Boathouse	4483 Discharge North	4621 UT Student Housing
	4541 Kollmeyer East	4484 East Arm East	4622 DS Rollingwood
	4542 Kollmeyer West	4485 Dam North	4623 Jasper

Habitat Quality Index Calculation
The habitat quality component of the ALI is calculated from the substrate, cover, shoreline, and riparian sub-components. Each sub-component is calculated by site for a given year. The habitat site score is calculated as the mean of the sub-components, then the habitat site scores are averaged by lake to yield annual habitat quality scores.

Substrate Sub-component
Substrate conditions can be a limiting factor in the biological health of a lake or stream, thus it has been suggested in the technical literature that every habitat index contain some measurement of substrate characteristics (Rankin 1995). The substrate sub-component of the ALI is a combination of substrate quality and quantity. Substrates at each habitat site are classified as bedrock, boulder, cobble, gravel, sand, silt, or woody debris. Each substrate parameter is assigned an abundance value of 0 (absent), 1 (sparse <10%), 2 (moderate 10-40%), 3 (heavy 40-75%), or 4 (dense >75%) during data collection. Substrates are assigned scores that rank them from undesirable substrate (low score) to desirable substrate (high score) (Table 8). The courser substrates such as cobble and gravel are desirable as they are likely characteristic of unaltered natural conditions (Rankin 1995). Bedrock is designated as undesirable because it is not ideal substrate for benthic communities. Silt is designated as undesirable because it represents sedimentation of smaller particle sizes which is known to degrade habitats by lowering interstitial dissolved oxygen and reducing benthic production (Chapman 1988).

Table 8: Scores for parameters in the littoral substrate.

Substrate	Score
Bedrock (> 4000mm)	1
Boulder (250 - 4000 mm)	2
Cobble (64 - 250 mm)	3
Gravel (2 - 64 mm)	3
Sand (0.06 - 2 mm)	2
Silt, Clay, Mud (< 0.06 mm)	1
Woody Debris	2

Abundance values are multiplied by scores for each substrate, and then the products are summed at each site to give a site substrate score. The combination of the abundance values with the ranked scores allows for an estimation of both substrate quality and quantity, which are commonly used indices for assessing habitat (Rankin 1995, Ohio EPA 2010). The 5^{th} and 95^{th} percentiles were calculated from metrics of all three lakes as the lower and upper bounds of the sub-component score. The final substrate sub-component is converted to a scale of 0 to 100 using the following equation:

Substrate sub-component = 100((Truncated metric – 5^{th} percentile)/(95^{th} percentile – 5^{th} percentile))*

Cover Sub-component

Available cover is another aspect of the physical habitat that has significant influence on aquatic organisms by providing shelter and an influx of organic matter (Angermeier and Karr 1984, Benke et. al. 1985). The ALI incorporates submergent macrophytes, emergent macrophytes, snags, woody debris, overhanging vegetation, rock ledges, boulders, and human structures to measure the amount of available cover. Floating macrophytes and aquatic weeds were considered in the original development of the habitat quality component; however, these parameters are also addressed in the vegetation component of the ALI and were therefore removed. Each cover parameter is assigned an abundance value of 0 to 4 where categories are similar to the substrate sub-component parameters. The sum of the abundance values for all cover parameters is calculated to obtain the site cover score. The cover score is truncated and interpolated similar to the substrate sub-component.

Shoreline Sub-component

The shoreline sub-component is a measure of bank erosion potential and modification by development. A third of this sub-component is comprised of the substrate along the shorelines of each lake. The substrate composition along the lake edge is important because the biology within the lake responds differently to different types of particulate erosion from shoreline sources (Rankin 1995). Similar to the substrate sub-component, shoreline substrate at each habitat site is classified as bedrock, boulder, cobble, loose sand, fine sediment, and vegetation. Each shoreline substrate parameter is assigned an abundance value of 0 (absent), 1 (sparse <10%), 2 (moderate 10-40%), 3 (heavy 40-75%), or 4 (dense >75%) during data collection. Substrates are assigned scores that rank each substrate as desirable (higher score) to undesirable (low score) (Table 9). The desirable substrate on the shoreline of Lake Long is shifted towards slightly smaller particle size material as it is a lentic system year round while Lady Bird Lake and Lake Austin have more riverine properties, especially during release periods from up-river. Abundance values are multiplied by the score values for each substrate parameter and then the products are summed at each site to give a shoreline substrate score.

