5.0 Program Results

The previous section defined the objectives of the seven research projects identified by the Science Panel. This section provides a summary of the program's quality assurance protocol and the results and conclusions for each of the seven projects.

5.1 Quality Assurance

Quality assurance and collaboration were essential to enabling successful completion of the selenium program. DQOs, workplans, data, and summary reports were developed through a collaborative approach involving principal investigators, CH2M HILL, and the Science Panel. Each document was reviewed and discussed numerous times to ensure the project team was in consensus with the approach, results, and observations. Conditions that warranted changes in approach were reviewed and approved by the project team. Documents developed as part of the selenium program were reviewed by the project team and approved by the Science Panel prior to release to the public.

A detailed *Quality Assurance Project Plan* (CH2M HILL, 2006) was developed to define the process through which the environmental data would be collected for the selenium program to ensure they would be of the appropriate quality to achieve the DQOs defined for the program and each project. The *Quality Assurance Project Plan* also discusses specific protocols for sampling, sample handling and storage, chain of custody, laboratory analyses, data handling, data management, and data evaluation and assessment. It also specifies requirements for performance evaluations, corrective actions, and preventive maintenance of equipment.

5.2 Pending Results

A few final reports have not been received but are imminent and will be submitted as addendums to the existing reports. Results from Project 2B for brine shrimp, water, and seston during 2007 are included here as preliminary tables, but the final interpretive report for all 2006 through 2007 has not yet been received. A final report for Project 5, Brine Shrimp Kinetics Study, is due shortly once final experiments requested by the Science Panel have concluded. These experiments were intended to verify and provide additional detail to the information already in hand.

5.2.1 Summary of Results

Detailed workplans were developed by each project's principal investigator in conjunction with CH2M HILL and the Science Panel to reflect the project's DQOs (see Section 4.0). The *Selenium Program Manual* includes project DQOs, workplans, and SOPs for the six initial projects (CH2M HILL, 2006). Detailed discussion of project background, objectives, methods, and results are found in each project's final report, included in Appendices C through I of this document. Field and laboratory studies were initiated in May 2006 and generally ended in September 2007. Field and laboratory work for Projects 3 and 5 continued into the first quarter of 2008. Each principal investigator documented the methods used and results of the study, and provided discussion of and conclusions from the project in a final summary report. The project reports are included in the appendices. This section provides a summary of the results and observations for each project.

5.2.2 Project 1A, Concentration and Effects of Selenium in Shorebirds

Weber State University's Dr. John Cavitt completed the sampling program for Project 1A over two nesting seasons (2006 and 2007). The following provides a summary of data and results from Cavitt's reports, *Concentration and Effects of Selenium on Shorebirds* (Cavitt, 2008b) and *Selenium and Mercury Concentrations in Breeding Female American Avocets at Ogden Bay* (Cavitt, 2008b), both found in Appendix C.

2006 Sampling Season

Collections. Adult American avocets, avocet eggs, water, sediment, and dietary samples were collected from each of three colonies at Great Salt Lake (Antelope Island, Ogden Bay, and Saltair) (see Figure 5-1), and adult black-necked stilts and stilt eggs were collected from the Ogden Bay site. Of the three colonies, the Antelope Island colony was the only true open-water site; the Ogden Bay colony is where the Weber River flows into the lake along the eastern shore and the Saltair colony is adjacent to the Kennecott Utah Copper Corporation outfall on the southern shore.

Adult tissue analysis. Five American avocets were collected from each of three colonies at Great Salt Lake, and five black-necked stilts were collected from the Ogden Bay site. Selenium concentrations in blood and liver (shown in Table 5-1) were not different between stilts and avocets, between sexes, or among sites. Blood and liver selenium concentrations had a significant positive relationship when all samples were combined, but not for avocets alone (from all colonies), or for avocets from Antelope Island or Saltair. Overall mean blood selenium concentration was 29 micrograms per gram (µg/g) and ranged from 12 to 68 µg/g (n = 19; geometric mean = 27; 95 percent CI [on the arithmetic mean] = 22 - 36 µg/g); overall mean liver selenium concentration was 19 µg/g and ranged from 8.3 to 40 µg/g (n = 20; geometric mean = 18; 95 percent CI = 15 - 23 µg/g).

TABLE 5-1
Summary of Statistics for Selenium Analysis (µg/g dry weight) for Shorebirds
Collected at Great Salt Lake, 2006

Colony	Tissue	*n*	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Antelope Island	Blood	4	19.7	3.8	1.9	16	23	19.5
Ogden Bay	Blood	10	36.0	16.5	5.2	20	68	33.1
Saltair	Blood	5	23.5	8.8	3.9	12	34.7	22.1
Antelope Island	Liver	5	12.3	3.1	1.4	8.3	16	11.9
Ogden Bay	Liver	10	20.6	9.5	3.0	11	40	18.8
Saltair	Liver	5	23.6	8.7	3.9	15	38	22.5
Antelope Island	Egg	21	2.3	0.4	0.1	1.6	2.9	2.2
Ogden Bay	Egg	39	2.3	0.7	0.1	1.2	3.6	2.2
Saltair	Egg	8	5.6	2.3	0.8	2.9	9.2	5.1

Body mass. There was no significant difference between body mass of males and females. Although there was a significant negative relationship between liver selenium concentration and body mass, body mass was not significantly related to blood selenium.

Diet. The diet of American avocets varied by location. Avocets at Antelope Island, where there are no freshwater sources, had 100 percent brine flies in their digestive tracts. At Ogden Bay, avocet digestive tracts contained 66 percent midges, 20 percent brine flies, and the remaining 14 percent various other invertebrates. Avocets from Saltair contained 40 percent midges, 36 percent brine flies, and the remaining 24 percent were various other invertebrates. Black-necked stilt digestive tracts from Ogden Bay contained 50 percent various beetles, 30 percent water boatmen, and 20 percent brine flies.

Selenium concentrations in invertebrates ranged from 0.3 µg/g in snails from Ogden Bay to 3.8 µg/g in brine flies from Saltair; however, brine fly selenium concentration did not significantly differ among sites.

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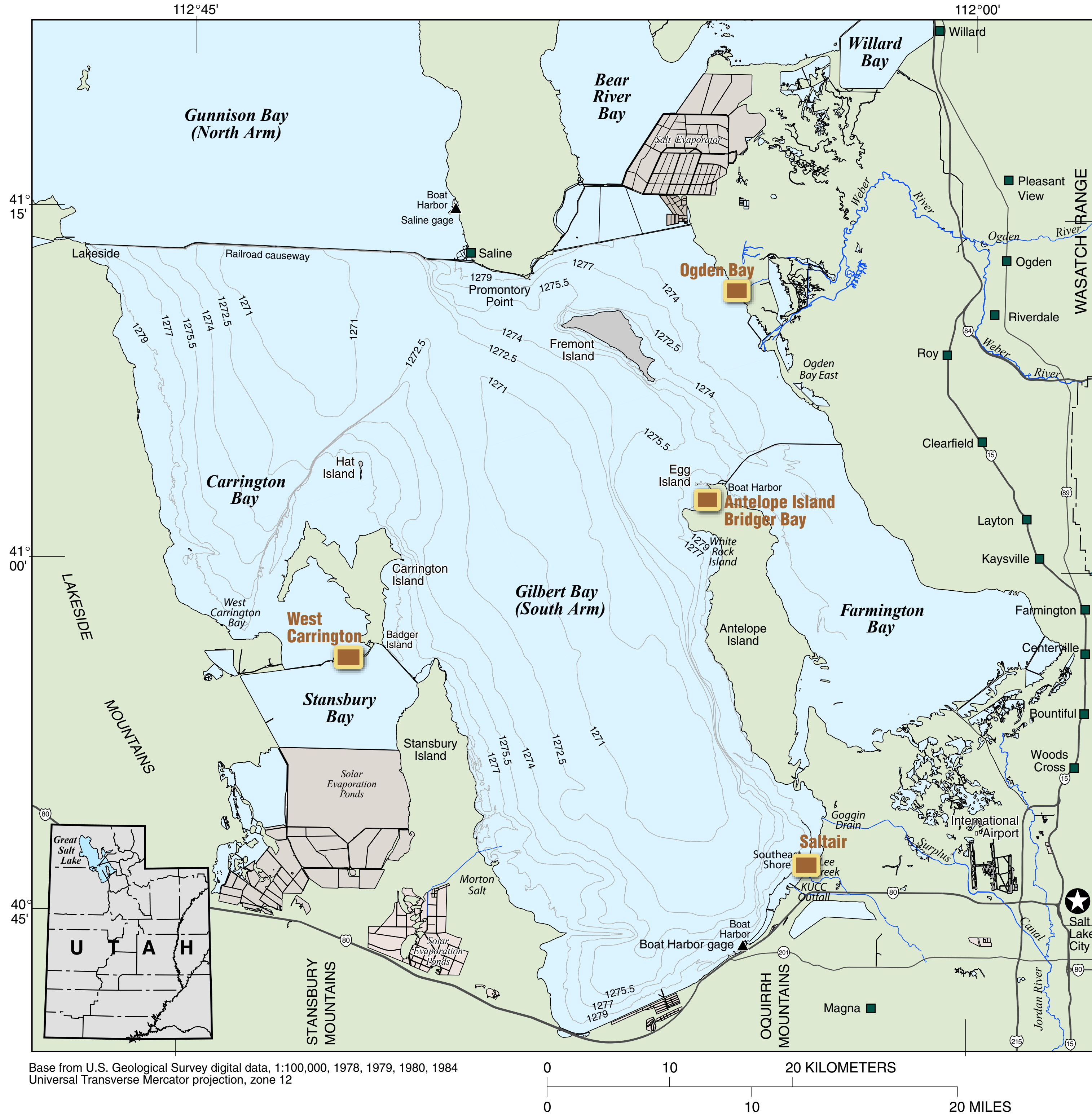

