Review Draft
Prioritization of Brine Shrimp and Brine Fly Bioassay Test Pollutants for Gilbert Bay, Great Salt Lake, Utah
July 22, 2013

Problem Statement: The Utah Division of Water Quality (Division) intends to derive water quality criteria specific to the Great Salt Lake in accordance with the draft Great Salt Lake Water Quality Strategy (DWQ, 2012). In support of these efforts, the Division is implementing a grant from the Utah Water Quality Board to conduct toxicity testing on brine flies and brine shrimp. Because resources are limited, the top pollutants need to be prioritized for additional testing and research.

Conclusion: Pollutants are recommended to be evaluated in the following order of priority: arsenic, copper, methylmercury, and lead. The prioritization of ammonia, cadmium, total mercury, selenium, thallium, and zinc and the remaining priority pollutants is deferred.

Background

At the request of the Great Salt Lake Advisory Council, the Division received a grant from the Utah Water Quality Board to conduct bioassays (specifically toxicity testing) using brine shrimp and brine flies as test organisms. This testing is identified as a critical step in deriving numeric criteria in the Great Salt Lake Water Quality Strategy, Strategy for Developing Numeric Criteria (DWQ, 2012). The testing will also provide data useful for setting Utah Pollution Discharge Elimination System permit effluent limits and assessing water quality.

Methods

In 2011, the Division commenced analyzing samples collected from Gilbert, Farmington and Bear River Bay, twice per year. One intended use of the data generated by these efforts was to prioritize pollutants for bioassay testing. Although additional data from the past 10-15 years is available, this data was not used pending validation. Great Salt Lake water is prone to causing analytical interferences and historical analytical data should be validated prior to using. The pedigree of the 2011-2012 data is known and is representative of current conditions.

Table 1 shows the summary statistics for the 2011-2012 monitoring. Target analytes for the 2011-2012 monitoring included total arsenic, cadmium, copper, lead, mercury, selenium, thallium, ammonia, and dissolved methylmercury. At each monitoring location (Figure 1), samples were collected 1 meter from the surface and 1 meter from the bottom of the water column. At some locations, a chemocline was present and the bottom sample was collected from the denser stratum commonly referred to as the deep brine layer. The concentrations of some analytes increased markedly in the deep brine stratum. The deep brine stratum is inhospitable to brine shrimp and brine flies because of the higher salinity and low dissolved oxygen. Therefore, the concentrations measured in the deep brine layer are not representative of potential exposures to brine flies and brine shrimp. Although brine flies and brine shrimp are not exposed to the pollutant concentrations in the deep brine stratum, some mixing of the deep brine stratum with the overlying oxic stratum occurs (Belovsky et al., 2011). To include this potential migration of pollutants from the deep brine layer to the oxic strata, pollutant concentrations in the deep brine stratum were also considered but were given a lower weighting than the concentrations in the oxic stratum.

The arithmetic mean concentrations from both the oxic and deep brine strata from 2011-2012 were compared to freshwater and marine chronic benchmarks which were either 1) Utah freshwater 4-day criteria, 2) USEPA marine chronic continuous criteria, or 3) other sources. These benchmarks are readily available for many USEPA priority pollutants and provide an objective method for ranking the pollutants for testing. The specific applicability of the benchmarks for predicting toxicity to brine shrimp or brine flies was not evaluated.

The arithmetic mean concentrations measured in Gilbert Bay were divided by freshwater and marine benchmarks and were ranked according to the resulting quotients (Tables 2 and 3, respectively). The pollutant rankings were further modified based on existing brine shrimp and brine fly toxicity studies (Table 4), whether the pollutant is present in discharges to Great Salt Lake, the pollutant's amenability to regulatory controls, and other factors. Other factors include which designated use, birds or aquatic life, is the most sensitive as shown on Figure 3 of the Great Salt Lake Water Quality Strategy, Strategy for Developing Numeric Criteria (DWQ, 2012).

Results

The ranking of pollutants for additional toxicity testing in order of priority are: arsenic, copper, methylmercury, and lead. Prioritizing the following pollutants is deferred: zinc, ammonia, total mercury, cadmium, selenium, and thallium. The rationale for each of the rankings is as follows:

1. Arsenic

Arsenic is selected as the pollutant with the highest priority. Arsenic is a USEPA priority pollutant and is present in Utah Pollution Discharge Elimination System (UPDES) discharges to Gilbert Bay. When compared to the freshwater benchmark, arsenic in the oxic stratum and deep brine layer had the 3rd and 5th highest quotients, respectively. When compared to the marine benchmarks, arsenic in the oxic stratum and deep brine layer are the highest and 2nd highest quotients, respectively. Arsenic concentrations are lower in the oxic stratum than the deep brine stratum (Figures 2 and 3, respectively).

The results of a full life cycle test conducted with brine shrimp, sodium arsenate, and Gilbert Bay dilution water suggests that brine shrimp are relatively insensitive to arsenic (Brix et al., 2003) and supports arsenic as a lower priority for additional testing. However, no toxicity data are available for brine flies. The lack of data for the sensitivity of brine flies to arsenic and the results of the benchmark comparisons support arsenic as the highest priority pollutant. The study of Brix et al., (2003) will be reviewed in detail to determine if toxicity testing using brine shrimp and arsenic should be repeated.

2. Copper

Copper was assigned the 2nd highest priority for testing after arsenic. Copper is a USEPA priority pollutant and is present in UPDES discharges to Gilbert Bay. When compared to the freshwater benchmarks, copper in the oxic stratum and deep brine layer had the 7th and 8th highest quotients, respectively. When compared to the marine benchmarks, copper had the third highest quotients for both the oxic and deep brine strata. Copper concentrations are lower in the oxic stratum than in the deep brine stratum (Figures 4 and 5, respectively).

Brix et al., (2006) measured an EC_{50} (concentration at which 50% of the test population showed a reduction in hatching success) for Great Salt Lake brine shrimp exposed to copper. The EC_{50} with laboratory dilution was 12 µg/l and 68 µg/l when Great Salt Lake was the source of the dilution water. These EC_{50}s support that the site-specific chemistry of Gilbert Bay water decreases the observed toxicity of copper when compared to laboratory water. However, no data were available for brine flies and an EC_{50} is not optimal for deriving chronic numeric criteria. These factors result in copper being the 2nd highest priority.

3. Methylmercury

Methylmercury is recommended as the 3rd highest priority. Total mercury, which includes methylmercury, is a USEPA priority pollutant. UPDES discharges to Gilbert Bay contain trace concentrations of mercury measured in parts per trillion (ppt). However, about 80%, of the mercury in Great Salt Lake is from air deposition (Naftz et al., 2009). Some of this mercury is changed into methylmercury by the microbes in Great Salt Lake.

Methylmercury concentrations increased by 15 times from the oxic stratum to the deep brine stratum (Figures 6 and 7, respectively). Methylmercury is readily absorbed by aquatic organisms resulting in biomagnification between trophic levels that often results in the higher trophic levels having the highest exposures.

Some of the mercury analytical results for the 2011-2012 are anomalous. Specifically, for several samples the concentrations of methylmercury exceeded total mercury concentrations. Total mercury includes methylmercury, so methylmercury concentrations should never exceed total mercury. These data met all of the analytical quality controls and were not qualified. The mean concentration in the oxic layer from the 2011-2012 data was 0.001 µg/l. This concentration is consistent with those measured by Wurtsbaugh et al. (2011) and Naftz et al. (2011) suggesting the outliers in the 2011-2012 data set do not adversely affect the representativeness of the mean.

When compared to the freshwater benchmark, methylmercury in the oxic and deep brine layer have the 4th highest and highest quotients, respectively. The freshwater benchmark, based on the protection of aquatic life, is not a USEPA or Utah numeric criterion. Utah does not have a methylmercury criterion and the USEPA criterion is a fish tissue concentration based on human health. The comparison value used is for protection of aquatic life based on a database that included fish, daphnids, and algae (LANL, 2013). No benchmarks specific to marine waters were identified.

In other aquatic systems such as the Great Lakes, biomagnification of methylmercury resulted in the criteria being based on protection of birds (USEPA, 1995). If birds are more sensitive than the brine shrimp and brine flies, methylmercury may be a lower priority for toxicity testing on brine shrimp and brine flies. However, no toxicity data for brine flies or brine shrimp are available and the bird exposures are still being evaluated. Therefore, methylmercury is recommended for additional testing as the 3rd highest priority. Methylmercury was not prioritized higher because the dominant and uncontrollable source of mercury to Great Salt Lake is air deposition and there are no significant UPDES discharges of mercury.

4. Lead

Lead is a USEPA priority pollutant, is a pollutant in UPDES discharges to Gilbert Bay, and is recommended as the 4th highest priority. Lead concentrations increased by a factor of 5 between the oxic stratum and the deep brine stratum (Figures 8 and 9, respectively). When Gilbert Bay mean concentrations for the oxic stratum and deep brine stratum were compared to the freshwater benchmark, lead was ranked 8th and 6th, respectively. When the mean concentrations were compared to the marine benchmark, lead was ranked the fourth highest. In a test using San Francisco Bay brine shrimp, Gajbhiye and Hirota (1990) ranked lead higher in toxicity when compared to cadmium, copper, nickel, zinc, and manganese. No toxicity tests with Great Salt Lake biota are available. Therefore, lead is recommended as the 4th highest priority for testing with brine shrimp and brine flies.