The second part of the shoreline sub-component is the slope of the bank angle. This is another measure of potential bank erosion as a steeper bank is more likely to lose material than a more gradual slope. The bank angle score is designated as 1 if the bank is vertical, 2 if the bank is 30-75°, and 3 if the bank is <30°.

Shoreline development can degrade the natural habitat of a lake by increasing runoff potential or aquatic substrate and vegetation removal for structures extending into the lake. Shoreline structures have a greater potential to degrade habitat than those set back further from the shore. The development or human influence score is the sum of the survey values for each category of shoreline modification (buildings, commercial, docks, bulkheads, roads, or lawn). Each category is designated as 1 if absent, 0.5 if adjacent to the shoreline, and 0 if on the shoreline.

The three scores are transformed to a percentage so that they are on a comparable scale. A site shoreline score is calculated as the average of the bank angle, substrate, and human influence score. The shoreline score is truncated and interpolated similar to other habitat sub-components

Table 9: Rank scores for parameters in the shoreline substrate.

Shoreline Substrate	**Score on Walter E. Lake Long**	**Score on Lady Bird Lake and Lake Austin**
Bedrock (> 4000 mm)	1	1
Boulder (250 - 4000 mm)	1	2
Cobble/gravel (2 - 250 mm)	2	2
Loose sand (0.06 - 2 mm)	2	1
Fine sediment (< 0.06 mm)	1	1
Vegetation	2	2

Riparian Sub-component

Another index commonly used in habitat indices is the riparian zone quality (Rankin 1995). The estimated riparian width, age of the riparian zone, stability, and species present are often major components used in the calculation of riparian quality. Such information allows for the assessment of the lake habitat on a large scale (Rankin 1995). Degradation experienced in the riparian zone can negatively affect the environmental integrity of the lake as a whole and will worsen as riparian zone degradation proceeds. Potential impacts would be increased nutrient loading along with increased sedimentation and erosion (Lowrance et. al. 1984).

Riparian data is collected and divided into nine categories (Table 10). Each riparian category is assigned an abundance value of 0 (absent), 1 (sparse <10%), 2 (moderate 10-40%), 3 (heavy 40-75%), or 4 (dense >75%) during data collection. The width of the riparian zone is also collected and assigned a value of 1 (<6m), 2 (6-12m), 3 (12-18m), or 4 (>18m). For each site the abundance values for canopy tree large, canopy tree small, understory woody shrubs, understory herbs, ground cover woody shrubs, and ground cover herbs are multiplied by the riparian zone width value and summed. For each invasive or barren/building category with an abundance value of 2 or greater at a site a value of -1 is assigned and multiplied by the riparian zone width value. This negative value is combined with the summation of abundances to yield the site riparian score. The riparian sub-component is truncated and interpolated similar to the other habitat subcomponents.

Table 10: Riparian categories used in the ALI.

Vegetation Layer	Riparian category
Canopy (> 5 meters)	Tree Large (> 0.3 M dbh)
	Tree small (< 0.3 M dbh)
	Invasives
Understory (0.5 - 5 meters)	Woody shrubs (includes saplings)
	Herbs (includes forbs and grasses)
	Invasives
Ground Cover (< 0.5 meters)	Woody shrubs (includes saplings)
	Herbs (includes forbs and grasses)
	Barren/Building

Aquatic Life Index

Introduction

Benthic macroinvertebrate communities have become common indicators used in the assessment of environmental quality within a water body. Communities respond to both short and long-term environmental stresses in water, sediment, and habitat quality (EPA 2011). This allows them to be a valuable tool to assess cumulative environmental impact to lakes and rivers. The benthic macroinvertebrate community structure is currently used in the Environmental Integrity Index for Austin streams (COA 2002). However, the calculations used to develop the aquatic life index in EII were not appropriate for use in the ALI because different benthic communities are indicative of healthy habitat in flowing versus standing waters. The community structure data collected from lake sites was transformed into qualitative metrics that describe aspects of the community (Barbour et. al. 1995), which were then used in multivariate analysis to determine which metrics best describe the lake communities.