FIGURE 5-1

Project 1A – Shorebirds Sampling Locations

Great Salt Lake Water Quality Studies

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Water and sediments. Three water and three sediment samples were collected from each colony site. The selenium concentration in water collected from Saltair (mean = 34 µg/L) was significantly higher than in water collected from the other sites (Antelope Island mean = 0.29 µg/L and Ogden Bay mean = 0.22 µg/L). Sediment selenium was also higher (P = 0.07) at Saltair (mean = 1.7 µg/g) than from Antelope Island (mean = 0.4 µg/g) and Ogden Bay (mean = 0.4 µg/g).

Breeding productivity. Breeding (nest) success at Antelope Island was 0.94 with predation as the most common cause of nest failure (50 percent); at Ogden Bay, nest success was 0.97 and the most common cause of nest failure was flooding (nearly 50 percent); and at Saltair, no young were produced due to flooding.

Egg collection, examination, and selenium analysis. Seventy eggs (53 avocet and 17 stilt) were collected, and 68 were analyzed for total selenium (see Table 5-1). No abnormalities were observed in embryos. Mass of American avocet eggs did not differ among sites. The median selenium concentration in eggs from Saltair (n = 8, median = 5.4 µg/g) was significantly higher than median concentrations in those from Antelope Island (n = 21, median = 2.2 µg/g) and Ogden Bay (n = 39, median = 2.5 µg/g). Overall mean egg selenium concentration was 2.7 µg/g and ranged from 1.2 to 9.2 µg/g (n = 68; geometric mean = 2.4; 95 percent CI [on the arithmetic mean] = 2.3 – 3.0 µg/g).

2007 Sampling Season

Collections. Adult American avocets, avocet eggs, and diet samples were collected in 2007 from Ogden Bay (see Figure 5-1).

Breeding productivity. At the Ogden Bay breeding colony, 231 nests were initiated during 2007 and only 19 nests produced young. This was mostly due to losses from two flooding events and nest abandonment.

Adult collection and tissue analysis. Four female American avocets were trapped on their nests at the Ogden Bay colony. The Ogden Bay colony is located where the Weber River flows into the lake along the eastern shore. Elevated blood and liver selenium concentrations were found in all avocets, shown in Table 5-2. There was no significant relationship between blood and liver selenium concentrations in these birds. Selenium concentrations tended to be higher in avocets collected from Ogden Bay in 2006 than in 2007 (P = 0.08), but liver selenium was similar between years. Mercury concentrations in blood and liver, shown in Table 5-2, were not significantly associated with selenium concentrations. Body mass was not significantly associated with either mercury or selenium in blood or liver in these four birds.

TABLE 5-2
Summary Statistics for Selenium and Mercury Analyses (µg/g dry weight) for American Avocets (Shorebirds)
Collected at Great Salt Lake, 2007

Colony	Tissue	*n*	Mean	95% CI[2]	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Selenium									
Ogden Bay	Blood	4	17.3	8.4 - 26	5.6	2.8	12.0	23.0	16.6
Ogden Bay	Liver	4	13.3	8.7 - 18	2.9	1.4	11.0	17.0	13.0
Ogden Bay	Egg[1]	4	2.2	1.7 - 2.6	0.3	0.1	1.8	2.4	2.1
Mercury									
Ogden Bay	Blood	4	0.9	0.7 - 1.1	0.1	0.1	0.7	1.0	0.9
Ogden Bay	Liver	4	2.0	1.2 - 2.7	0.5	0.2	1.7	2.7	1.9
Ogden Bay	Egg[1]	4	0.3	0.08 - 0.5	0.1	0.1	0.1	0.4	0.3

NOTES:
[1] Pooled egg selenium and mercury.
[2] Based on arithmetic mean.

Egg collection, examination, and selenium analysis. Eleven eggs were collected from the four nests where females were trapped, and two eggs were collected from the oviducts of females that were captured on their nests. Selenium results for eggs from each nest were pooled and the mean egg selenium for each nest was used in the analyses. There was a trend towards a positive relationship between blood and egg selenium ($P = 0.07$) but no relationship was observed between liver and egg selenium, based on blood and liver selenium from females trapped on the nests and mean egg selenium from each nest. In addition, no relationship was observed between mercury in blood or liver and egg mercury concentrations. Selenium and mercury concentrations in eggs collected from oviducts of two females were similar to those in eggs from their nests.

Invertebrate analysis. Selenium concentration in a sample of brine fly larvae was 1.6 µg/g and in a sample of adult flies it was 1.2 µg/g. Mercury concentration was 0.1 µg/g in the adults and below the method detection limit in larvae.

5.2.3 Project 1B, Concentration and Effects of Selenium in Gulls, Grebes, and Ducks

The sampling program for Project 1B was largely completed by Utah State University's Dr. Michael Conover over two nesting seasons, 2006 and 2007. Gulls were sampled in both 2006 and 2007. Eared grebes were sampled in the fall of 2006. Goldeneye samples were collected in the 2005 through 2006 fall to winter season. The following provides a summary of data and results from Conover et al. (2008a, 2008b, and 2008c) found in Appendix D.

California Gulls

Collections. Adult California gulls, eggs, water, sediment, and diet samples were collected from three colonies in both 2006 (Hat Island, Antelope Island, and Great Salt Lake Minerals

[GSLM]) and 2007 (Hat Island, GSLM, and an offsite freshwater colony at Neponset Reservoir) (see Figure 5-2).

Food analyses for adults. Of the gulls collected from Great Salt Lake colonies, only one contained more than a single kind of food item (60 percent brine shrimp, 35 percent corixids, and 5 percent midges). Most of the others contained 100 percent brine shrimp (about 75 percent); fewer contained brine fly larvae (7 percent) or corixids (7 percent) in their digestive tracts. Besides brine shrimp, brine flies, and corixids, they had also eaten midge larvae, earthworms, carp, and various types of garbage. Only gulls from GSLM contained corixids and midge larvae. The eight gulls from Neponset Reservoir that had food in their esophagus had fed on garbage and terrestrial insects.

Food items collected from GSLM and Hat Island were analyzed for selenium and mercury. Selenium concentrations in brine shrimp were highest at the Hat Island colony. Mercury levels in brine shrimp were similar between GSLM and Hat Island colonies. Brine shrimp collected by Dr. Conover during 2006 contained higher selenium concentrations than samples collected from the same colonies during 2007.

Selenium analyses of adults collected during 2006 through 2007. Because no male-female differences were found in blood or liver selenium concentrations, results from males and females were combined. Selenium concentrations in gulls eating various food items also were not different. Among individual gulls, selenium concentrations in blood and liver were highly correlated.

Among gulls collected from different colonies, a significant difference in the concentration of selenium in blood was found, but not in livers. In both 2006 and 2007, selenium concentrations were highest in blood of gulls collected at the GSLM colony, which is near where water from the Bear River flows into Great Salt Lake, and lowest in gulls from the Antelope Island colony in 2006 and Hat Island in 2007. Gulls from the Hat Island colony had intermediate concentrations of selenium in 2006 and Neponset gulls had intermediate levels of selenium in 2007, as shown in Table 5-3. This pattern of the highest selenium concentrations being recorded at the GSLM colony was true for selenium concentrations in blood, liver, eggs, and sediment, although differences among colonies were significant only for blood. For gulls collected at the GSLM colony, those collected during 2006 had higher selenium concentrations in their blood than those from 2007 ($F = 4.57$; *d.f.* = 1, 22; $P = 0.04$), but selenium levels in their livers were similar ($F = 0.59$; *d.f.* = 1, 22; $P = 0.59$). Overall mean blood selenium concentration (both years and all locations combined) was 17 µg/g and ranged from 4.8 to 46 µg/g ($n = 71$; geometric mean = 15; 95 percent CI [on the arithmetic mean] = 14.7 - 19.1 µg/g). Overall mean liver selenium concentration was 8.2 µg/g and ranged from 3.9 to 15 µg/g ($n = 71$; geometric mean = 7.8; 95 percent CI = 7.6 - 8.8 µg/g).

