An Examination of Mercury (Hg) Contamination in Kejimkujik National Park: The Role of Geological Sources.

by

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Submitted in partial fulfillment of the requirements
for the degree of Master of Science

at

Dalhousie University
Halifax, Nova Scotia
September 1, 2001

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Date: September 1, 2001

Author: Krista D. Page

Title: "An Examination of Mercury (Hg) Contamination in Kejimkujik National Park: The Role of Geological Sources"

Department: Earth Sciences

Degree: M.Sc. Convocation: Fall Year: 2001

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Abstract

Recent studies have shown that mercury (Hg) levels in many fish from remote lakes exceed the recommended guidelines for human consumption. Most of these studies conclude that the source of contamination lies in the atmosphere. Kejimkujik National Park (KNP), Nova Scotia, is considered to be a pristine ecosystem in which fish and loon Hg levels are anomalously high. Studies in the park have shown that atmospheric Hg concentrations may not be high enough to account for the Hg levels in the biota, indicating that the park may be an unusual system in terms of Hg distribution and migration.

A variety of new Hg data sets produced in the park over the last 5-10 years were integrated into a GIS database, using watersheds as the common parameter, to establish new relationships and correlations. In addition, the levels of Hg found in natural geological environments (i.e. bedrock and shear zones), and the potential for this Hg to be released to the environment were investigated.

The results indicate that (1) wetlands are an excellent source of Hg to downstream lakes, (2) relatively high levels of Hg are associated with watersheds underlain by biotite-rich granite, (3) the breakdown of biotite releases Hg to the environment, and (4) Hg vapor is also being released from structural features in the park (i.e. the TSZ and GHT).

Taken together, these results suggest that there are geological sources of Hg in the park that are affecting the Hg geochemical budget in the Kejimkujik system. However, since Hg has to be methylated for it to enter the food chain, for Hg to build up in a watershed and in the biota, there needs to be (i) a trapping mechanism that will keep Hg in the watershed (e.g. wetlands) *and* (ii) conditions that favor the formation of methylmercury (e.g. high organics). In KNP, watersheds that are underlain by biotite-rich granite and have moderate to high percentages of wetlands tend to have higher Hg levels in their lakes and biota.

This study has applications for the evaluation of geological contributions to Hg contamination studies in the aquatic systems of moderate climates. Any watershed that is underlain by biotite-rich granite and has a high percentage of wetlands might be an area of anomalous Hg levels.

Acknowledgements

I would like to thank my supervisor, Dr. Brendan Murphy (STFX), for his enthusiasm, generous support, and continuous advice. My motivation for this thesis was sustained by Brendan's incredible knowledge of Nova Scotia geology, his overwhelming commitment to this project, and his willingness to let me explore my own research interests.

I wish to thank Tim Webster, my COGS supervisor for his commitment to high quality GIS, RS, and geological research. His input into my thesis has been remarkable. I would like to thank Tim for all of his great ideas, his time, and his capability to push me to my full potential.

I would like to acknowledge Terry Goodwin for his contribution to the shear zone study, as Terry and I undertook most of this study together. Terry is an excellent field partner, whose humor made a lot of dreary field days pass by much quicker. I would like to thank Terry for his help with my understanding of analytical techniques, geochemical analysis, and sampling methods.

Paul Smith has made a significant intellectual contribution to the bedrock and shear zone studies in this thesis. I would also like to thank him for his financial support.

I would like to thank Anne-Marie O'Beirne-Ryan for her endless encouragement and guidance with every aspect of my thesis.

I wish to thank the Toxic Substance Research Initiative (TSRI) team for their financial support. In particular I would like to thank Andy Rencz, Al Sangster, and Tom Clair.

Finally, I would like to thank my parents, who have shown me nothing but support and encouragement throughout my whole university career. I would like to especially thank my father, Brian Page, who was my field assistant. He donated a lot of his time, patience, resources, and energy to this project. Thanks dad!