Ammonia (deferred)

Ammonia is a USEPA priority pollutant but UPDES discharges to Gilbert Bay do not include ammonia. Ammonia concentrations increased by a factor of 4 between the oxic stratum and the deep brine stratum (Figures 10 and 11, respectively).

When compared to the freshwater benchmark, ammonia in the oxic stratum and deep brine layer had the 2nd highest quotients. When compared to the marine benchmark, ammonia in the oxic stratum and deep brine layer had the 2nd highest and highest quotient, respectively. No toxicity tests are available for ammonia on Great Salt Lake brine shrimp and brine flies.

The prioritization of ammonia is deferred for two reasons. First, an ammonia criterion is not a high priority for Gilbert Bay because ammonia is not a pollutant in UPDES discharges. The source of some or most of the ammonia may be the brine shrimp and brine flies and elevated ammonia concentrations are common in terminal lakes (Belovsky et al., 2011). The second reason is uncertainties regarding the concentrations of ammonia. Unpublished ammonia results for monthly samples collected by the Artemia Association between June 2012 and June 2013 were compared to the concentrations in Table 1. The Artemia Association results were lower than the Division's results. The minimum and maximum ammonia concentrations measured in Artemia Association samples for the oxic stratum were 0.01 and 0.35 mg/l, respectively whereas the minimum and maximum observed in the Division's samples were 0.67 and 2.2 mg/l (Table 1). The discrepancy between the Division and Artemia Association results are due to natural variability in ammonia concentrations or analytical error. In either case, the representativeness or accuracy of the Division is uncertain and will require additional sampling to determine the source(s) of the discrepancies. Prioritization of ammonia is deferred pending more data.

Zinc (deferred)

Zinc is a USEPA priority pollutant but was not a target analyte for the 2011 and 2012 sampling. Zinc is present in UPDES discharges to Gilbert Bay. Analytical data from the Division's Bluefish Database indicate that the mean concentration in Gilbert Bay is 3 μg/l. Utah's 4-hour freshwater criterion is 120 µg/l (100 mg/l hardness), the USEPA marine criterion is 81 µg/l, and Brix et al. (2006) EC_{50} for Great Salt Lake brine shrimp was 300 µg/l . Based on a comparison of these benchmarks to Gilbert Bay concentrations, zinc will be prioritized for future monitoring.

Total Mercury (deferred)

Mercury is a USEPA priority pollutant and is present in UDPES discharges to Gilbert Bay. The concentrations increase between the oxic stratum and deep brine stratum (Figures 12 and 13, respectively). When compared to the freshwater benchmark, mercury in the oxic stratum and deep brine layer had the 5th and 3rd highest quotients, respectively. When compared to the marine benchmark, the quotients for mercury in the oxic stratum and deep brine layer were 6th and 5th highest respectively. Total mercury was assigned a lower priority than suggested by the comparisons to the benchmarks for two reasons. The primary reason is that methylmercury was already selected as the 3rd highest priority. The average fraction of methylmercury to total mercury in the oxic stratum of Gilbert Bay is 25-35% (DWQ, 2011-2012 monitoring; Naftz et al., 2011; Wurtsbaugh, 2011) supporting that the majority of potential toxicity of mercury will be attributable to the methylated fraction (AUNZ, 2000). The second reason is that like discussed for methylmercury, there are no significant sources of total mercury in discharges to Gilbert Bay.

Thallium (deferred)

Thallium is a USEPA priority pollutant but is not in UDPES discharges to Gilbert Bay except in trace amounts. Mean thallium concentrations in Gilbert Bay were 0.034 µg/l and 0.052 µg/l for the oxic stratum and deep brine layer, respectively. When compared to the freshwater benchmark, the quotients for the oxic and deep brine strata were 1st and 4th, respectively. When compared to the marine benchmark, the quotients were the lowest. Thallium is given a low priority because of the lack of UDPES sources and the uncertainty regarding the benchmarks. No USEPA or Utah numeric criteria are available for thallium and the benchmarks used were given a “low reliability” rating by the authors (AUNZ, 2000).

Cadmium (deferred)

Cadmium is a USEPA priority pollutant but discharges to Gilbert Bay only contain trace amounts. Concentrations were close to the detection limit for both the oxic and deep brine strata (Figures 13 and 14, respectively). When compared to the freshwater benchmark, cadmium concentrations in the oxic stratum and deep brine layer had the 9th and 7th highest quotients, respectively. When compared to the marine benchmark, cadmium concentrations in the oxic stratum and deep brine layer had the 7th and 6th highest quotients , respectively. Brix et al., (2006) measured an EC_{50} of 11,859 µg/l for Great Salt Lake brine shrimp exposed to cadmium that indicates brine shrimp are relatively insensitive to cadmium. No toxicity data were found for brine flies. The maximum concentration measured in 2011 and 2012 was 0.28 µg/l which is several orders of magnitude below the brine shrimp EC_{50}. The low concentrations measured in Great Salt support cadmium being deferred.

Selenium (deferred)

Selenium is a USEPA priority pollutant and UDPES discharges to Gilbert Bay do contain selenium. When compared to the freshwater benchmark, selenium in the oxic stratum and deep brine layer had the 6th and 9th (of 9) quotients, respectively. When compared to the marine benchmarks, selenium in the oxic stratum and deep brine layer had the 5th and 7th highest quotients of 8, respectively.

Gilbert Bay has a numeric criterion based on bird egg tissue because bird reproduction was determined to be the most sensitive toxic endpoint for selenium (DWQ, 2008). Brix et al., (2004) conducted acute tests on selenate with brine shrimp, brine flies, and algae. Of the three organisms, brine shrimp were the most sensitive, followed by the algae, and then brine flies. Therefore, additional testing for selenium is a low priority.

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TABLES and FIGURES

Table 1

Summary Statistics for Gilbert Bay Samples Collected July, 2011; October, 2011; June, 2012; and October, 2012

All Samples

Analyte	Average (µg/l)	Minimum (µg/l)	Maximum (µg/l)	Std Dev (µg/l)	Count
As	78.119	27.900	157.000	25.543	67
Cd	0.045	0.010	0.280	0.064	67
Cu	2.525	0.175	15.000	2.683	67
Hg	0.0089	0.001	0.047	0.013	67
Me	0.0048	0.00015	0.00293	0.0084	66
Pb	2.074	0.439	13.400	2.488	67
Se	0.378	0.197	0.776	0.112	67
Tl	0.038	0.010	0.113	0.015	67
Ammonia	2.24	0.67	10.1	2.4	48

Oxic Stratum

Analyte	Average (µg/l)	Minimum (µg/l)	Maximum (µg/l)	Std Dev (µg/l)	Count
As	69.739	27.900	102.000	19.323	48
Cd	0.020	0.010	0.048	0.013	48
Cu	1.841	0.880	3.750	0.583	48
Hg	0.004	0.001	0.017	0.003	48
Me	0.001	0.000	0.005	0.001	48
Pb	1.095	0.439	1.490	0.204	48
Se	0.356	0.197	0.756	0.092	48
Tl	0.034	0.010	0.045	0.007	48
Ammonia	1.278	0.67	2.02	0.38	36

Deep Brine Stratum

Analyte	Average (µg/l)	Minimum (µg/l)	Maximum (µg/l)	Std Dev (µg/l)	Count
As	103.125	45.800	157.000	26.906	16
Cd	0.122	0.010	0.280	0.094	16
Cu	4.677	0.175	15.000	4.907	16
Hg	0.025	0.002	0.047	0.018	16
Me	0.016	0.001	0.029	0.010	16
Pb	5.177	1.060	13.400	3.688	16
Se	0.446	0.238	0.776	0.145	16
Tl	0.052	0.023	0.113	0.024	16
Ammonia	5.14	0.905	10.1	3.3	12

Table 2
Comparison of Gilbert Bay Mean Concentrations from 2011-2012 to Freshwater Benchmarks

Rank	Analyte	Mean, oxic stratum (µg/l)	Chronic Benchmark (µg/l)	Ref.	Ratio
1	Tl	0.034	18	2	0.002
2	Ammonia	1.278	2.21	1	0.6
3	As	69.739	150	1	0.5
4	MeHg	0.001	0.0028	2	0
5	Hg	0.004	0.012	1	0.3
6	Se	0.356	4.6	1	0.08
7	Cu	1.841	30.5	1	0.06
8	Pb	1.095	18.6	1	0.06
9	Cd	0.020	0.76	1	0.03

Rank	Analyte	Mean, deep brine stratum (µg/l)	Chronic Benchmark (µg/l)	Ref.	Ratio
1	MeHg	0.016	0.0028	2	6
2	Ammonia	5.14	2.21	1	2
3	Hg	0.025	0.012	1	2
4	Tl	0.052	0.03	5	2
5	As	103.125	150	1	0.7
6	Pb	5.177	18.6	1	0.3
7	Cd	0.122	0.76	1	0.2
8	Cu	4.677	30.5	1	0.2
9	Se	0.446	4.6	1	0.1

Notes:
1: Utah (freshwater) 4-day criterion, adjusted to 400 mg/l hardness when appropriate. Ammonia benchmark based on pH of 8 and temperature 18˚C
2: LANL, 2009 Tier II value for protection of aquatic life communities
5: Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 2. 2000. http://www.environment.gov.au/water/publications/quality/pubs/nwqms-guidelines-4-vol2.pdf