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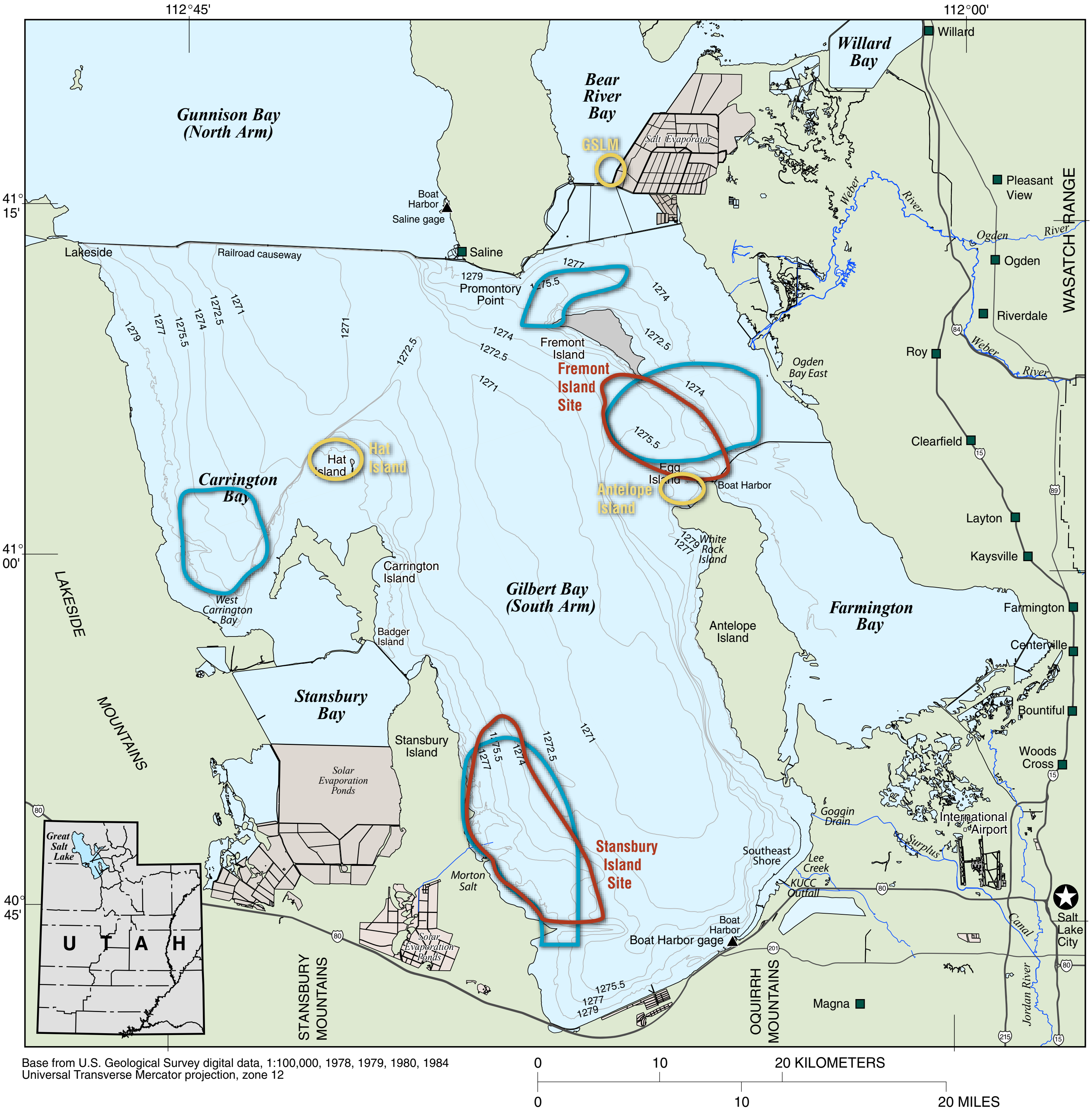

LEGEND

- Goldeneyes
- Eared Grebes
- California Gulls

Locations are not to scale.

FIGURE 5-2
Project 1B – Gull, Eared Grebe, and Goldeneye Sampling Locations
Great Salt Lake Water Quality Studies
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TABLE 5-3
Summary Statistics for Selenium and Mercury Analyses (µg/g dry weight) for California Gulls Collected at Great Salt Lake, 2006 and 2007

Colony	Tissue	Year	*n*	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Selenium									
Antelope Island	Blood	2006	12	13.9	6.2	1.8	6.4	25.0	12.6
Great Salt Lake Minerals	Blood	2006	11	25.1	10.5	3.2	5.0	37.0	22.1
Great Salt Lake Minerals	Blood	2007	12	20.9	11.9	3.4	8.7	45.7	18.2
Hat Island	Blood	2006	12	16.0	6.9	2.0	6.3	29.0	14.6
Hat Island	Blood	2007	12	10.7	5.0	1.4	4.8	23.0	9.8
Neponset	Blood	2007	12	15.5	7.9	2.3	5.0	32.2	13.8
Antelope Island	Liver	2006	12	7.3	2.4	0.7	4.0	13.0	7.0
Great Salt Lake Minerals	Liver	2006	11	9.2	2.9	0.9	3.9	13.0	8.8
Great Salt Lake Minerals	Liver	2007	12	9.3	3.3	1.0	6.2	15.0	8.8
Hat Island	Liver	2006	12	7.8	2.2	0.6	5.6	13.0	7.6
Hat Island	Liver	2007	12	7.2	1.4	0.4	4.7	9.7	7.1
Neponset	Liver	2007	12	8.3	2.4	0.7	5.6	13.0	8.0
Antelope Island	Egg	2006	11	2.8	0.5	0.2	2.1	4.1	2.7
Great Salt Lake Minerals	Egg	2006	11	3.4	0.5	0.2	2.6	4.3	3.3
Hat Island	Egg	2006	11	2.8	0.5	0.2	2.0	3.4	2.8
Neponset	Egg	2007	12	2.8	0.5	0.1	2.2	3.8	2.7
Mercury									
Great Salt Lake Minerals	Blood	2007	12	3.0	2.1	0.6	0.6	7.6	2.3
Hat Island	Blood	2007	12	3.0	0.9	0.3	0.6	4.3	2.7
Neponset	Blood	2007	12	1.3	1.0	0.3	0.2	3.2	0.8
Great Salt Lake Minerals	Liver	2007	12	4.2	3.3	0.9	0.6	9.9	3.0
Hat Island	Liver	2007	12	5.6	2.4	0.7	0.8	9.8	4.9
Neponset	Liver	2007	12	2.4	2.0	0.6	0.3	5.9	1.6
Neponset	Egg	2007	12	0.3	0.2	0.1	0.1	0.7	0.2

Mercury analyses of adults during 2007. Blood selenium concentrations were correlated with mercury levels in blood but not livers. Selenium concentrations in livers were not correlated with mercury levels in either the blood or the liver.

Mercury concentrations in blood and liver were similar in gulls collected from the Hat Island and GSLM colonies. However, gulls from Neponset Reservoir had significantly lower mercury concentrations in blood and liver than gulls from Hat Island and GSLM colonies.

Body mass. Male gulls were significantly heavier than female gulls and neither male nor female body mass was significantly correlated with selenium or mercury in blood or liver.

Selenium and mercury analyses of water and sediment. Only single water and sediment samples were analyzed from each colony. Waterborne selenium concentration was higher at Hat Island than at the other Great Salt Lake colonies in 2006 but not in 2007.

Selenium and mercury analyses of eggs. Selenium concentrations did not differ among eggs collected from the different Great Salt Lake colonies. The overall mean selenium concentration in eggs was 2.9 µg/g and ranged from 2.0 to 4.3 µg/g (*n* = 45; geometric mean = 2.9; 95 percent CI [on the arithmetic mean] = 2.8 - 3.1 µg/g). Mercury was analyzed only for eggs from Neponset Reservoir in 2007. Mean mercury concentration in these eggs was 0.26 µg/g and ranged from 0.07 to 0.70 µg/g (*n* = 12; geometric mean = 0.21; 95 percent CI = 0.14 - 0.38 µg/g).

Analyses of eggs and chicks for viability and deformities. Among the sample of 24 eggs randomly sampled from 3-egg clutches during the late incubation period from Great Salt Lake colonies (72 eggs total), all contained developing late-incubation stage embryos except a single egg that came from the GSLM colony. No embryo deformities were found in any eggs collected or 100 newly hatched chicks observed in the colonies.

Eared Grebes

Collections. Eared grebes were collected in September and November 2006 from near Antelope Island and near Stansbury Island (see Figure 5-2).

Food analyses. All grebes had a mass of feather fragments and brine shrimp cysts in their gizzard but individual food items in the gizzard could not be identified. Identification of other food items was limited to items in the birds' esophagus. During September, grebes fed primarily on adult brine shrimp and adult brine flies. During November, food items in the grebes were almost entirely adult brine shrimp.