Chapter 1 – Introduction

1.1. GENERAL STATEMENT

Mercury (Hg), a naturally occurring element, is a toxic, volatile, and global pollutant that can remain in the atmosphere for long periods of time and may be transported hundreds of kilometers from its original source (Lindqvist, 1994). Recent studies in the Northern Hemisphere have shown that Hg levels in many fish from pristine lakes exceed the recommended guidelines for human consumption (e.g. Watras et al., 1994; Haines et al., 1994; Brouard et al., 1994). In most of these studies, the source of contamination is thought to be atmospheric (Lindqvist, 1994).

Kejimkujik National Park (KNP), located in southwest Nova Scotia (Figure 1.1), is considered to be a pristine ecosystem in which fish and loon Hg levels are anomalously high. Loons in the park have blood Hg levels that are three times higher than any other loon population that has been tested in North America (Mercury Team, 1998). Compared to other sites in North America, studies in the park have shown that Hg levels in the atmosphere are only low to moderate, and therefore might not be high enough to account for the Hg levels observed in the biota (Beauchamp et al., 1998a, b). This could indicate that the park is an unusual system in terms of Hg distribution and migration. As a result, KNP has been the location of numerous Hg studies in the last number of years (Mercury Team, 1998; Rencz, 2000, CD-ROM; O'Driscoll et al., 2000).

A major part of this thesis involves the integration of previously collected Hg data sets into a Geographic Information System (GIS) database in order to examine correlations and relationships between the data sets. This thesis also attempts to examine the potential geological contribution of Hg to the Kejimkujik system by analyzing Hg levels in bedrock and shear zones cutting the bedrock.

1.2. BACKGROUND

In 1988, Dr. Joseph Kerekes of the Canadian Wildlife Services (CWS) began monitoring the loons in KNP in order to obtain information on the effects of acid precipitation (Common Loons, 1996, http). The results showed that the loons in the park