Table 3
Comparison of Gilbert Bay Mean Concentrations from 2011-2012 to Marine Benchmarks

Rank	**Analyte**	**Mean, oxic stratum (µg/l)**	**Chronic Benchmark (µg/l)**	**Ref.**	**Ratio**
1	As	69.739	36	3	2
2	Ammonia	1.278	1.6	3	0.8
3	Cu	1.841	3.1	3	0.6
4	Pb	1.095	8.1	3	0.1
5	Se	0.356	71	3	0.01
6	Hg	0.004	0.94	3	0.004
7	Cd	0.020	8.8	3	0.002
8	Tl	0.034	17	4	0.002

Rank	**Analyte**	**Mean, deep brine stratum (µg/l)**	**Chronic Benchmark (µg/l)**	**Ref.**	**Ratio**
1	Ammonia	5.14	1.6	3	3
2	As	103.125	36	3	3
3	Cu	4.677	3.1	3	2
4	Pb	5.177	8.1	3	0.6
5	Hg	0.025	0.94	3	0.03
6	Cd	0.122	8.8	3	0.01
7	Se	0.446	71	3	0.01
8	Tl	0.052	17	4	0.003

Notes:
2: LANL, 2009 Tier II value for protection of aquatic life communities
3-USEPA 4-day marine criteria, Ammonia benchmark based on pH of 8 and temperature 18˚C
4: Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 2. 2000.
http://www.environment.gov.au/water/publications/quality/pubs/nwqms-guidelines-4-vol2.pdf

Table 4
Existing Toxicity Studies for Great Salt Lake, Utah

Reference	Test Organism	Pollutants	Notes
Gajbhiye, S. N. and R. Hirota. 1990. Toxicity of Heavy Metals to Brine Shrimp *Artemia*. J. of the Indian Fisheries Assoc. 20, pp-43-50	Brine Shrimp (San Francisco Bay)	Pb, Cd, Cu, Ni, Zn, Fe, Mn	LC50s, tested additivity, Toxicity of Pb>Cd>Cu>Ni>Zn>Fe>Mn
Brix, K.V., R.D.Cardwell, and W.J. Adams. 2003. Chronic toxicity of arsenic to the Great Salt Lake brine shrimp, *Artemia franciscana* . *Ecotox* Environ. Safety. 54:169-175, Feb	GSL Brine Shrimp and GSL dilution water	As: chronic NOEC=8mg /l Chronic LOEC=15 mg/l	We determined the chronic toxicity of arsenic (sodium arsenate) to the Great Salt Lake brine shrimp, *Artemia franciscana*. Chronic toxicity was determined by measuring the adverse effects of arsenic on brine shrimp growth, survival, and reproduction under intermittent flow-through conditions. The study commenced with <24-h-old nauplii, continued through reproduction of the parental generation, and ended after 28 days of exposure. The concentrations tested were 4, 8, 15, 31, and 56 mg/L dissolved arsenic. The test was conducted using water from the Great Salt Lake, Utah as the dilution water. Adult survival was the most sensitive biological endpoint, with growth and reproduction somewhat less sensitive than survival. The no observed effect concentration (NOEC) for survival was 8 mg/L, and the lowest observed effect concentration (LOEC) was 15 mg/L dissolved arsenic. The LOEC for growth and reproduction was greater than the highest concentration tested, 56 mg/L. Based on survival, the final chronic value (geometric mean of the NOEC and LOEC) was 11 mg/L dissolved arsenic. The F_1 generation appeared to acclimate to the prior arsenic exposure of the parental generation and was significantly less sensitive than the parental generation. For example, survival for the

			F_1 generation through day 12 was 100% in 56 mg/L dissolved arsenic, compared to 26% for the parental generation. Growth of the F_1 generation was significantly less than that of the parental generation across all concentrations including the control, indicating a generational difference in brine shrimp growth rather than an arsenic effect. This study represents one of the few full life cycle toxicity tests conducted with brine shrimp.
Brix, K.V., R.M. Gerdes, W.J. Adams, and M. Grosell. 2006. Effects of Copper, Cadmium, and Zinc on the Hatching Success of Brine Shrimp (*Artemia franciscana*). Arch. Environ. Toxicol. 51, 580-583	GSL Brine Shrimp	**Cu**: EC50=12 ug/l (lab); EC50 GSL=68 ug/l **Cd**: EC50=11,859 (lab) ug/l **Zn**: EC50=289 (lab) ug/l	Hatching success measured.
Forsythe II, B.L. and S.J.Klaine. 1994. The interaction of sulfate and selenate (Se^{+6}) effects on brine shrimp, *Artemia* SPP. Chemosphere Vol. 29, Issue 4, 789-800	San Joaquin Brine Shrimp	Se	Sulfate has been shown to be antagonistic to selenate toxicity in aquatic organisms. Brine Shrimp, *Artemia spp.*, flourish in evaporation ponds of the San Joaquin Valley which have selenium concentrations between 1 and 6,000 µg/l. The salinity is dominated by Na_2SO_4 rather than NaCl in these ponds. Brine shrimp raised in artificial seawater at 25°C exhibited a 96h LC50 of 0.006 mg/l selenate with sulfate levels at 0.05 mg/l. The LC50 for those in waters containing 14,000 mg/l sulfate was 81.97 mg/l selenate. Developmental assay results indicated that selenate had no effect on emergence or hatching of brine shrimp regardless of the sulfate concentration. However, selenate

			was lethal to nauplier larvae. Mortality was significantly reduced with increased sulfate concentration in the media.
Berthelemy-Okazaki, N. and D. Ingraham. Effect of Mercury on the brine shrimp *Artemia* from the Great Salt Lake. Poster	GSL Brine Shrimp	Hg (Hg2+?)	Undergraduate Research, not published. NOEC 100 µg/L
Brix, K.V., D.L. DeForest, R. Cardwell, and W.J. Adams. 2004. Derivation of a Site-Specific Water Quality Standard for Selenium. Environ Toxicol Chem. 2004 Mar;23(3):606-12.	GSL Brine Shrimp, brine fly, *Ephydra cinerea*, *Dunaliella viridis*	Selenate	Brine Shrimp Acute LC50=78 mg/l Acute LOEC=8 mg/l Acute NOEC=3 mg/l Brine Flies Acute LC50=490 mg/l Acute LOEC=691 mg/l Acute NOEC=369 mg/l Algae Chronic EC50=45 mg/l Chronic EC50=32 mg/l Chronic NOEC=11 mg/l

Figure 1 Great Salt Lake Utah Division of Water Quality Sample Locations

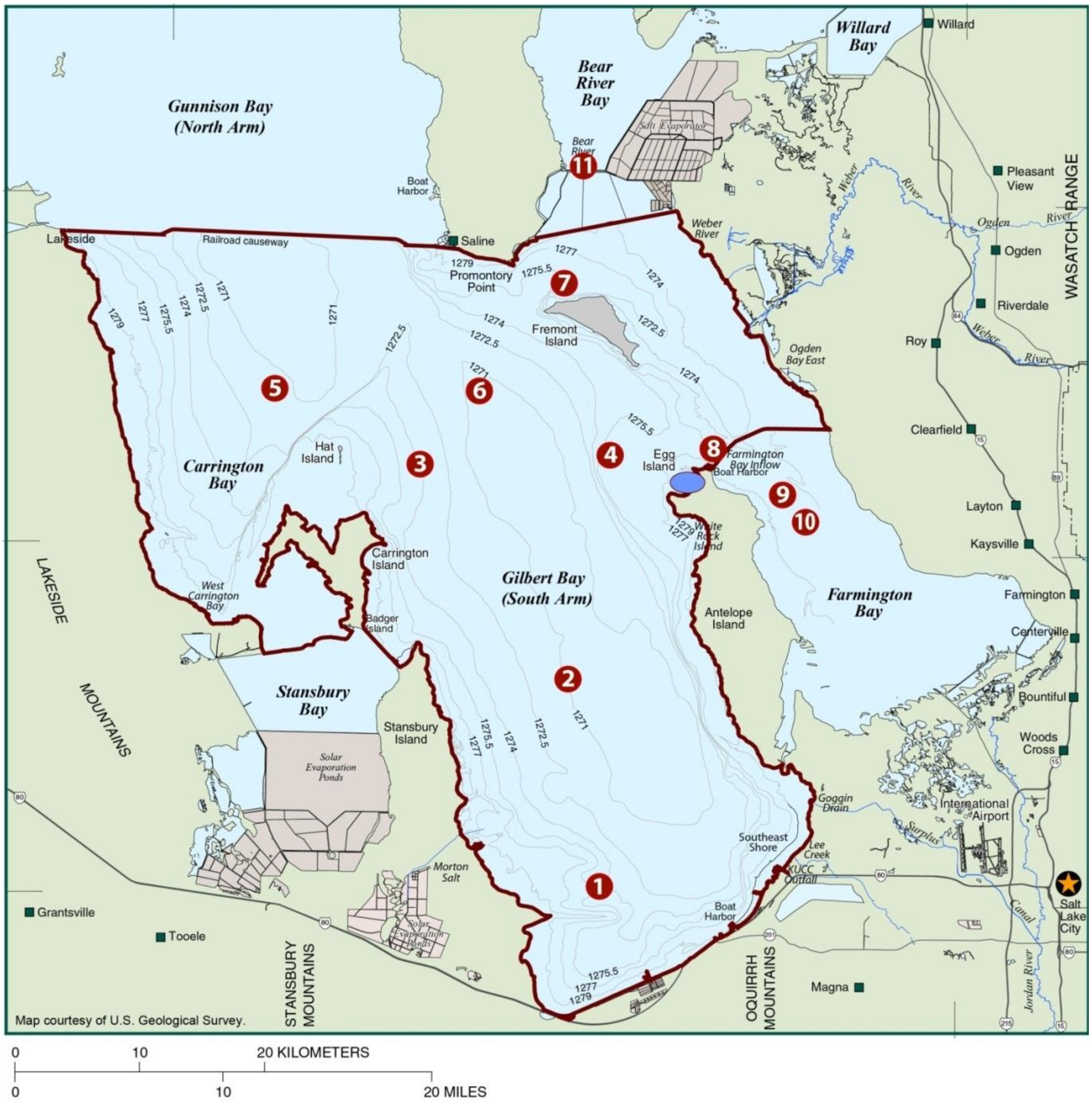


Figure 2
2011-2012 Gilbert Bay Oxic Stratum
Arsenic Concentrations (µg/L)