Selenium and mercury analyses. Selenium concentrations in livers (Table 5-4) were lower in grebes collected in September than in November and they were also lower in grebes collected near Antelope Island than those collected near Stansbury Island. Juveniles had lower selenium concentrations than adults but concentrations in males and females were not different. In blood, selenium concentrations differed only by collection site (Antelope Island blood selenium was lower than in blood from Stansbury Island birds). Mercury concentration in the blood of grebes was lower in those collected in September than in November and lower in birds collected near Antelope Island than in those from near Stansbury Island. Juveniles had lower blood mercury than adults but males and females were not different.

TABLE 5-4
Summary Statistics for Selenium and Mercury Analyses (µg/g dry weight) for Eared Grebes
Collected at Great Salt Lake, 2006

Location	Tissue	Month	Age	*n*	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Selenium										
Antelope Island	Blood	Sept	Adult	6	24.8	11.0	4.5	6.8	36.3	21.9
Antelope Island	Blood	Sept	Juv	6	15.3	15.9	6.5	0.3	45.9	7.6
Antelope Island	Blood	Nov	Adult	4	14.0	3.2	1.6	10.3	17.8	13.7
Antelope Island	Blood	Nov	Juv	7	12.9	5.3	2.0	1.1	16.1	10.2
Stansbury Island	Blood	Sept	Adult	4	16.9	9.8	4.9	7.7	25.6	14.6
Stansbury Island	Blood	Sept	Juv	6	16.6	9.4	3.9	6.8	32.7	14.6
Stansbury Island	Blood	Nov	Adult	8	35.5	12.1	4.3	22.2	55.3	33.8
Stansbury Island	Blood	Nov	Juv	2	28.7	4.2	3.0	25.7	31.7	28.5
Antelope Island	Liver	Sept	Adult	6	13.6	2.7	1.1	10.7	16.8	13.3
Antelope Island	Liver	Sept	Juv	9	7.7	2.2	0.7	5.0	11.9	7.5
Antelope Island	Liver	Nov	Adult	5	7.5	0.7	0.3	7.0	8.7	7.4
Antelope Island	Liver	Nov	Juv	10	7.2	0.5	0.2	6.4	8.2	7.1
Stansbury Island	Liver	Sept	Adult	4	10.5	6.8	3.4	5.6	20.3	9.1
Stansbury Island	Liver	Sept	Juv	11	8.1	2.1	0.6	5.5	12.7	7.8
Stansbury Island	Liver	Nov	Adult	13	21.8	4.1	1.1	17.2	28.4	21.4
Stansbury Island	Liver	Nov	Juv	2	21.0	4.5	3.2	17.8	24.2	20.8
Mercury										
Antelope Island	Blood	Sept	Adult	6	5.3	1.8	0.8	3.2	8.2	5.1
Antelope Island	Blood	Sept	Juv	6	4.8	3.7	1.5	0.1	8.6	2.2
Antelope Island	Blood	Nov	Adult	4	4.1	0.7	0.3	3.2	4.7	4.1
Antelope Island	Blood	Nov	Juv	7	3.2	1.5	0.6	0.1	4.3	2.0
Stansbury Island	Blood	Sept	Adult	4	5.5	0.9	0.4	4.8	6.7	5.5
Stansbury Island	Blood	Sept	Juv	6	6.7	1.8	0.7	3.5	8.6	6.4
Stansbury Island	Blood	Nov	Adult	8	14.3	1.9	0.7	11.5	18.0	14.2
Stansbury Island	Blood	Nov	Juv	2	12.3	4.3	3.1	9.3	15.4	11.9
Stansbury Island	Liver	Sept	Adult	4	6.9	2.7	1.4	4.6	10.5	6.5
Stansbury Island	Liver	Sept	Juv	6	12.2	10.1	4.1	4.5	32.2	9.9
Stansbury Island	Liver	Nov	Adult	9	15.4	6.2	2.1	5.9	28.0	14.2
Stansbury Island	Liver	Nov	Juv	1	17.9	–	–	17.9	17.9	17.9

When all birds were combined, mean selenium concentration in blood was 21 µg/g, and concentrations ranged from 0.3 to 55 µg/g (*n* = 43; geometric mean = 16; 95 percent CI [on the arithmetic mean] = 17 – 25 µg/g); in liver it was 12 µg/g and ranged from 5.0 to 28 µg/g (*n* = 60; geometric mean = 13; 95 percent CI = 10 – 14 µg/g). Mean mercury concentration in blood was 6.9 µg/g and concentrations ranged from 0.05 to 18 µg/g (*n* = 43; geometric mean = 4.9; 95 percent CI = 5.6 – 8.4 µg/g); in liver it was 13 µg/g and ranged from 4.5 to 32 µg/g (*n* = 20; geometric mean = 11; 95 percent CI = 9.4 – 16 µg/g). When all grebes were included, there were significant positive relationships between selenium concentrations in blood and liver and between selenium and mercury concentrations in blood. When juvenile males, adult males, juvenile females, and adult females collected in November were analyzed separately, selenium concentrations in blood were correlated with selenium concentrations in liver in all sex and age groups. In males, selenium concentrations in the liver and blood were correlated with mercury levels in blood but not mercury levels in livers. In females, selenium concentrations were not associated with mercury concentrations.

When all grebes were combined, a positive relationship was seen between body mass and selenium concentrations in blood and liver and mercury concentrations in liver. This association is undoubtedly a result of increased mass of the birds while they were on the lake and the increased selenium and mercury concentrations in the late-season birds. When only grebes collected in November were considered and each age and sex group was analyzed separately, body mass was not correlated with selenium or mercury concentrations with one exception—mass of juvenile females was highly positively correlated with mercury blood levels.

Common Goldeneyes

Collections. Common goldeneyes were collected in two general areas (Fremont Island and Stansbury Island) in November through December 2005 and January through March 2006 (see Figure 5-2).

Selenium and mercury analyses. Selenium and mercury concentrations, shown in Table 5-5, in both livers and blood did not vary by age, but collection site (Fremont Island versus Stansbury Island) affected selenium concentrations in liver and also mercury concentrations in both liver and blood. When all birds were combined, mean selenium concentration in blood was 17 µg/g and concentrations ranged from 1.1 to 33 µg/g (*n* = 40; geometric mean = 14; 95 percent CI [on the arithmetic mean] = 14 – 19 µg/g); in livers the mean for selenium was 15 µg/g and concentrations ranged from 3.6 to 34 µg/g (*n* = 40; geometric mean = 13; 95 percent CI = 13 – 18 µg/g). Mean mercury concentration in blood was 14 µg/g and concentrations ranged from 0.6 to 30 µg/g (*n* = 40; geometric mean = 12; 95 percent CI = 12 – 17 µg/g); in liver the mean was 39 µg/g and concentrations ranged from 1.6 to 114 µg/g (*n* = 40; geometric mean = 11; 95 percent CI = 30 – 48 µg/g).

TABLE 5-5
Summary Statistics for Selenium and Mercury Analyses (µg/g dry weight) for Common Goldeneyes
Collected at Great Salt Lake, November–December 2005 and January–March 2006

Location	Tissue	Month	*n*	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Selenium									
Fremont Island	Blood	Nov	1	4.3	–	–	4.3	4.3	4.3
Fremont Island	Blood	Dec	9	14.7	6.0	2.0	7.8	28.0	13.8
Fremont Island	Blood	Jan	9	20.6	8.0	2.7	11.0	33.0	19.3
Stansbury Island	Blood	Nov	1	3.5	–	–	3.5	3.5	3.5
Stansbury Island	Blood	Dec	1	7.8	–	–	7.8	7.8	7.8
Stansbury Island	Blood	Feb	8	19.4	4.3	1.5	13.0	24.0	18.9
Stansbury Island	Blood	Mar	11	16.4	9.1	2.7	1.1	32.0	12.5
Fremont Island	Liver	Nov	1	5.8	–	–	5.8	5.8	5.8
Fremont Island	Liver	Dec	9	9.4	3.0	1.0	5.7	14.0	8.9
Fremont Island	Liver	Jan	9	17.4	6.4	2.1	7.2	25.2	16.2
Stansbury Island	Liver	Nov	1	4.4	–	–	4.4	4.4	4.4
Stansbury Island	Liver	Dec	1	5.5	–	–	5.5	5.5	5.5
Stansbury Island	Liver	Feb	8	18.6	3.5	1.2	11.0	22.1	18.3
Stansbury Island	Liver	Mar	11	18.7	9.4	2.8	3.6	34.0	15.6
Mercury									
Fremont Island	Blood	Nov	1	2.2	–	–	2.2	2.2	2.2
Fremont Island	Blood	Dec	9	8.5	2.9	1.0	3.4	13.4	7.9
Fremont Island	Blood	Jan	9	14.2	3.5	1.2	9.0	19.0	13.8
Stansbury Island	Blood	Nov	1	4.6	–	–	4.6	4.6	4.6
Stansbury Island	Blood	Dec	1	8.5	–	–	8.5	8.5	8.5
Stansbury Island	Blood	Feb	8	17.5	3.7	1.3	13.2	23.2	17.2
Stansbury Island	Blood	Mar	11	19.4	10.1	3.0	0.6	30.0	13.6
Fremont Island	Liver	Nov	1	2.8	–	–	2.8	2.8	2.8
Fremont Island	Liver	Dec	9	14.4	7.7	2.6	5.4	30.0	12.8
Fremont Island	Liver	Jan	9	36.9	14.3	4.8	10.8	59.1	33.6
Stansbury Island	Liver	Nov	1	5.1	–	–	5.1	5.1	5.1
Stansbury Island	Liver	Dec	1	11.6	–	–	11.6	11.6	11.6
Stansbury Island	Liver	Feb	8	51.2	15.8	5.6	23.0	71.2	48.6
Stansbury Island	Liver	Mar	11	60.1	35.8	10.8	1.6	114.0	38.9

Significant relationships were identified between selenium concentrations in liver and selenium in blood or mercury concentrations in liver; selenium and mercury in blood and liver were all highly correlated with each other. Body mass and liver mass, shown in Table 5-6, were not correlated with concentrations of selenium or mercury in either blood or liver. Fat mass was negatively correlated with selenium concentrations in liver, mercury concentrations in liver, and mercury concentrations in blood.