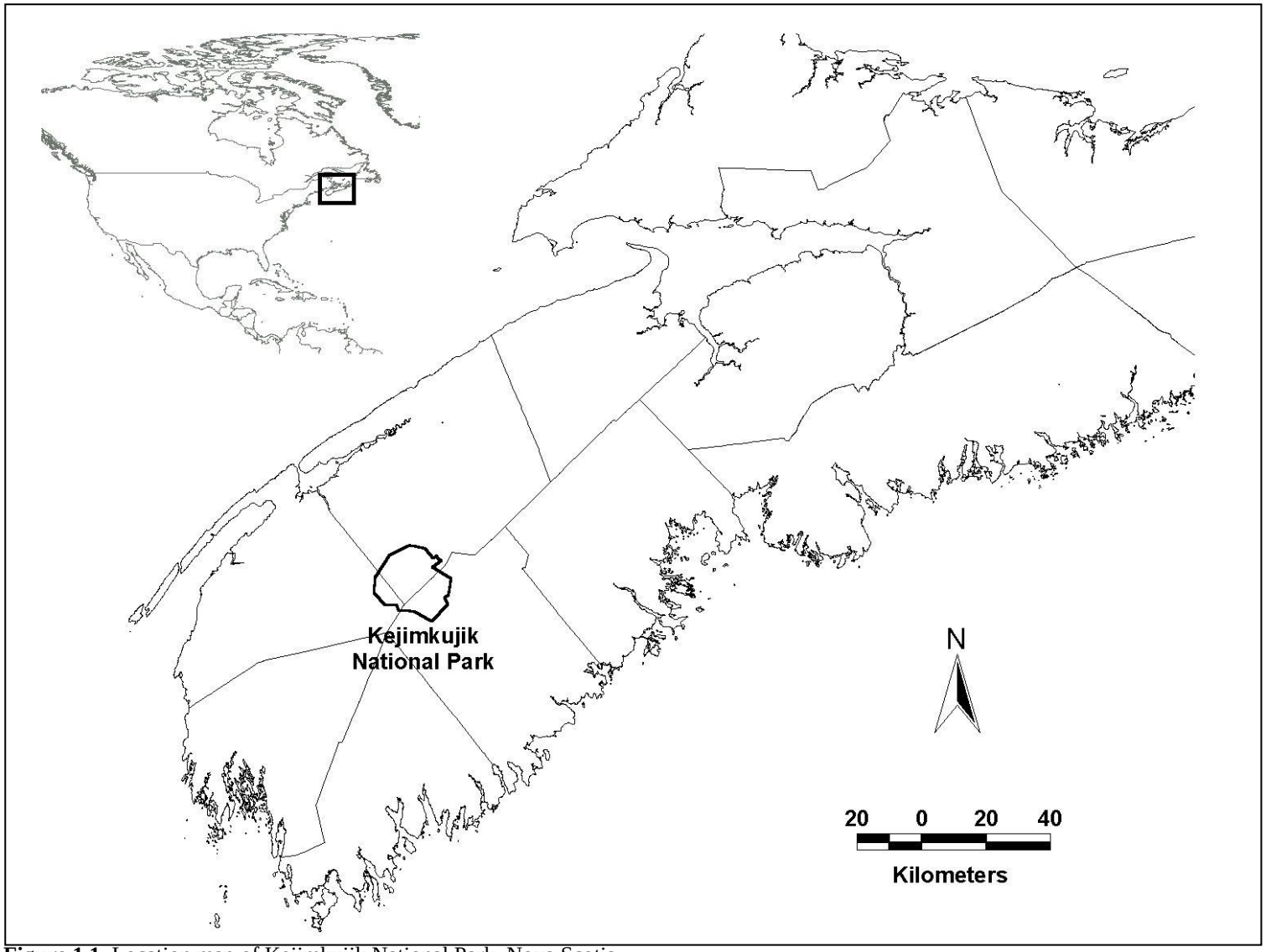


Figure 1.1. Location map of Kejimkujik National Park, Nova Scotia.

have a reproductive success rate of about 0.29 chicks per residential pair (Kerekes et al., 1995), about half of the productivity required to maintain a growing loon population (McIntyre, 1994). In 1995, the CWS started testing loon blood for toxic chemicals, such as PCBs and organochlorines. Mercury was the only chemical that yielded high toxic levels (Nocera, 1999, http). Further studies by Burgess (1996, http), Burgess et al. (1998), and Evers et al. (1998) showed that blood Hg levels in the Kejimkujik Loons were about three times higher than any other loon population that has been tested in North America (Figure 1.2).

In 1996, Environment Canada assembled a multi-disciplinary team of research scientists including biologists, chemists, geologists, limnologists, meteorologists, and GIS experts from universities and various levels of government to study the potential sources and processes that may account for the anomalous Hg levels in the loons (Mercury Team, 1998). In 1999, A. Rencz (Geological Survey of Canada) received three years of funding from the Toxic Substance Research Initiative (TSRI) program in order to explore the origin of the Hg levels in the park. In the past five years, as a result of these and other studies, new information and data pertaining to Hg sources and processes in a variety of environments within the park have emerged.

1.3. PREVIOUS, CURRENT, AND FURTHER WORK

The research for this thesis is part of the TSRI project and was based on data and ideas that had been generated by Environment Canada and the TSRI team by the summer of 2000. Therefore, the following section places work that was complete by the TSRI team by the summer of 2000 in “Previous Work”, the work that was being carried out during the summer of 2000 as "Current Work” and work that was planned for the 2000-2001 year as “Further Work”.