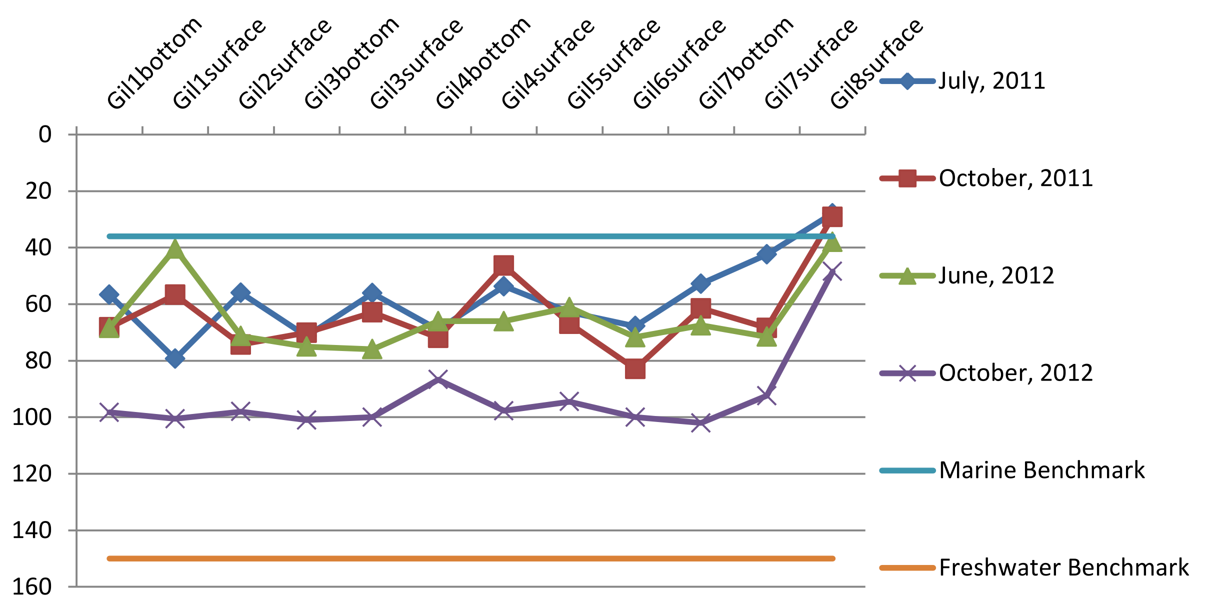


Figure 3
2011-2012 Gilbert Bay Deep Brine Stratum
Arsenic Concentrations (µg/L)

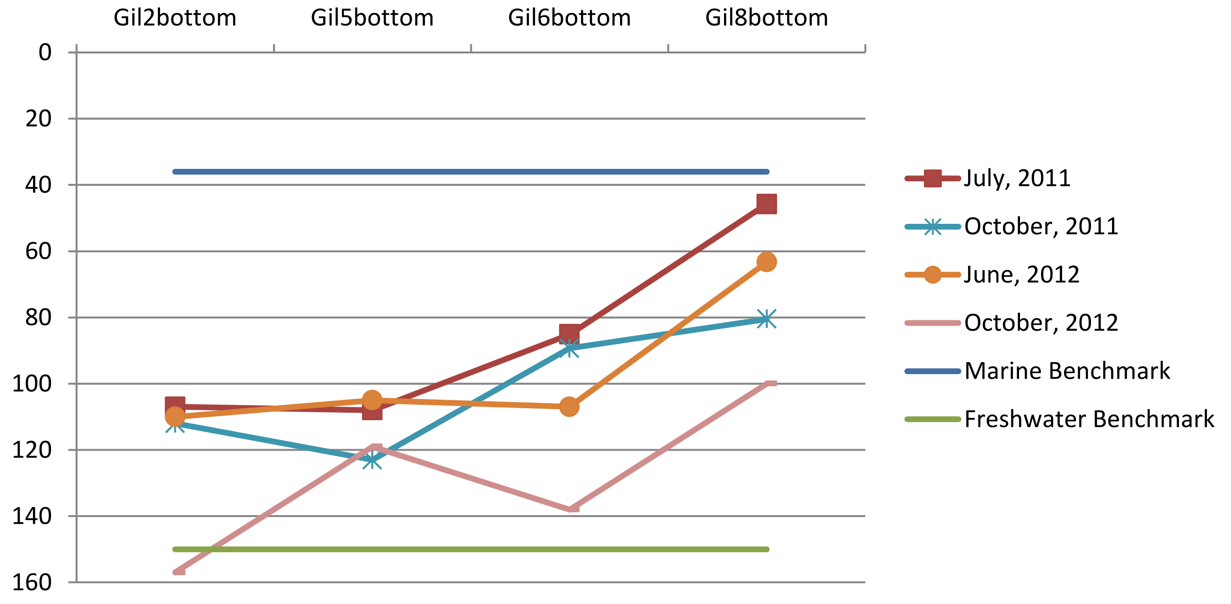


Figure 4
2011-2012 Gilbert Bay Oxic Stratum
Copper Concentrations (µg/L)

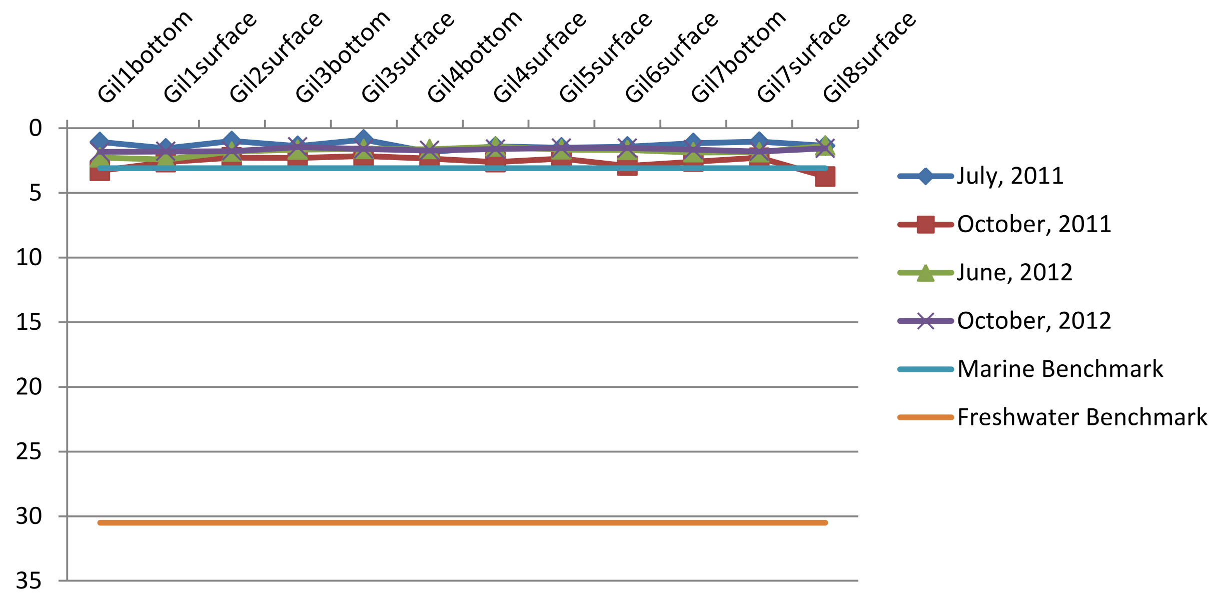


Figure 5
2011-2012 Gilbert Bay Deep Brine Stratum
Copper Concentrations (µg/L)