Among Fremont Island ducks, selenium and mercury concentrations in both liver and blood samples varied by collection date; but this was not true for Stansbury Island ducks. Body mass, liver mass, and fat mass did not vary by collection date for either Fremont Island or Stansbury Island ducks.

TABLE 5-6
Summary Statistics for Body Mass, Liver Mass, and Fat Mass (grams wet weight) for Common Goldeneyes Collected at Great Salt Lake, November–December 2005 and January–March 2006

Location	Month	n	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Body Mass								
Fremont Island	Nov	1	1150.0	–	–	1150.0	1150.0	1150.0
Fremont Island	Dec	9	1120.4	106.6	35.6	962.0	1246.0	1115.8
Fremont Island	Jan	9	1105.9	85.6	28.5	1038.0	1254.0	1103.1
Stansbury Island	Nov	1	1094.0	–	–	1094.0	1094.0	1094.0
Stansbury Island	Dec	1	1191.0	–	–	1191.0	1191.0	1191.0
Stansbury Island	Feb	8	1052.4	73.9	26.1	954.0	1159.0	1050.1
Stansbury Island	Mar	11	1048.7	71.3	21.5	921.0	1155.0	1046.5
Liver Mass								
Fremont Island	Nov	1	27.0	–	–	27.0	27.0	27.0
Fremont Island	Dec	9	35.2	6.6	2.2	26.0	48.0	34.7
Fremont Island	Jan	9	32.4	7.1	2.4	23.0	47.0	31.8
Stansbury Island	Nov	1	42.0	–	–	42.0	42.0	42.0
Stansbury Island	Dec	1	36.0	–	–	36.0	36.0	36.0
Stansbury Island	Feb	8	26.3	3.5	1.2	22.0	32.0	26.0
Stansbury Island	Mar	11	32.8	5.8	1.7	23.0	43.0	32.3
Fat Mass								
Fremont Island	Nov	1	17.0	–	–	17.0	17.0	17.0
Fremont Island	Dec	9	14.2	7.8	2.6	5.4	28.4	12.5
Fremont Island	Jan	9	10.6	3.1	1.0	6.1	14.8	10.2
Stansbury Island	Nov	1	9.5	–	–	9.5	9.5	9.5
Stansbury Island	Dec	1	19.0	–	–	19.0	19.0	19.0
Stansbury Island	Feb	8	8.3	5.3	1.9	4.9	20.7	7.4
Stansbury Island	Mar	11	7.8	5.6	1.7	3.7	21.1	6.5

5.2.4 Project 2A, Synoptic Survey of Selenium in Periphyton and Brine Fly Larvae from the Benthic Zone

The sampling program for Project 2A was completed by Utah State University's Dr. Wayne Wurtsbaugh during 2006. The following provides a summary of data and results from Wurtsbaugh's *Preliminary Analyses of Selenium Bioaccumulation in Benthic Food Webs of the Great Salt Lake, Utah* (2007), found in Appendix E.

Brine fly larvae and pupae were sampled from biostromes and shore-zone sediments from locations near the northern and southern ends of Antelope Island (Bridger Bay and Gilbert South) during June 2006. The periphyton algae of the biostromes and the bulk sediment were also characterized for selenium content and a new sampling method for brine flies on biostromes proved to be a useful tool for work in Great Salt Lake. Through additional tests performed in April 2007, it was confirmed that acid digestion of the biostrome calcareous material provided the best measure of periphyton selenium, undiluted by the inorganic matrix. Acidified biostrome periphyton selenium concentrations exceeded those of nearby surface sediments, and both were significantly higher than either sand or unacidified biostromes. In total, Wurtsbaugh estimated that about 90 percent of the lake's selenium mass is contained in the top 2 cm of lake sediment and biostrome material (see Wurtsbaugh, 2007, Table 5).

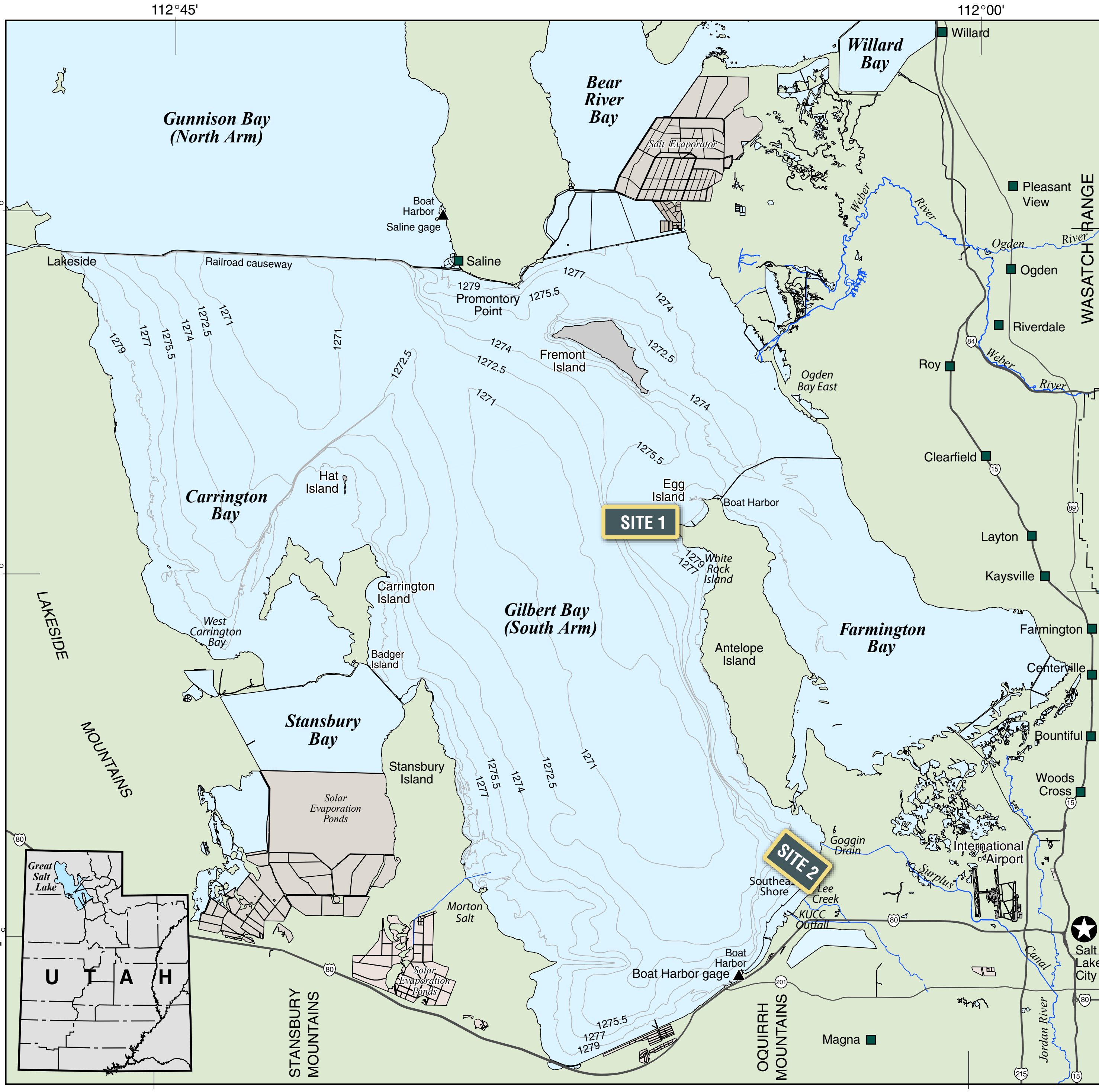
The limited number of biostrome, sediment, and larvae/pupae samples did not provide adequate information to develop a predictive relationship between the selenium in brine fly food sources and the brine fly tissue. Therefore, geometric mean values of the selenium concentrations in acidified biostromes, shore-zone sediment, and brine fly larvae and pupae were taken from this study to incorporate into the food web model. Brine fly larvae were found to be much more abundant on the biostrome structures than on nearby sand or mud substrates, and it is appropriate that the selenium in biostrome periphyton be used in the model as the representative food for the larvae.