It is widely recommended to have a set of reference conditions in which to compare changes in biological communities. As all three lakes in Austin are reservoirs formed by man-made dams, no truly natural reference site exists. Thus historical data and best professional judgment has been used to create reference conditions for the aquatic life component of the ALI (Hughes 1995).

Sampling Protocol

Benthic macroinvertebrates are collected once per year at several locations on each lake (Table 11). As Lake Austin and Lady Bird Lake are riverine systems sites were chosen to represent the entire upstream to downstream reach of each lake, while Lake Long sites were chosen as equidistant transects that would represent aspects of the entire lake. Three distinct kick net (500um net) samples are collected at each site along transects extending from the shore. Collection should begin in a maximum of 0.5 m of water and no farther than 10 feet from the shore, and move along the transect towards the shore for 30 seconds. Scuds (amphipods) are separated from the rest of the sample, which will be picked and preserved in 89% ethanol for later identification and enumeration. The number of scuds will be estimated using 4 grids of a Caton subsampler.

Table 11: Collection of macroinvertebrates on each lake. Only littoral samples used.

	Lake Austin	Lake Long	Lady Bird Lake
Number of Samples	1/yr	1/yr	1/yr
Collection Entity	WRE	WRE	WRE
Sites	4534 DS Ullrich	4476 Dam South	4615 Gazebo
	4535 DS Bull Creek	4477 Intake South	4617 Holiday Inn
	4538 Across Emma Long	4478 Intake North	4620 Stratford Dr.
	4539 OPP Commons Ford	4481 Discharge South	
	4542 Kollmeyer	4483 Discharge North	
		4485 Dam North	

Aquatic Life Index Calculation

Twenty-four (24) metrics are currently computed to describe benthic macroinvertebrate communities in local lakes and streams. Two metrics used in the TCEQ Quantitative and Qualitative Aquatic Life Use scores were not considered in this analysis as they are calculated from the other metrics. Principal Component Analysis (PCA) was performed on the metrics for benthic macroinvertebrate data collected from Lady Bird Lake, Lake Long, and Lake Austin in 2009 and 2010 (Figure 1). PCA showed that the number of non-insect taxa, number of EPT taxa, number of Ephemeroptera taxa, and number of intolerant taxa could be closely related. The percent as dominant guild was positively correlated to the percent as collectors and negatively correlated to the percent as Chironomidae. Percent as tolerant organisms was positively correlated to percent as predators and the percent dominance (top 1) was correlated to the Hilsenhoff Biotic Index (HBI). Metrics from each group that showed statistical differences between sites were chosen as candidate metrics for the aquatic life component of the ALI (Table 12).

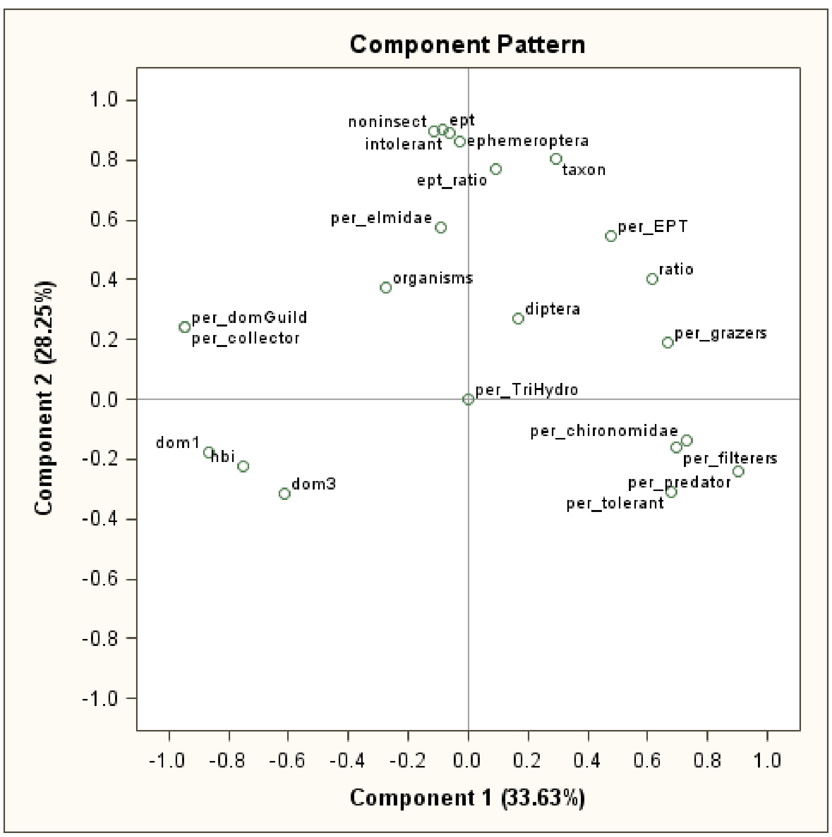

Figure 1: PCA ordination of benthic macroinvertebrate metrics.