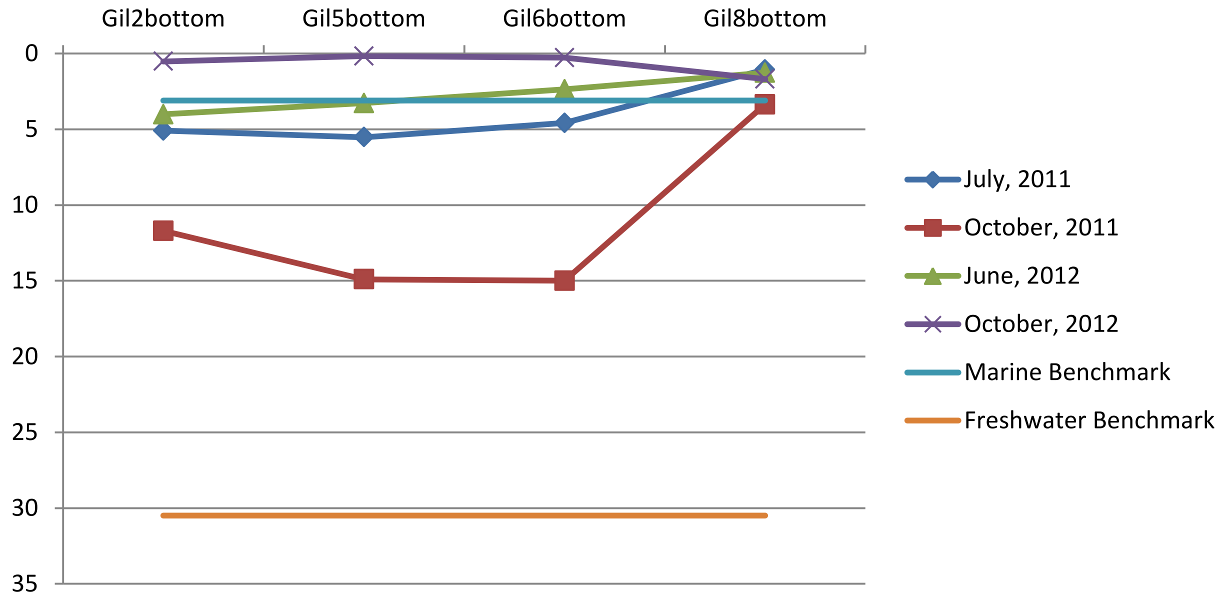


Figure 6
2011-2012 Gilbert Bay Oxic Stratum
Methyl Mercury Concentrations (ng/L)

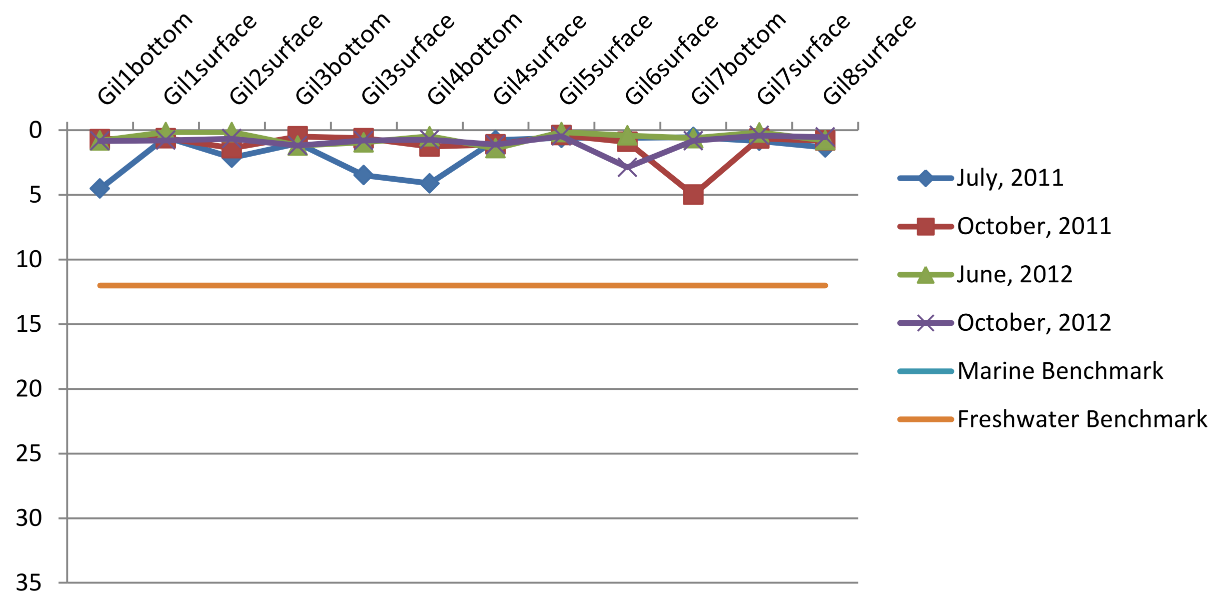


Figure 7
2011-2012 Gilbert Bay Deep Brine Stratum
Methyl Mercury Concentrations (ng/L)

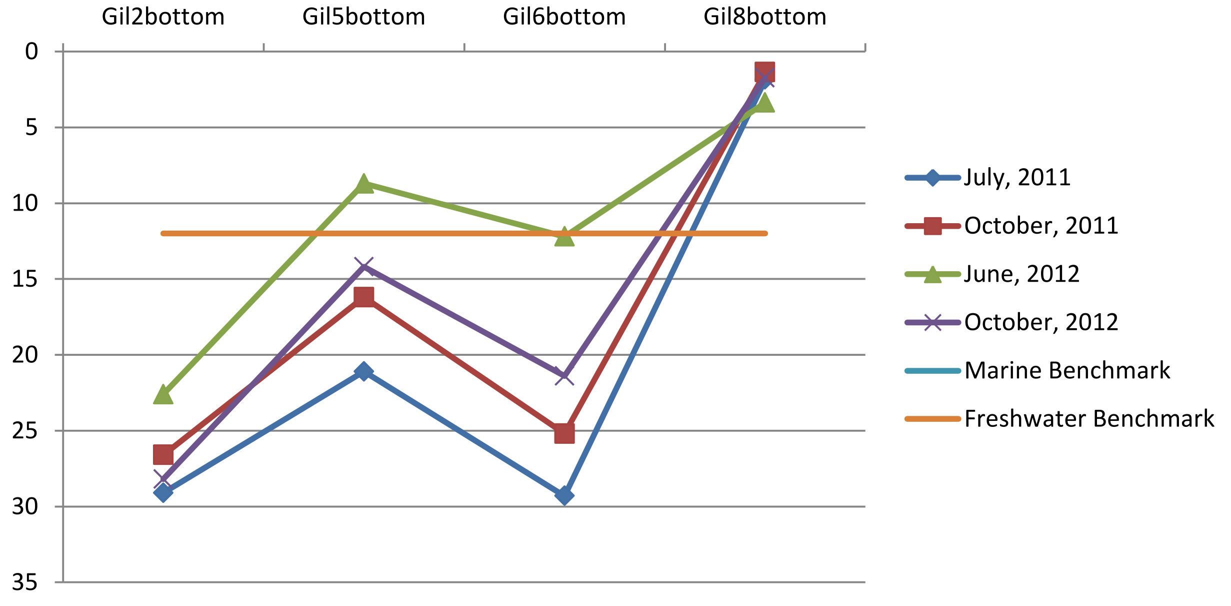


Figure 8
2011-2012 Gilbert Bay Oxic Stratum
Lead Concentrations (µg/L)

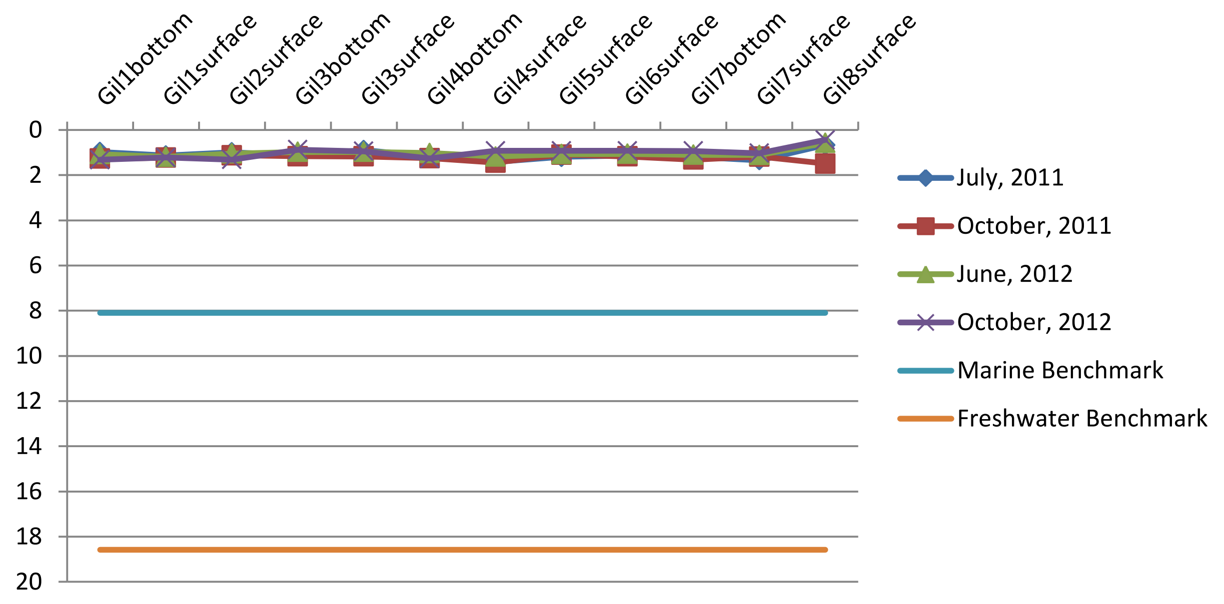


Figure 9
2011-2012 Gilbert Bay Deep Brine
Lead Concentrations (µg/L)