1.3.1. Previous Work

Since Hg contamination in pristine ecosystems is perceived to originate from the atmosphere, atmospheric studies were among the first to be conducted in the park. Beauchamp et al. (1998a, b) measured the total gaseous mercury (TGM) levels in the

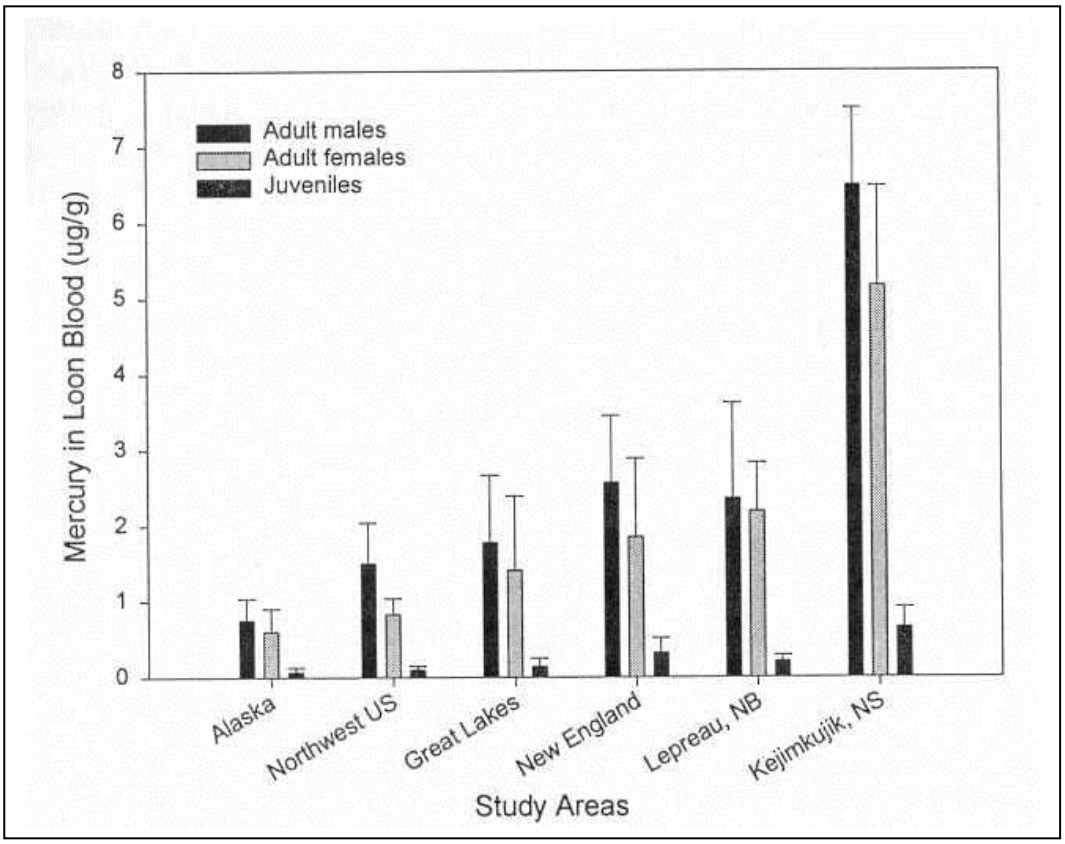


Figure 1.2. Mean blood Hg levels for Common Loons tested across North America. All of the American data are from Evers et al. (1998). New Brunswick and Nova Scotia data are from Burgess et al. (1998). Figure taken from Burgess et al. (1998).

atmosphere and the total Hg in precipitation and wet deposition levels. These values were then compared to other sites that had been tested in North America. A summary of these results is shown in Tables 1.1a-c. The average TGM concentration in the park (for 1996) was 1.49 ng/m^3 (Table 1.1a), the average Hg in precipitation level (for 1996-1997) was 9.4 ng/L (Table 1.1b), and the average Hg deposition level (for 1996-1997) was 8.7 ug/m^2/yr (Table 1.1c). When compared to other values in North America, these average values for KNP are in the low to moderate range. Therefore, because the park is receiving only average levels of Hg from the atmosphere, the atmosphere alone might not account for the high levels of Hg found in the loons.