Table 12: Metrics used based on multivariate analysis of the data.

Metrics Used	
# of EPT Taxa	Percent EPT
# of Taxa	Percent Dominance (Top 3)*
Percent as Tolerant Organisms*	Percent as Chironomidae*
Hilsenhoff Biotic Index*	

*indicates metrics in which high scores represent poor community health (reverse scale)

Percent Dominant Guild was originally included but the strong negative correlation with Percent as Chironomidae seemed to over penalize most site scores. The benthic macroinvertebrate component was then calculated as:

> Metric score = ((p95 – value)/(p95-p5))*100 for reverse scale parameters
> Metric score = ((value – p5)/(p95-p5))*100 for normal scale parameters
> Site score = average of the six metric scores for that site
> Benthic component = average of the site scores for a particular lake

Where p95 is the 95th percentile for each metric and p5 is the 5th percentile for each metric. As there are no reference sites available in any of the lakes, the best observed condition for each metric was used as the reference condition on which to compare metric scores. The percentiles were used instead of maximums and minimums to eliminate any data that may be excessively high or low. The reverse versus normal calculation difference is due to reverse scale metrics increasing as the community health decreases in quality, thus the score should decrease.

Vegetation Index

Introduction

Aquatic vegetation in a lake can be beneficial to the biota that inhabit the lake such as fish and invertebrates but can also provide necessary habitat for waterfowl by providing both shelter and food sources (Weisner et. al. 1997). The vegetation tends to be most beneficial when it is present in intermediate levels. For instance, total vegetative cover at 10-44% has been reported as the optimal condition for abundance and growth of young largemouth bass (Miranda and Pugh 1997, Trebitz et. al. 1997). Macrophytes present in the littoral zone also filter nutrients from runoff and can prevent bank erosion from wave action (Howard-Williams 1981, Wilson and Keddy 1986). Without this layer of vegetation to uptake extra nutrients from runoff, algal blooms would likely occur more often which can have many detrimental effects on the biological health of the water body. Excess aquatic vegetation can lead to large nutrient loadings as they are released during a large scale die-off periods. Heavy, surfacing aquatic vegetation, is also less aesthetically pleasing to recreational users.

As the aquatic vegetation is an integral part of the environmental health of a lake system, we added parameters to monitor the amount and type of vegetation present in the lakes as a part of the ALI. The vegetative index should provide an excellent view to the environmental conditions of each lake as aquatic vegetation responds to nutrients, contaminants, herbicides, metals, and turbidity (EPA 2011).

Sampling Protocol

Lake surveys of vegetation are conducted by the Texas Parks and Wildlife Department every year on each lake and more often on Lake Austin in order to manage hydrilla growth effectively. Since macrophytes are slower to respond to the changing environmental factors than phytoplankton, a yearly sampling should be adequate to accurately represent the integrity of the water body (EPA 2011). The total acreage of the lake along with the number of acres occupied by each species is recorded and transformed into a percentage of cover. A total percent cover is also calculated by adding the number of acres occupied by each species on the lake and dividing that number by the total acreage of the lake.

Vegetation Index Calculation

For each sampling event the number of taxa score, percent cover score, and percent exotic score are calculated. The number of taxa score is the number of taxa found divided by the maximum number of taxa found on any of the three lakes between 2008 and 2010 multiplied by 100. The maximum number of taxa found in this time period is used as a reference condition to compare other data. Under optimal conditions the number of taxa should be high (EPA 2011), but the number of species present cannot be expected to be more than what has previously been present. Thus the maximum as a reference condition serves to regionalize this metric.