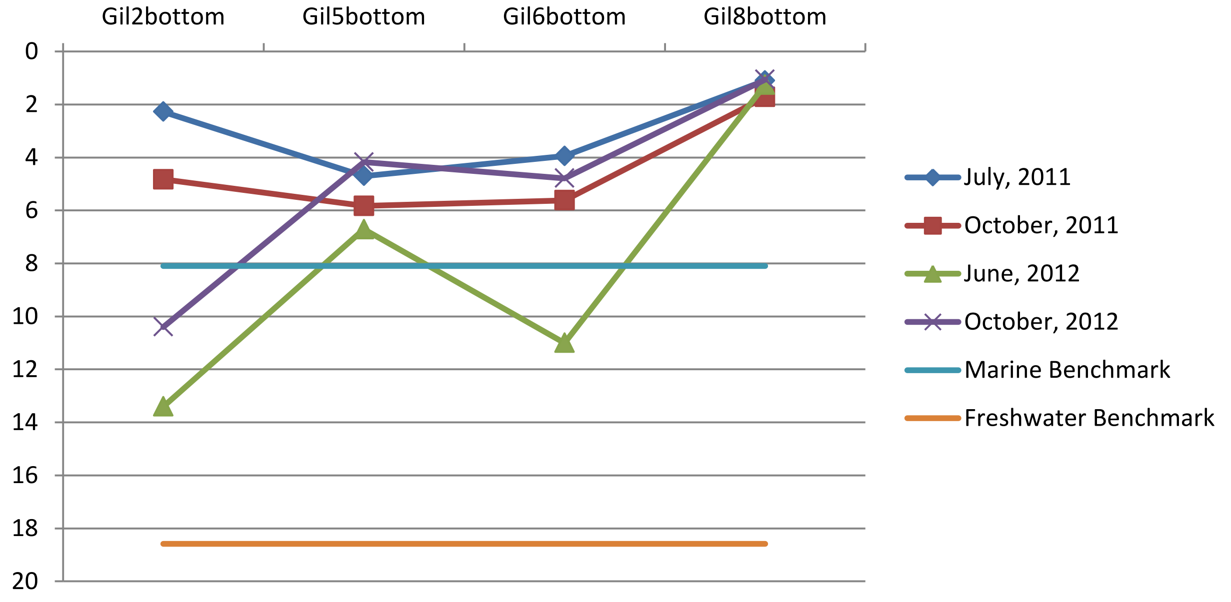


Figure 10
2011-2012 Gilbert Bay Oxic Stratum
Ammonia Concentrations (mg/L)

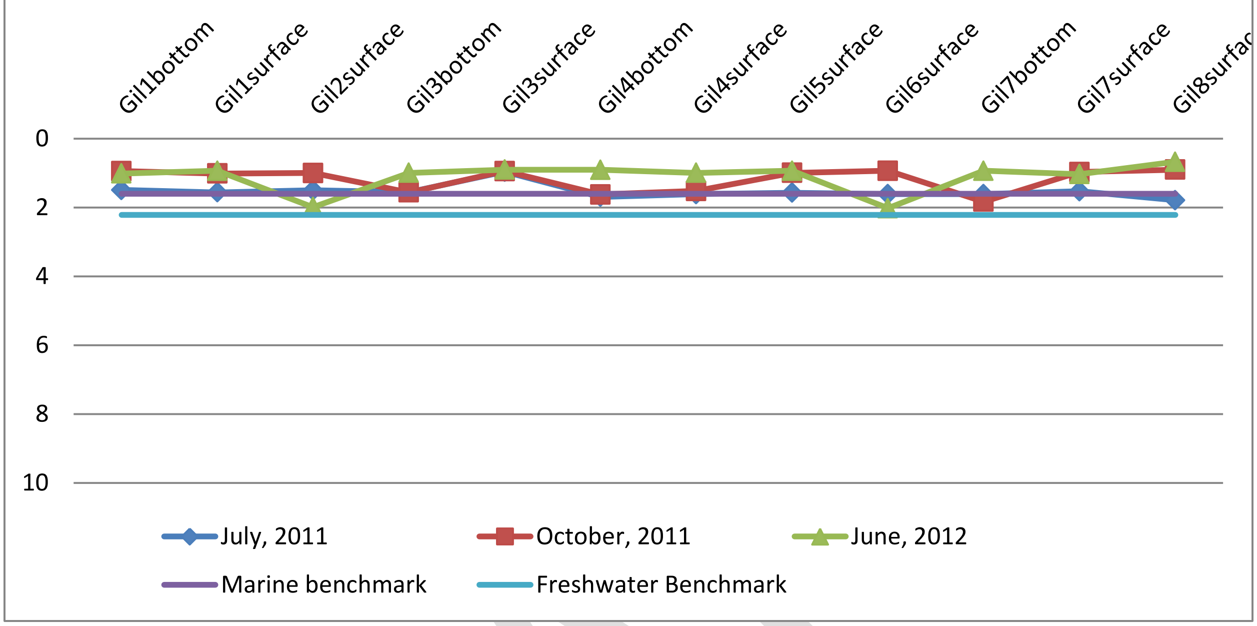
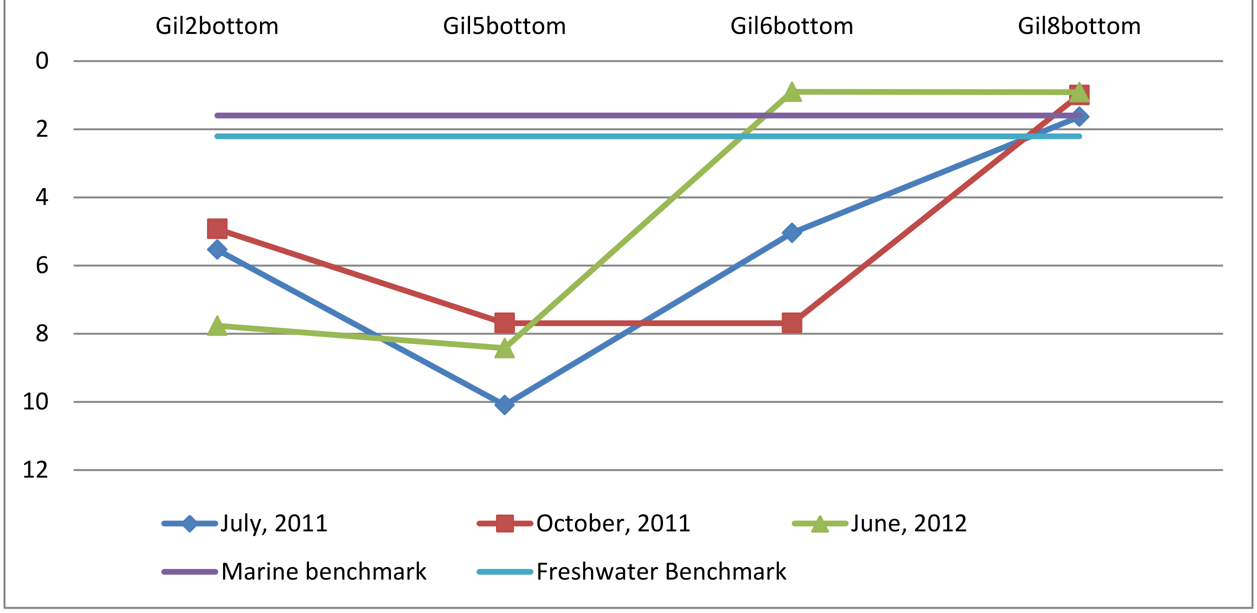


Figure 11
2011-2012 Gilbert Bay Deep Brine Stratum
Ammonia Concentrations (mg/L)



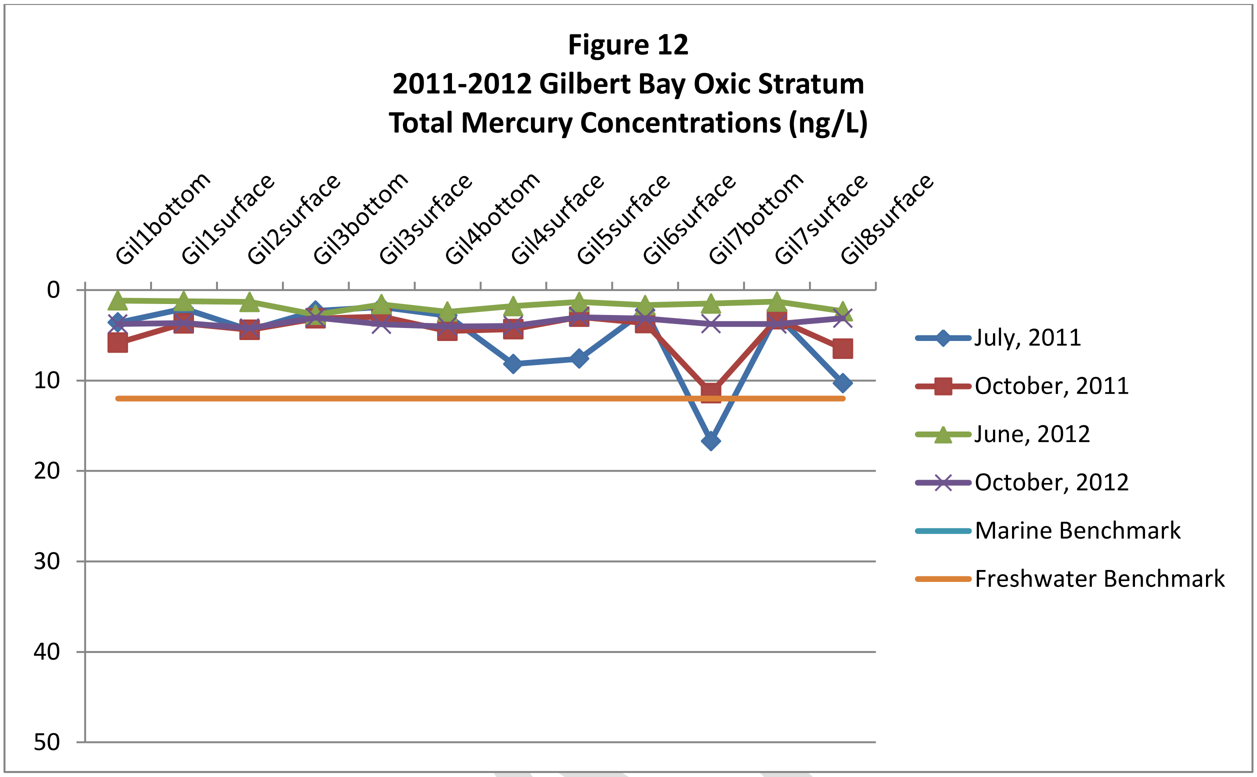


Figure 12
2011-2012 Gilbert Bay Oxic Stratum
Total Mercury Concentrations (ng/L)