Further data collection in the park revealed that the fish in the park range in concentration from 0.05 to 2.30 ppm Hg (d'Entremont et al., 1998 and Rutherford et al., 1998), and many exceed the human consumption guideline of 0.5 ppm (Nagpal, 1999, http). The lake water samples taken in the park range between 0.87 to 7.40 ppt Hg (Rencz, 2000, CD-ROM), and these concentrations are all below the drinking water guidelines of 1.0 ppb (Canadian Environmental, 2000, http). Lake sediment samples range between 0.03 to 0.19 (dry weight) ppm Hg (Rencz, 2000, CD-ROM), and most of them fall below the Canadian Environmental Guideline of 0.17 ppm (Canadian Environmental, 2000, http). The average bedrock value from 146 samples gathered in southwest Nova Scotia is 3.3 ppb Hg (Smith, 2000). Vegetation samples (red maple and white pine) taken in the park range between 5-33 ppb Hg (A. Rencz, written communication, 2000, January 24), and all of them fall within calculated plant background levels of 3-100 ppb (Lodenius, 1994). Soil samples were taken in the park, however those results were not made available for this study.

1.3.2. Current Work

Currently, more data on bedrock, soils, and lake sediments are being gathered in the park and new data on tills, wetlands, and stream water are being gathered. Now that a number of data sets have been collected, the TSRI team is beginning to focus on Hg processes and fluxes in the park, i.e. (1) the flow of Hg into and out of lakes and streams,

Mean TGM (ng/m^3)	Location
3.22	Egbert (ON)
2.30	Lake Michigan (MI)
2.21	Pt. Petre (ON)
2.00	Underhill (VT)
2.00	South Haven (MI)
1.79	Acadia (ME)
1.77	North Central Pacific
1.64	Florida
1.56	St. Andrews (NB)
1.49	**Kejimkujik (NS)**
1.57	Wisconsin (USA)
1.47	St. Anicet (QE)
0.55	Ross I. Antarctic

Table 1.1a. Mean total gaseous mercury (TGM) atmospheric concentrations from various sites in North America. The Kejimkujik data were gathered in 1996, all other sites were gathered in the early 1990's. Background TGM concentrations in the Northern Hemisphere are 1.5 ng/m^3. Table modified from Beauchamp et al. (1998a).

Mean[Hg] ng/L	Location
12.0	Lake Barco (FL)
11.5	Wisconsin (USA)
11.0	St. Andrews (NB)
10.8	South Haven (MI)
10.5	Little Rock Lake (WI)
10.2	Dexter (MI)
10.2	Dorset (ON)
10.3	St. Andrews (NB)
10.0	Sturgeon Pt (NY)
9.4	**Kejimkujik (NS)**
9.0	North Pacific
8.3	Vermont (VT)
7.9	Pellston (MI)
7.0	St. Anicet (QE)
6.0	Little Rock Lake (WI)
4.0	Rawson Lake (ON)

Table 1.1b. Total Hg concentrations in precipitation from various sites in North America. The Kejimkujik data were gathered in 1996-1997, most other sites were gathered in the early 1990's. Table modified from Beauchamp et al. (1998b).

Hg Deposition $ug/m^2/yr$	Location
12.7	South Haven (MI)
9.4	South Haven (MI)
9.3	Underhill (VT)
9.1	Dexter (MI)
8.7	Wisconsin (USA)
8.7	Dexter (MI)
8.7	**Kejimkujik (NS)**
8.3	St. Andrews (NB)
6.8	Wisconsin (USA)
5.8	Pellston (MI)
5.5	Pellston (MI)

Table 1.1c. Annual total Hg deposition via precipitation from various sites in North America. The Kejimkujik data were gathered in 1996-1997, all other sites were gathered in the early 1990's. Table modified from Beauchamp et al. (1998b).

(2) food chain processes, (3) microbial processes, (4) Hg flux from the air to the water/soil and vice versa, and (5) weathering processes.

1.3.3. Further Work

The objective of the TSRI group is to create Hg mass balance models for a number of lakes in the park and to perform a geospatial analysis.