Selenium concentrations in the brine flies ranged from 0.9 to 2.0 micrograms of selenium per gram (µg Se/g) and varied between life stages and sites. Concentrations increased from larvae (1.3 µg Se/g) to pupae (1.5 µg Se/g), and this difference was significant (P less than 0.05). Concentrations were higher in adult flies (1.8 µg Se/g) than in pupae, but there were insufficient samples (three) to determine if this was significant. A two-way analysis of variance indicated that the brine flies in Bridger Bay (1.6 µg Se/g) had significantly higher concentrations of selenium than did those in Gilbert South (1.3 µg Se/g) (P less than 0.001).

Figure 5-3 shows a map of brine fly and biostrome sampling locations. Table 5-7 summarizes selected results.

TABLE 5-7
Key Brine Fly Results from 2006–2007
Great Salt Lake Studies: Ranges of Values

	Water concentrations (µg Se/L)	Sediment concentrations (µg Se/g dw)	Tissue concentrations (µg Se/g dw)
Water/sediment	0.37 – 0.43	1.4 – 9.8	
Brine fly larvae			0.9 – 1.5
Brine fly pupae			1.1 – 2.0
Brine fly adults			1.8 – 1.9
Biostrome periphyton			0.9 – 2.2



Base from U.S. Geological Survey digital data, 1:100,000, 1978, 1979, 1980, 1984
Universal Transverse Mercator projection, zone 12

0 10 20 KILOMETERS
0 10 20 MILES

FIGURE 5-3
Project 2A – Benthic Zone Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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5.2.5 Project 2B, Synoptic Survey of Selenium in Water, Seston, and Brine Shrimp

The sampling program for Project 2B was completed by Brad Marden during 2006 and 2007. The following provides a summary of data and results from Marden's *Project 2B: Synoptic Survey of the Pelagic Zone: Selenium in Water, Seston, and Artemia* (originally with 2006 results, only) and his 2007 update found in Appendix F. The final 2006 through 2007 summary report of all data is still pending.

Brad Marden's data on brine shrimp and lake characteristics included data on water quality, seston chemistry, chlorophyll concentrations, algal cell counts, complete density estimates of brine shrimp by life stage, and brine shrimp selenium content.

The brine shrimp displayed a characteristic seasonal cycle of abundance during the 2006 through 2007 data collection period that is typical of a generally "healthy" population. The phytoplankton was also found to be typical of the lake, with the midsummer community dominated by the chlorophyte *Dunaliella* sp. Selenium concentrations in water were not significantly variable spatially but changed seasonally, with a net increase of 0.1 to 0.2 µg Se/L for the lake water column over the period of study. Similarly, seston and brine shrimp selenium concentrations variably increased over the period of study. However, no statistically significant relationships were found between brine shrimp selenium concentrations and those in water or seston in the 2006 result summary or in the analysis of data from combined years. The 2007 results indicated more elevated brine shrimp tissue selenium concentrations than 2006. Those 2007 values (upper ends of ranges, Table 5-8) were all analyzed from filters in contrast to the values from 2006, without the use of filters, that never exceeded 3.5 mg Se/kg dry weight (dw). The change in methods and subsequent shift to higher brine shrimp concentrations suggest that the 2007 brine shrimp values should be used as most representative of current lake conditions.

Figure 5-4 shows a map of sampling locations for the brine shrimp study. Table 5-8 summarizes selected results.

TABLE 5-8
Brine Shrimp Results from 2006–2007
Great Salt Lake Studies: Ranges of Values

	Water concentrations (µg Se/L)	Tissue concentrations (µg Se/g dw)
Water	0.398 – 0.899	
Adults/Juveniles		0.31 – 7.1
Nauplii and cysts		0.09 – 5.4
Seston		0.29 – 4.5

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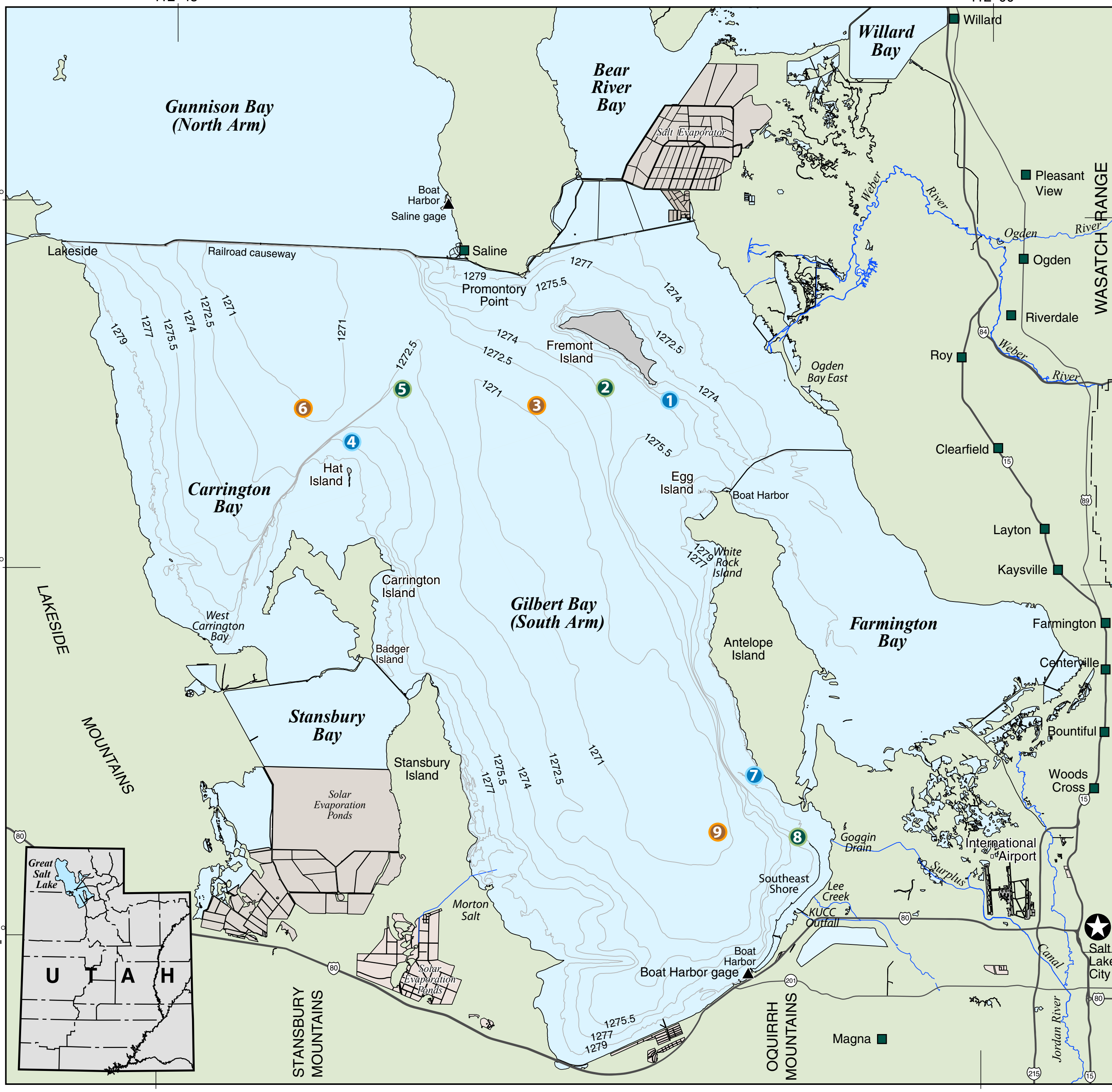

Base from U.S. Geological Survey digital data, 1:100,000, 1978, 1979, 1980, 1984
Universal Transverse Mercator projection, zone 12

0 10 20 KILOMETERS
0 10 20 MILES

LEGEND

- 1 - 3 Meter Deep Location
- 5 - 6 Meter Deep Location
- 8 - 9 Meter Deep Location

FIGURE 5-4
Project 2B – Pelagic Zone Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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5.2.6 Project 3, Measurement of Selenium Loads to Great Salt Lake

The sampling program for Project 3 was completed by the USGS's Dr. David Naftz over a 15-month period in 2006 and 2007. The following provides a summary of data and results from USGS's *Estimation of selenium loads entering the south arm of Great Salt Lake, Utah: Final Report* (Naftz et al., 2008), found in Appendix G.