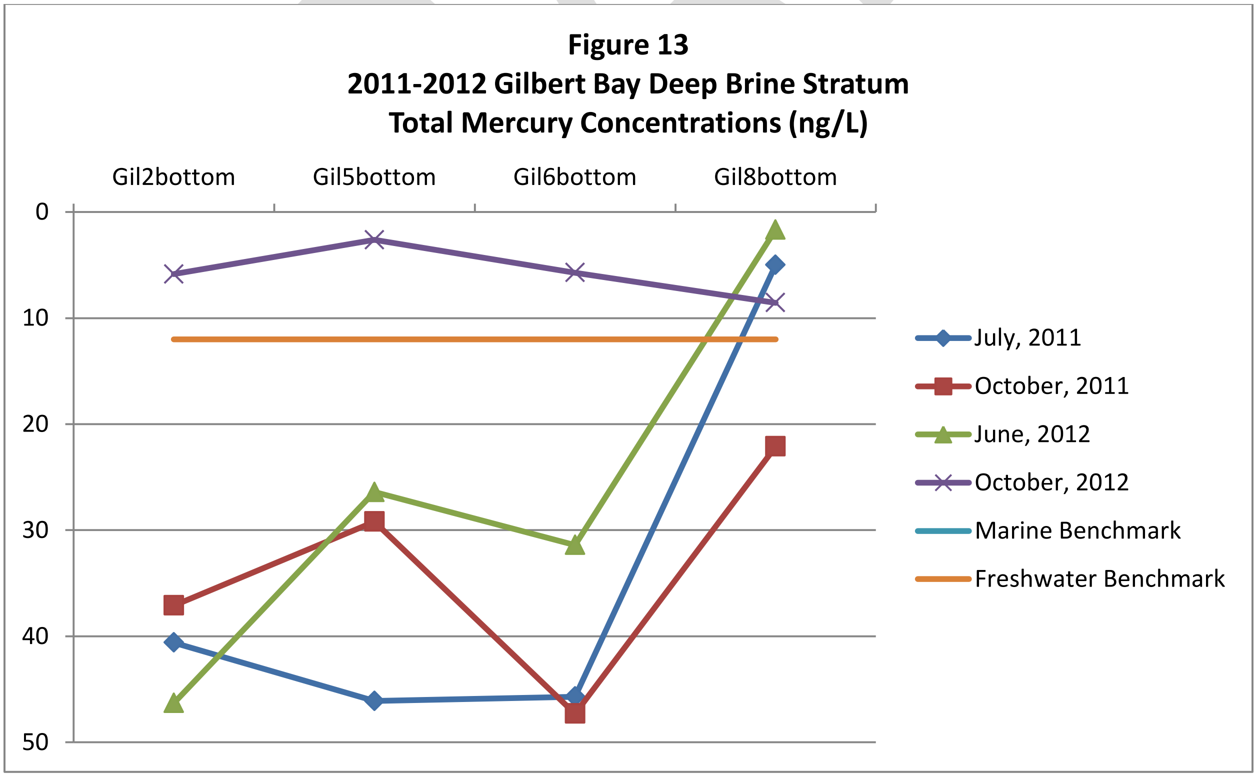


Figure 13
2011-2012 Gilbert Bay Deep Brine Stratum
Total Mercury Concentrations (ng/L)

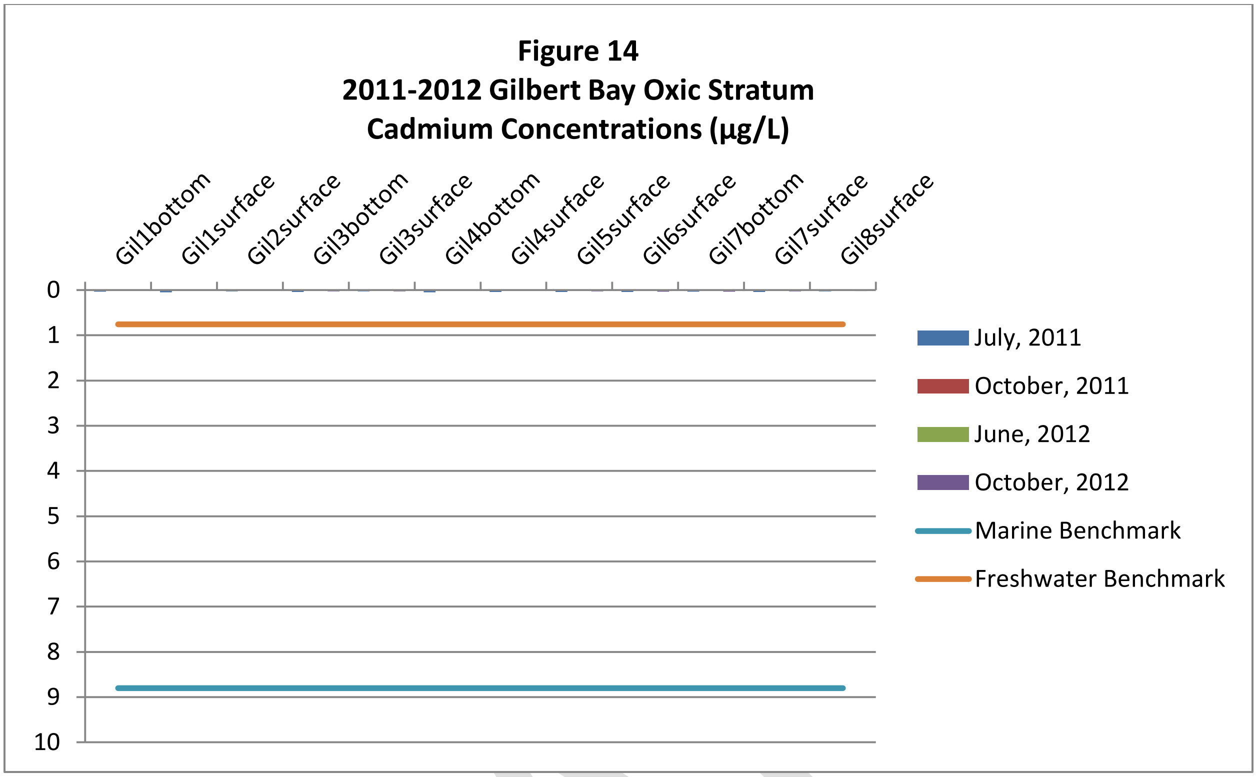


Figure 14
2011-2012 Gilbert Bay Oxic Stratum
Cadmium Concentrations (µg/L)