Native vegetation is often preferred by fauna present in a lake, but cannot always compete with exotic species that have been introduced. Not only are exotic plants not preferred but they can have negative effects on local fauna as seen with a decrease in fish biomass due to presence of exotic plants (Weaver et. al. 1997). To capture these detrimental effects on the environment, the percent of exotic cover is calculated and used in the vegetation component of the ALI. The percent exotic score is 100 minus the percent cover of all of the exotic species found in the sampling event, consequently the score should rise with less exotic cover.

Lastly, the percent cover score is calculated as:

$$(1 - (|25 - \text{Total Percent Cover}|) / 50) * 100$$

While it is known that some intermediate level of cover is optimal for the environment, it can depend on the current status of the lake as to where that range falls. Lady Bird Lake had an average total coverage of 2.5% between 2008 and 2010 while Lake Austin had an average total coverage of 29.7%. With consideration to the average macrophyte coverage currently on the lakes, the largemouth bass (an abundant fish in Austin lakes) habitat requirements and the recreational uses of these lakes, 25% was chosen as the optimal reference percentage for the percent cover score. The score will decrease as the percent cover of the lake departs from 25% in either direction. Any Total Percent Cover above 75% will be set to 0. For each sampling event the mean of the number of taxa score, percent cover score, and percent exotic score is calculated to give an event vegetative score. The event vegetative score is then averaged by year on each lake to provide the vegetation component of the ALI.

Eutrophication Index

Introduction

Eutrophication has been defined as the movement of a water body's trophic status in the direction of more plant biomass (Carlson and Simpson 1996). This can include increased algal biomass, macrophyte biomass, and nuisance algae blooms which lead to a decreased aesthetic appeal, decreased number of desirable game fish, loss of accessibility, and increased cost of drinking water treatment (EPA 2011) The trophic status of each lake is estimated from phytoplankton chlorophyll-a data (Carlson and Simpson 1996, Carlson 1977). Chlorophyll-a data provides a sound measurement for instantaneous algal biomass; however, a longer time period cumulative measure was sought for the ALI. The US EPA Clean Lakes Program lists the major components that could be monitored to assess the biologic component of a lake as the algal pigments, algal genera, cell densities, cell volumes, macrophyte coverage, nutrients, bacteria components, and fish flesh data (EPA 2011). WRE biologists monitor the phytoplankton community using taxonomic identifications and abundance data. Community composition metrics are calculated from the data and combined with the chlorophyll-a data to obtain the Eutrophication Index. Sampling is conducted several times a year on each lake to represent the trophic status in a given year as accurately as possible given the seasonal differences that occur naturally in phytoplankton growth. The Eutrophication Index will allow the WRE biologists to track any changes in trophic status within a lake more efficiently These data can then be used to trace sources of degradation and formulate corrections that can be made through City planning, engineering, and funding mechanisms.

Parameters/Metrics

Table 13 lists the metrics suggested by the EPA in order to quantify the condition of the phytoplankton community in a water body. The City of Austin investigated the use of all suggested metrics but results indicate that only percent cyanobacteria, percent green algae, percent diatoms, and percent chrysophytes were useable in the development of the index. Percent centric/pennate diatoms were not available for all data sets and were ultimately not used to characterize the community structure based on this lack of data. Percent colonial greens, percent euglenophytes, and percent dinoflagellates showed no differences between any lake sites and were not used for the index development.

Table 13: Phytoplankton community metrics and responses to eutrophication.

Metric	Response to eutrophication
Percent Cyanobacteria	**Increase**
Percent Green Algae	**Increase**
Percent Diatoms	**Decrease**
Percent Chrysophytes	**Decrease**
Percent Anabaena, Aphanizomenon, Microcystis	Increase
Percent Centric Diatoms	Not used
Percent Pennate Diatoms	Not used
Percent Colonial Greens	Increase
Percent Euglenophytes	Not used
Percent Dinoflagellates	Not used

Sampling Protocol

Phytoplankton chlorophyll-a and species composition samples are collected during water quality lake runs on each lake (Table 14). Samples on Lake Austin will be collected by the Lower Colorado River Authority during April, June, August, and October. Lake Long samples are collected by the City of Austin during March, July, and October. Samples on Lady Bird Lake are collected by the City of Austin 4 times a year with 2 samples collected under non-release conditions (October 15 – March 15) and 2 samples under release conditions (March 15 – October 15) . All phytoplankton samples are collected 0.2 m from the surface. Chlorophyll-a samples are collected with a 250 mL amber bottle, stored on ice, and taken to the LCRA lab for analysis while phytoplankton identification samples are collected in 1 L bottles, stored on ice, preserved with 10% formalin, and taken to Winsborough Consulting for identification and enumeration.