One of the main obstacles to creating Hg mass balance models in the park is the lack of data for some important features. Figure 1.3 provides an overview of the previous data sets, and their associated Hg values, which have been gathered in the park. As implied from Figure 1.3, further studies on the concentration and distribution of Hg in groundwater and structural features need to be incorporated into the project. Structural features have been examined as part of this thesis.

In order for the TSRI team to perform a geospatial analysis in the park, the data sets that have been collected (e.g. fish, water, etc.) need to be integrated into a common database. A common GIS database, integrating all of the Hg and related data sets available up to the summer of 2000, has been created as part of this thesis.

1.4. THESIS OBJECTIVES

This thesis is part of a larger project funded by the Toxic Substance Research Initiative (a cooperation between Health Canada and Environment Canada). The three main objectives of this thesis are: (1) to establish correlations and relationships between various Hg data sets that have been gathered in the park, (2) to develop a better understanding of Hg levels in underlying bedrock lithologies, and (3) to examine the influence of structural features, such as shear zones, that transect the park.

1.5. THESIS ORGANIZATION

The first three chapters of this thesis provide the necessary background for the study. This chapter (chapter 1) gives an introduction and an overview. Chapter 2 provides the geological setting for the study area. Chapter 3 gives an overview on Hg levels and behavior in the environment and provides the conceptual framework for chapters 4-6.