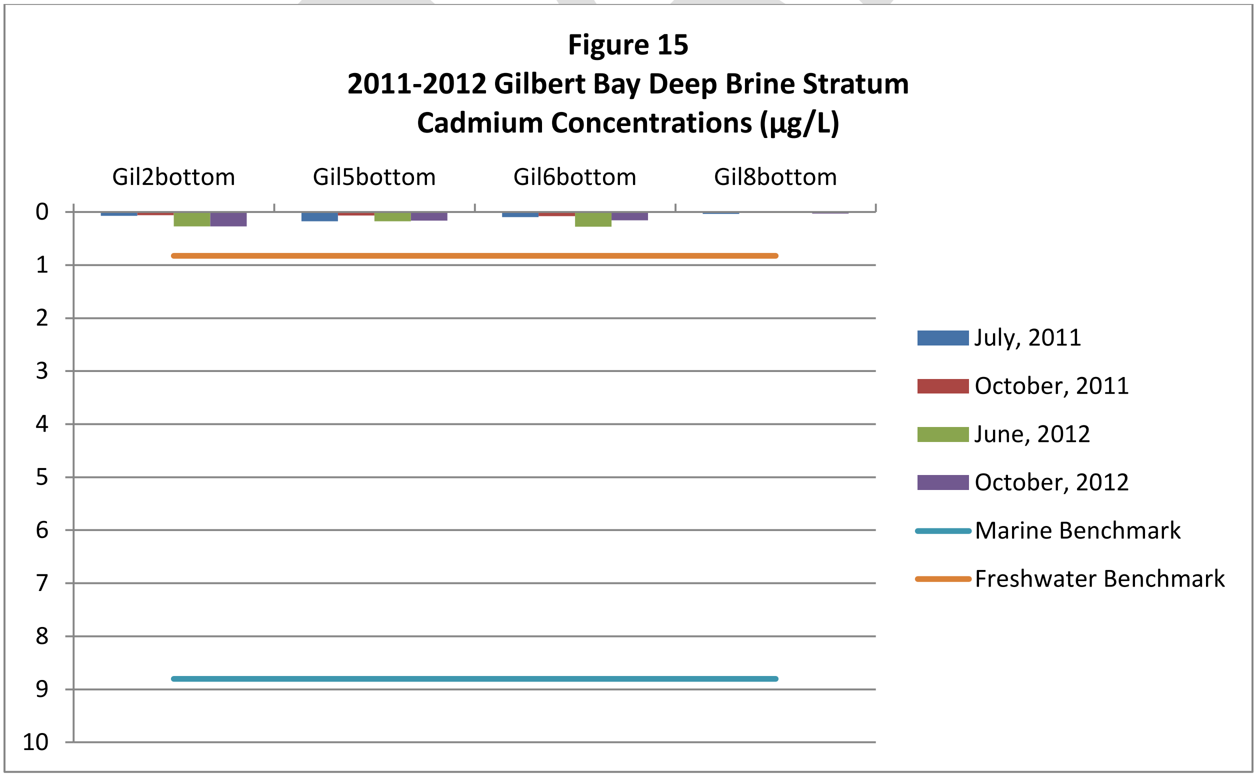


Figure 15
2011-2012 Gilbert Bay Deep Brine Stratum
Cadmium Concentrations (µg/L)

Figure 16
2011-2012 Gilbert Bay Oxic Stratum
Selenium Concentrations (µg/L)

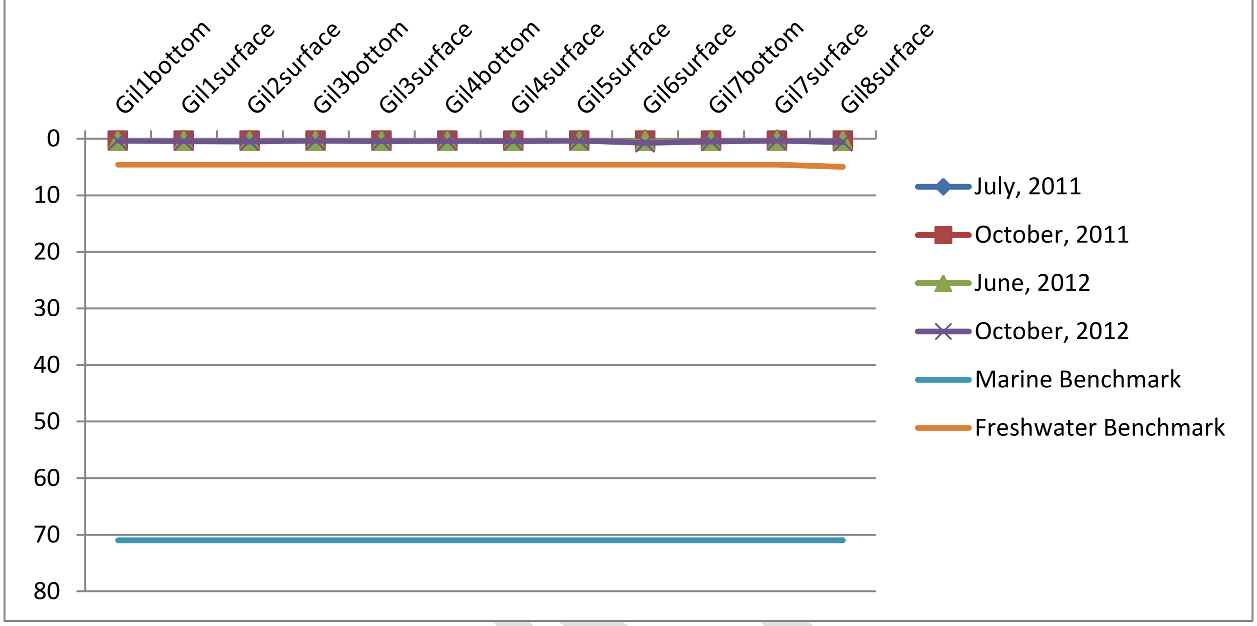


Figure 17
2011-2012
Gilbert Bay Deep Brine Stratum
Selenium Concentrations (µg/L)

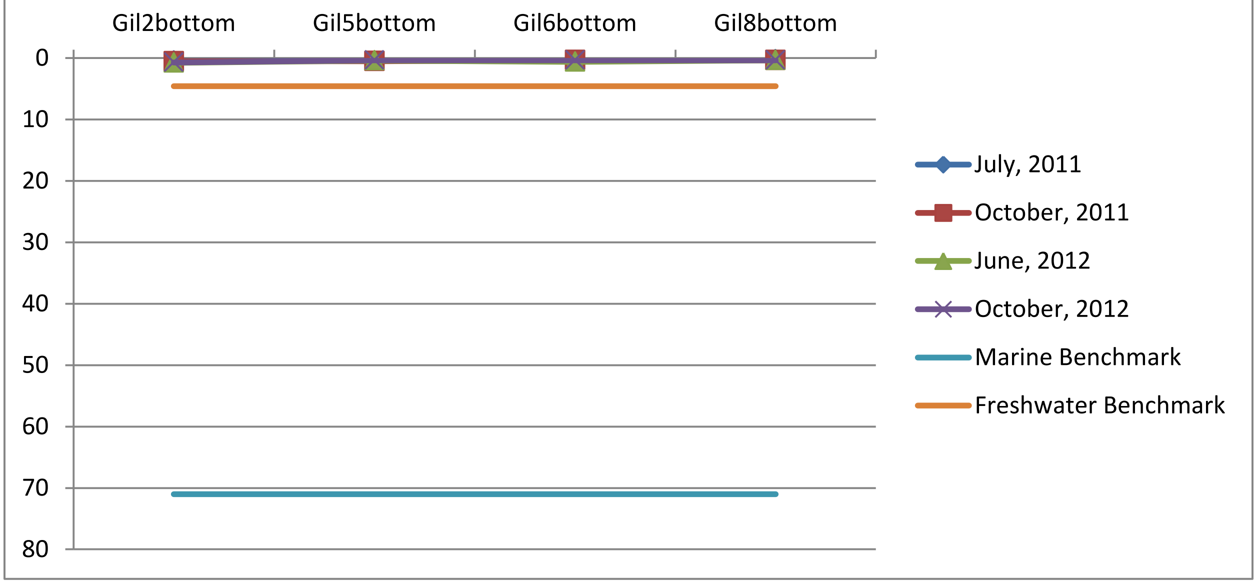


Figure 18
2011-2012 Gilbert Bay Oxic Stratum
Thallium Concentrations (µg/L)

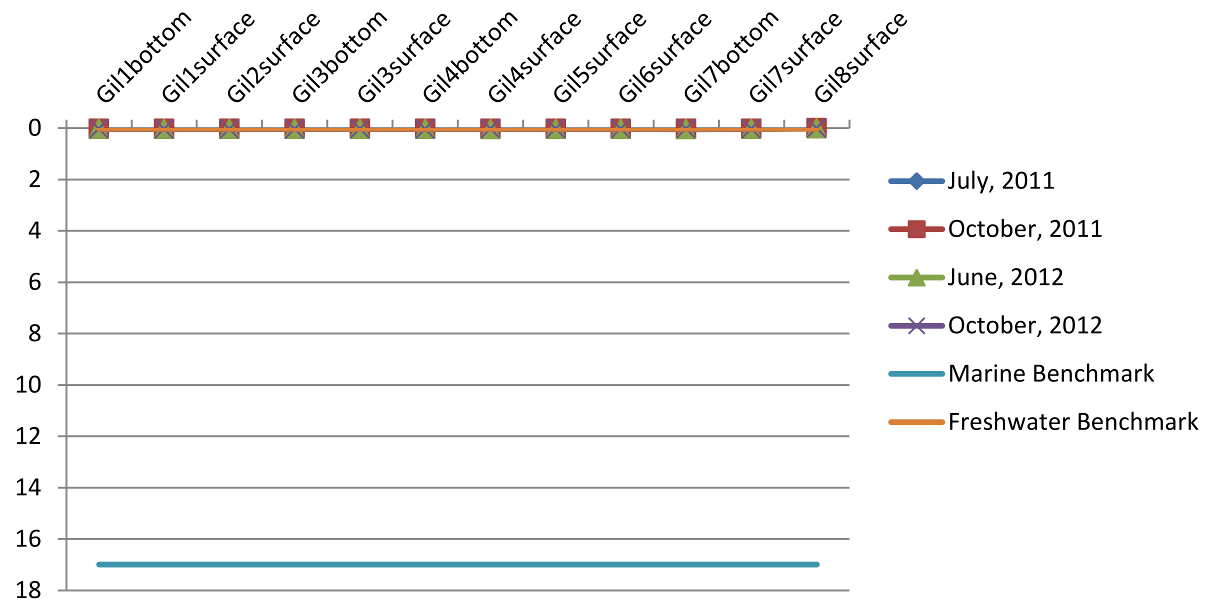


Figure 19
2011-2012 Gilbert Bay Deep Brine Stratum
Thallium Concentrations (µg/L)