Six gages were operated for water quality sampling and flow measurements, and standard USGS models (LOADEST) were used to match statistically significant loading models to the measured loads at each gage to produce daily loading estimates over the period of record. Total estimated selenium influent load was 1,540 kg, with an annual (May 2006 to April 2007) load of 1,480 kg over the full 15-month study period. The Kennecott Utah Copper Corporation outfall and Goggin Drain contributed the greatest proportion of loads among sites (27 percent each), although the Bear River contributed an almost equal amount (26 percent). The Farmington Bay outlet site measured the combined flow northward to the main lake out of Farmington Bay. The Weber River gage measured one branch of the Weber River and did not measure the entire flow. Loads from the Weber River were corrected for the total river volume of water. The greatest total loads over time at all sites occurred during May 2006. Most of the influent selenium was in the dissolved phase as selenate ($Se6^{+}$), which was determined by subtraction of selenite ($Se4^{+}$) from total amount of dissolved selenium in the samples. Measurements at the railroad causeway partially separating the north and south arms of the lake indicated a net positive flow and selenium load from south to north over the period of record with a mean loss from the south arm of 2.4 kg Se/day.

The mean selenium concentration in the south arm of the lake increased over the 15-month period of the study and exceeded the change in concentration (0.17 µg Se/L) that could be expected from the simple addition of influent loads. Additional unmeasured sources of selenium could account for as much as 1,500 kg of additional load during the 2006 through 2007 period.

Table 5-9 summarizes selected project findings. Figure 5-5 shows the map of sampling locations.

TABLE 5-9
Project 3 Data Summary

Site	15-mo. Stream Loading (kg) (n)	Se Speciation (% selenite) (2 samples ea)	Causeway Loads to North (kg/day) (5 samples)	In-lake Increase in Conc. (µg Se/L) (46 samples)	Estimated Increase in Lake Conc. from streams (µg Se/L)
Bear River	400 (42)	17 – 27			
Weber River	54 (12)	30 – 33			
Goggin Drain	420 (41)	22 – 33			
Lee Creek	120 (14)	22 – 28			
Kennecott outfall	420 (134)	1.8 – 5.1			
Farmington Bay	170 (47)	14 – 20			
Causeway			2.4		
In-lake				0.16 – 0.34	0.17

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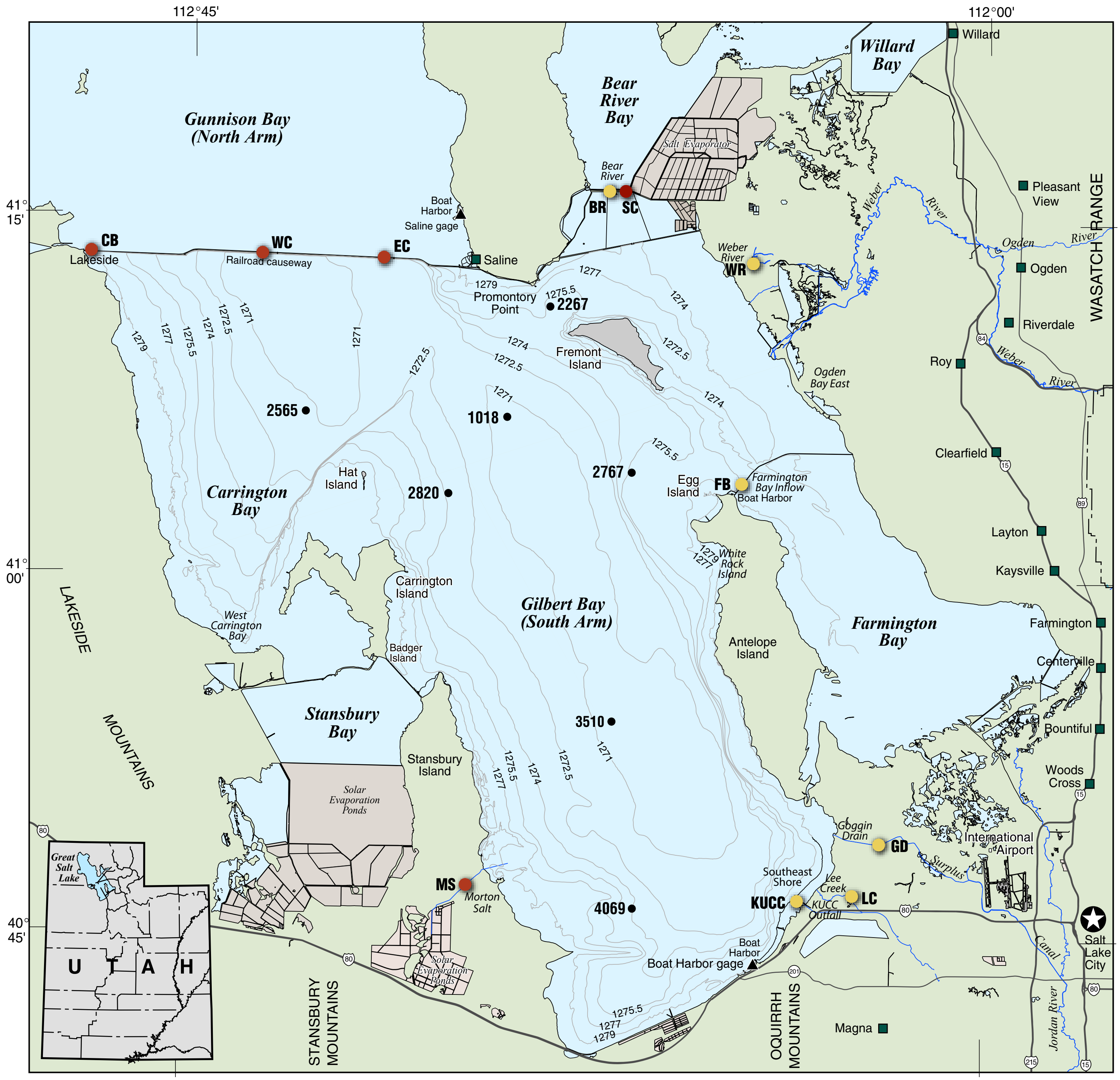

Base from U.S. Geological Survey digital data, 1:100,000, 1978, 1979, 1980, 1984
Universal Transverse Mercator projection, zone 12

0 10 20 KILOMETERS
0 10 20 MILES

LEGEND

- **AA** (red dot) Non-continuous Stream Gage and Sample Collection Site
- **AA** (yellow dot) Continuous Stream Gage and Sample Collection Site
- **4069** (black dot) Lake Monitoring Site

FIGURE 5-5
Project 3 – Selenium Load Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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5.2.7 Project 4, Measurement of Selenium Flux

The University of Utah's Dr. Bill Johnson completed the sampling program for Project 4 in 2006 and 2007. The following provides a summary of data and results from Johnson's *Estimation of selenium removal fluxes from the south arm of the Great Salt Lake, Utah: Final Report* (Johnson et al., 2008), found in Appendix H.

Project 4 provided a great amount of detail about in-lake geochemical processes and yielded estimates of important losses of selenium from the water column as well as estimates of gains through remobilization from particulate phases. Project 4 also provided baseline characterizations of selenium in the water column, as found in the upper, mixed layer, and the deep brine layer, as well as in sediments and as volatile compounds exiting the lake in vapor phase. Measurements of water showed that most selenium was present in the dissolved phase but that selenium concentrations were relatively higher in the particulate fraction of the deep brine layer. A net increase in water column selenium concentrations was measured during the study at some stations and was reported in the *Estimation of selenium loads entering the south arm of Great Salt Lake* report (Appendix G).

Sediment traps, cores, and bed sediment samples were collected and the material was analyzed for major and minor elements, including selenium. Radioisotope analyses were used to characterize sediment age by depth and sediment accumulation rates. The subsequent results yielded estimates of sedimentation rates and permanent sediment burial of selenium.

Volatilization of selenium from surface waters was discovered to be a major loss process for selenium from the water column and, although highly variable, probably accounts for a net loss of selenium more than 4-fold greater than that attributed to sediment burial. The estimates of volatilization required the measurement of total gas pressure, dissolved volatile species of selenium, direct estimates of flux from an *in situ* floating chamber, and modeled estimates of surface flux based on measurements of volatile selenium concentration gradients, water temperature, and wind speed during the 2006 through 2007 period.

Sedimentation fluxes were measured using sediment traps at several sites but appeared to be dominated by resuspension of surface sediments in the deep brine layer traps. In addition, the shallow sediment trap near the Bear River showed excessively high sedimentation rates attributable to riverine flux of sediments into the lake. However, other shallow sediment trap locations yielded sediment trap results useful in characterizing water column sedimentation loss rates uncomplicated by resuspension or tributary inputs. Those latter results were compiled as seasonal totals. Total sedimentation of selenium from the shallow layers was estimated as 383 kg over the year of measurement.

Thermistor string results revealed frequent displacement of the anoxic deep brine layer associated with seiches brought about by strong wind events. As a result, the seiches produced changing spatial patterns of anoxia overlying the lake's sediments. In theory, the seiches would affect resuspension of sediments as well as selenium remobilization and dissolution related to changing oxygenation of the overlying water. However, laboratory batch tests of sediment exposed to aerated or anoxic conditions did not reveal a significant potential for selenium remobilization from surface sediments through this route.