Table 14: Phytoplankton sampling schedule at each lake.

	Lake Austin	Lake Long	Lady Bird Lake
Number of Samples	4/yr	3/yr	4/yr
Collection Entity	LCRA	WRE	WRE
Sites	560 Mansfield Dam	4344 Dam	1 Basin
	561 Tom Miller Dam	4345 East Arm	2 1st Street
	573 Emma Long	4346 West Arm	5 Red Bud Isle

Eutrophication Index Calculation
The Eutrophication Index is defined as the mean of the Chlorophyll-a Score, Eutrophic Phytoplankton Score, and Non-Eutrophic Phytoplankton Score in a year. In order to compute the Chlorophyll-a Score, chlorophyll-a data is converted to quality values (a number between 0 and 100) based on a regional q-value curve. The q-value curve is generated following the median method protocol (COA 2002) using data collected in Lake Austin, Lake Long, and Lady Bird Lake from January 2000 to January 2010. The Chlorophyll-a Score for each lake is defined as the mean of these q-values.

The phytoplankton metrics incorporate the percentages for blue-green algae, green algae, chrysophytes, and diatoms. As blue-green and green algae increase during eutrophication, the percent of blue-green algae and the percent of green algae is used in the Eutrophic Phytoplankton metric while percent of chrysophytes and percent of diatoms is used in the Non-eutrophic Phytoplankton metric. The Eutrophic Phytoplankton metric is defined as:

100 – max(Percent of Blue-green Algae, Percent of Green Algae)

To match the calculation of other indices the Eutrophication Index scores more eutrophic water bodies on the low end of the scale, therefore, the value of the phytoplankton metric is subtracted from 100. Analysis of the data showed that the abundance of green algae or blue-green algae was elevated in any one sample. In order to keep the number of false high scores for this metric to a minimum, the two groups were combined and the maximum percentage is used for each sample. For similar reasons the Non-Eutrophic Phytoplankton metric is defined as:

Max(Percent of Chrysophytes, Percent of Diatoms)

The Eutrophic Phytoplankton Score is defined as the mean Eutrophic Phytoplankton metric in each lake while the Non-Eutrophic Phytoplankton Score is defined as the mean Non-Eutrophic Phytoplankton metric in each lake.

RESULTS AND CONCLUSIONS
After data collection in 2010 the ALI and individual subcomponents were calculated. Results show that the overall ALI score between the three lakes to be very similar (Table 15). All lakes are considered to be fair according to the scaling system. While the multi-metric score does not seem to be different between the three lakes, it is apparent that the subcomponents amongst the lakes are very different. Water quality (WQI) in Lady Bird Lake and Lake Long is fair while Lake Austin scores are in the good category, indicating that the nutrient concentrations are lower in Lake Austin than the other lakes. The sediment quality (SQI) of Lady Bird Lake was fair, Lake Austin was good, and Lake Long was very good. The low score in Lady Bird Lake is troubling because many people use this lake for recreational purposes; however, it does make sense as Lady Bird Lake is downstream of Lake Austin and many of the creeks in Austin flow into Lady Bird Lake. The culmination of the toxic materials is probably highest Lady Bird Lake because it receives the flow from all of the urbanized areas of Austin. The habitat quality (HQI) on the lakes is similar. This result was not expected because of the drastically different lakeshore, riparian areas, and watershed development of the three lakes. For example, Lake Long is surrounded by preserve with many natural riparian areas, while Lake Austin is largely bounded by artificial constructs such as bulkheads and residential lawns. Some investigation may be needed on the Habitat Quality Index in order to confirm that the habitat is being accurately represented in the calculations. The aquatic life (AQL) scores ranged from very good in Lady Bird Lake to marginal in both Lake Long and Lake Austin. The benthic communities on Lake Long are probably degraded by the eutrophic status of the lake while communities on Lake Austin are more than likely degraded because of the habitat. The vegetation (VI) scores were very good on Lake Long but marginal for both Lady Bird Lake and Lake Austin. The scores

for Lake Austin are low because of the high amounts of invasive species on the lake while Lady Bird Lake does not seem to have much aquatic vegetation at all. The City is addressing both of these problems through WPD programs and projects in aquatic plant management, and hopefully these scores will improve in upcoming years. The final subcomponent is the eutrophication status (EI) on the lakes, which ranged from good in Lady Bird Lake, fair in Lake Austin, and poor in Lake Long. While subject to blooms in the fall, Lady Bird Lake and Lake Austin often have low algal biomass. Lake Long is a warmer lake with more retention time and algal biomass seems to accumulate more in this lake.