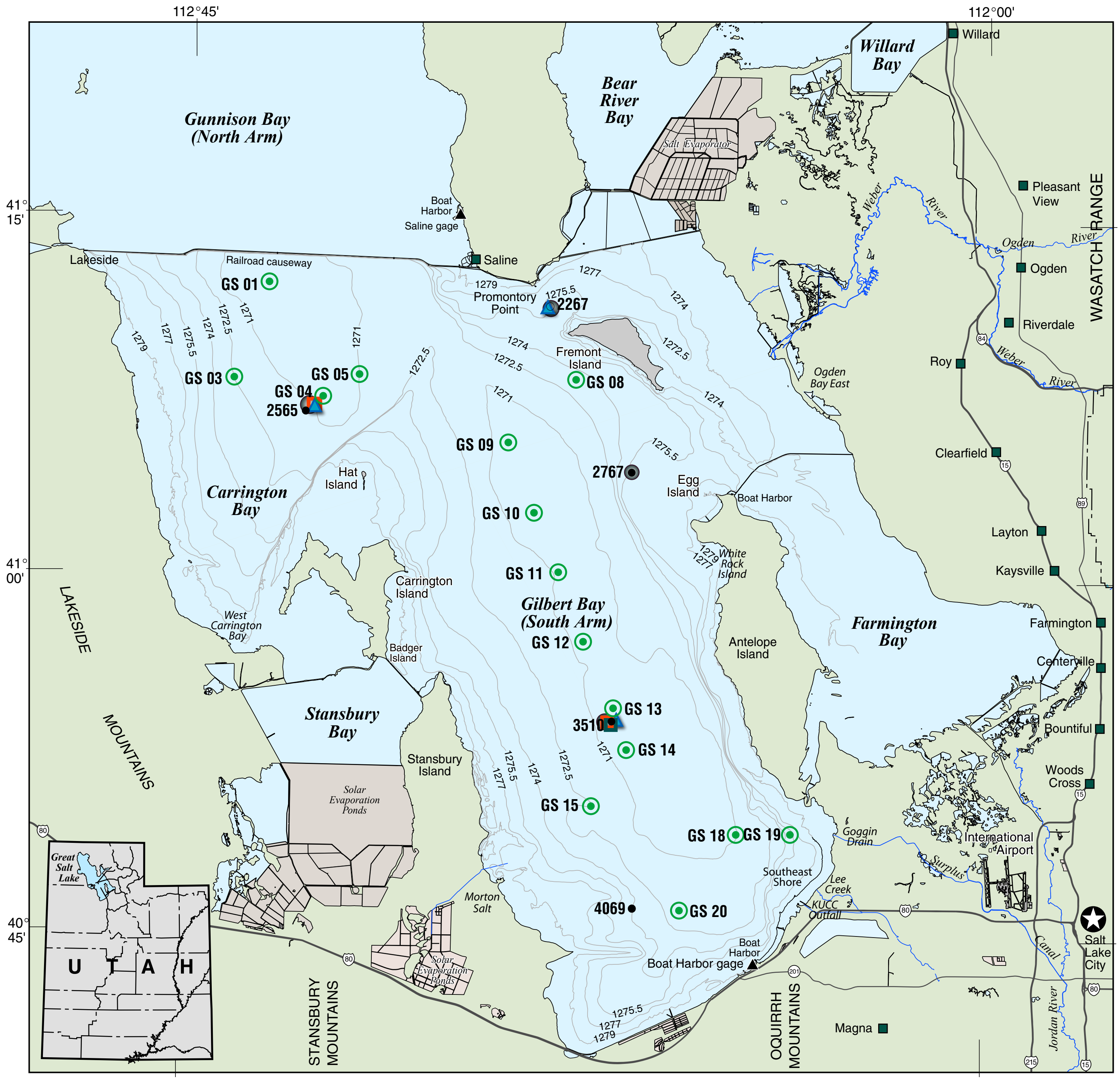
However, in addition to periodic and common wind-driven seiche movements of the deep brine layer, an overall shrinking of the areal coverage of the layer was observed during the 2006 through 2007 period. Johnson estimated that the newly exposed lake bottom sediments might have yielded as much as 25 kg of selenium to the water column during this period of DBL shrinkage.

In total, the mean estimates of various components of lake-wide mass balance of selenium over the study period, as reported by Johnson, include the following:

- Volatilization: 2,108 kg per year (estimated range is 1,380 to 3,210 kg per year)
- Permanent Sedimentation: 520 kg per year (estimated range is 45 to 990 kg per year)
- Shallow zone particulate sedimentation: 383 kg per year (estimated from his results)
- Deep brine layer dissolution and resuspension (internal loading): 25 kg per month (does not multiply to yearly value)
- Brine shrimp cyst removal: 28 kg per year (estimated range is 10 to 48 kg per year), median
- Selenium residence time in the lake: 3 to 5 years (knowing gain and loss terms)

The variability of each estimate was reported, as well.

Figure 5-6 shows sampling points. Table 5-10 lists selected findings from the study.



Base from U.S. Geological Survey digital data, 1:100,000, 1978, 1979, 1980, 1984
Universal Transverse Mercator projection, zone 12

0 10 20 KILOMETERS
0 10 20 MILES

NOTE: ALL LOCATIONS ARE APPROXIMATE.

LEGEND

- Dissolved Gas
- Sediment Cores
- Sediment Trap / Water Samples
- Thermistor Staging
- ADCP
- 4069 Lake Monitoring Site

FIGURE 5-6
Project 4 – Selenium Flux Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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TABLE 5-10
Project 4 Data Summary

Parameter	Se Concentration or Flux Estimate	Number of Samples
Raw water	0.25 – 3.11 µg/L	126
Filtered water	0.21 – 2.77 µg/L	126
Surface sediment (ooze)	0.83 +/- 0.36 mg/kg	12
Mineral sediment	1.19 +/- 0.22 mg/kg	12
Shallow-layer Sedimentation rates	$1.25*10^{-9}$ – $5.52*10^{-8}$ g/cm^2/yr	7
Permanent burial rates	500 kg/yr (weighted from all zones)	8
Volatilization	1,380 – 3210 kg/yr	23

5.2.8 Project 5, Brine Shrimp Kinetics Study

Dr. Martin Grosell at the University of Miami conducted this study to address specific objectives about brine shrimp selenium assimilation and bioaccumulation. The following provides a summary of data and results from Grosell 2007a and 2007b found in Appendix I. Dr. Grosell's final report is pending.

An initial objective of the study was to determine the variation in brine shrimp feeding rate as a function of salinity. The results suggested that optimal feeding rates could best be studied at 100 grams per liter (g/L) salinity. Higher salinities produced reduced feeding rates and reduced uptake of selenium directly from water.

The second objective investigated the uptake of selenium by brine shrimp after 24-hour exposures at a variety of ambient waterborne selenium concentrations. The results revealed clear saturation kinetics response at waterborne concentrations below 10 µg Se/L. Between 10 and 20 µg Se/L in water there was a "knee" in the brine shrimp response pattern. Much higher values of bioaccumulation were associated with water concentrations up to 40 µg Se/L. Higher water values (up to 80 µg Se/L) demonstrated decreased bioaccumulation, possibly due to selenium regulation by the brine shrimp.

In addition, the study involved feeding Se-75-labeled algae to brine shrimp over 1-hour exposures to estimate ingestion and assimilation efficiencies. The experiment produced a series of graphical relationships that can be used to specify assimilation efficiencies as a function of dietary selenium concentration. Low food concentrations (below 10 µg Se/g dw in algae) produced selenium assimilation efficiencies as high as 90 percent. Higher selenium concentrations in algae produced slightly lower assimilation efficiencies, leveling off near 75 percent in the 60 to 80 µg Se/g dw algae range.

Martin Grosell also presented the results of exposures showing the uptake of selenium by algae (*Dunaliella viridis*) in water containing from 1 to 50 µg Se/L (nominal concentrations) and subsequent feeding of algae containing radio-labeled selenium to Great Salt Lake brine shrimp. All waterborne selenium exposures of algae showed an initial period of rapid uptake over about 5 to 7 days, followed by an apparent depuration period lasting until about day 20, and then relatively constant tissue concentrations in algae that were exposure-dependent.

The final result of the study was a two-part model that adds waterborne and dietary exposures to produce an estimate of bioaccumulated selenium in brine shrimp. The final predictive model was based on uptake from water and food, computed separately. Predictions from water took the form of two scenarios. The first was a linear relationship between selenium in water and brine shrimp tissue for waterborne concentrations less than 2 µg Se/L. The second scenario described a logistic equation applicable for waterborne concentrations over 2 µg Se/L. The first scenario was chosen for Great Salt Lake modeling because it most closely matched field conditions.

The second part of the model described dietary exposure. The data describe an exponential decay, with assimilation efficiencies ranging from near 100 percent at low food concentrations to about 80 percent for all food concentrations over about 20 µg Se/g dw. Two tables (the two scenarios) were provided at the end of the report predicting steady-state brine shrimp tissue concentrations as would be estimated from Grosell's equations given a choice of water (vertical axis) or dietary (horizontal axis) concentrations. Scenario 1, for low waterborne concentrations within the ranges observed at Great Salt Lake, was chosen as the calculating equations as incorporated into the mass balance and exposure model.