Table 15: Subcomponent and ALI scores for 2010.

Watershed	**Year**	**WQI**	**SQI**	**HQI**	**AQL**	**VI**	**EI**	**ALI**
Lady Bird Lake	2010	56	54	60	78	41	67	59
Lake Austin	2010	68	63	57	39	48	62	56
Lake Long	2010	57	76	62	46	80	29	58

These initial scores serve as a baseline so that the WRE staff may assess any trends occurring in the lakes due to environmental disturbances or improvements after several years of monitoring. The subcomponent scores parse out the characteristics of each lake well and appear to be good indicators to assist the City of Austin in tracking the sources of impairment. This subcomponent analysis can be used in tandem with EII scores to gauge performance of WPD water quality programs and determine types of BMPs suitable for watersheds that can address source problems.

Although the initial construction of the ALI is complete, over the next several years it should be evaluated to confirm that conditions in Austin lakes are accurately depicted. Changes to the habitat subcomponent have already been discussed:

- Drop "Parks" and "Other" from the list of human influences in the shoreline portion of the subcomponent. There is a lack of information present in these categories as to whether or not the human influence is detrimental to environmental health of the lake.
- Drop "Floating macrophytes" and "Aquatic Weeds" from the cover portion of the subcomponent. They are redundant to the Vegetation Index.
- For 2011, add "Outfall" to the list of human influences in the shoreline portion of the subcomponent to reflect bank cuts, headwalls, and concentrated flow discharges.
- Consider only the portion of the zone where benthic macroinvertebrates may be collected when estimating the substrate cover in the littoral zone. This would address some instances during the first year of sampling where the substrate was estimated in deep water making it very difficult to distinguish the consistency of the lake bottom.
- Consider an extended riparian zone that stretches further away from the lake shore. This gives credit to a larger buffer for nutrient runoff which could potentially improve the health of the lake. Riparian zone width was collected beginning in 2011, but was not added to the calculation of the ALI until 2012. Prior to 2012, the riparian index was simply a summation of the abundance values of a category minus the number of invasive/barren/building categories with an abundance of 2 or greater. The riparian zone multiplier was not incorporated.
- Use a calculation period for one fiscal (October – September) year instead of one calendar year (January – December). This change would allow the ALI to match our current sampling protocol for the EII and provide data for performance measure and budget use as well as any other reporting needed on a Fiscal year basis.

Other subcomponent scores may need adjusting in the future as well. Further benthic macroinvertebrate data will allow WRE biologists to confirm that the metrics chosen as the basis for the Aquatic Life Index correctly assess the current integrity of the lake. Similarly, phytoplankton collected on the lake in the Eutrophication Index will be reevaluated on the basis of cumulative data..

As currently outlined above, the ALI can be used for public information, ranking of lakes, enforcement of standards, trend analysis, program/project/regulatory planning, coordination with regional environmental agencies, and possibly scientific research. From initial data collection and calculations, the ALI meets all of the objectives of initial project planning reproduced below and it should be a useful tool in assessing water quality of Austin lakes if continued as planned:

- Employ cost effective monitoring protocols and methods that can be implemented within current WRE budget and other resources.
- Use indicators that are sensitive to early signs of degradation and environmental changes.
- Use monitoring and assessment protocols that are scientifically sound, technically feasible, and appropriate to Central Texas Ecoregions
- Provide a method for relative prioritization of environmental needs for planning purposes.
- Provide a communication tool that may be represented visually and may be easily understood by the public.
- Provides feedback for City Council, City Management, and multiple City departments including WPD on environmental quality of each lake so that the appropriate programs, BMPs, regulations, and policies can be chosen based on the best available science and community goals for each water body.

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