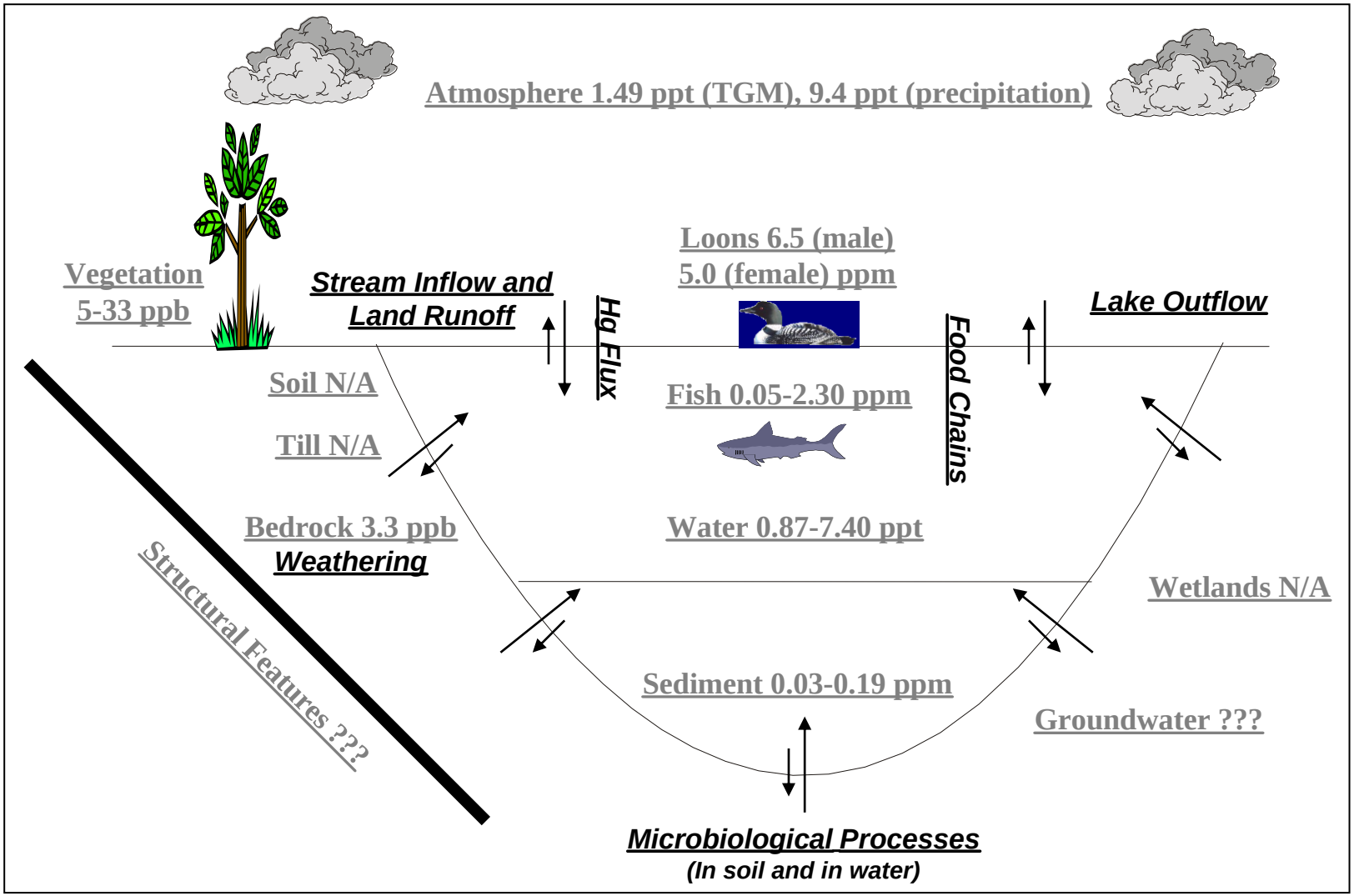


Figure 1.3. Overview of previous and current Hg data that have/are being gathered in the park. Hg parameters and levels for the park are in Times New Roman, grey, and underlined. Hg processes are in *Arial, black, italicized, and underlined*. Figure modified from Rencz (2000).

Chapters 4-6 are organized based on the three objectives stated above. Chapter 4 describes the creation and interpretation of the GIS database. Chapter 5 describes and interprets the results of Hg levels in bedrock. Chapter 6 describes and interprets Hg levels across shear zone traces that are identified in the park. Each of these three chapters are self-contained (i.e. an introduction, methodology, results, and discussion). Conclusions and implications for further work are presented in chapter 7.

Chapter 2 – Bedrock and Surficial Geology

In many regions, the chemistry of an ecosystem is influenced by the underlying bedrock geology and by the surficial geology. In order to examine this potential relationship in Kejimkujik National Park (KNP), the geology of this region is summarized in this chapter. In general, the park is underlain by Paleozoic metasedimentary rocks, Devonian granitoid intrusions, and Quaternary glacial tills. Although all of these rock types are described below, only the granitoid intrusions have been examined for Hg in this thesis.

2.1. REGIONAL GEOLOGY - SOUTHWEST NOVA SCOTIA

2.1.1. Paleozoic Geology

Southwest Nova Scotia is underlain by rocks of the Meguma terrane, an Appalachian suspect terrane that accreted to North America during the Early Devonian. Southwest Nova Scotia is primarily underlain by (1) the Cambro - Ordovician Meguma Supergroup, (2) the overlying Late Ordovician - Early Devonian Annapolis Supergroup, and (3) Devonian plutonic rocks (Figure 2.1; terminology after Schenk, 1995a).

2.1.1.1. Meguma Supergroup

The Meguma Supergroup predominately consists of a thick siliciclastic sequence that ranges in age from Late Cambrian or older to Early Ordovician and was deposited on a passive continental margin (Schenk, 1995a). The Meguma Supergroup is divided into two groups (Figure 2.2): (1) the Cambrian Goldenville Group, which is composed predominantly of greywacke with minor slate and was deposited in an abyssal-plain fan environment and (2) the Early Ordovician Halifax Group, which is composed predominantly of slate with minor greywacke and was deposited in the mid- or upper-fan area of a muddy deep-sea fan passing upwards into a prograding continental slope and shelf (Schenk, 1970; Schenk, 1995a).

In southwest Nova Scotia, the Goldenville Group is divided into three formations. In ascending order these are: (1) New Harbour, (2) Risser's Beach, and (3) West Dublin.

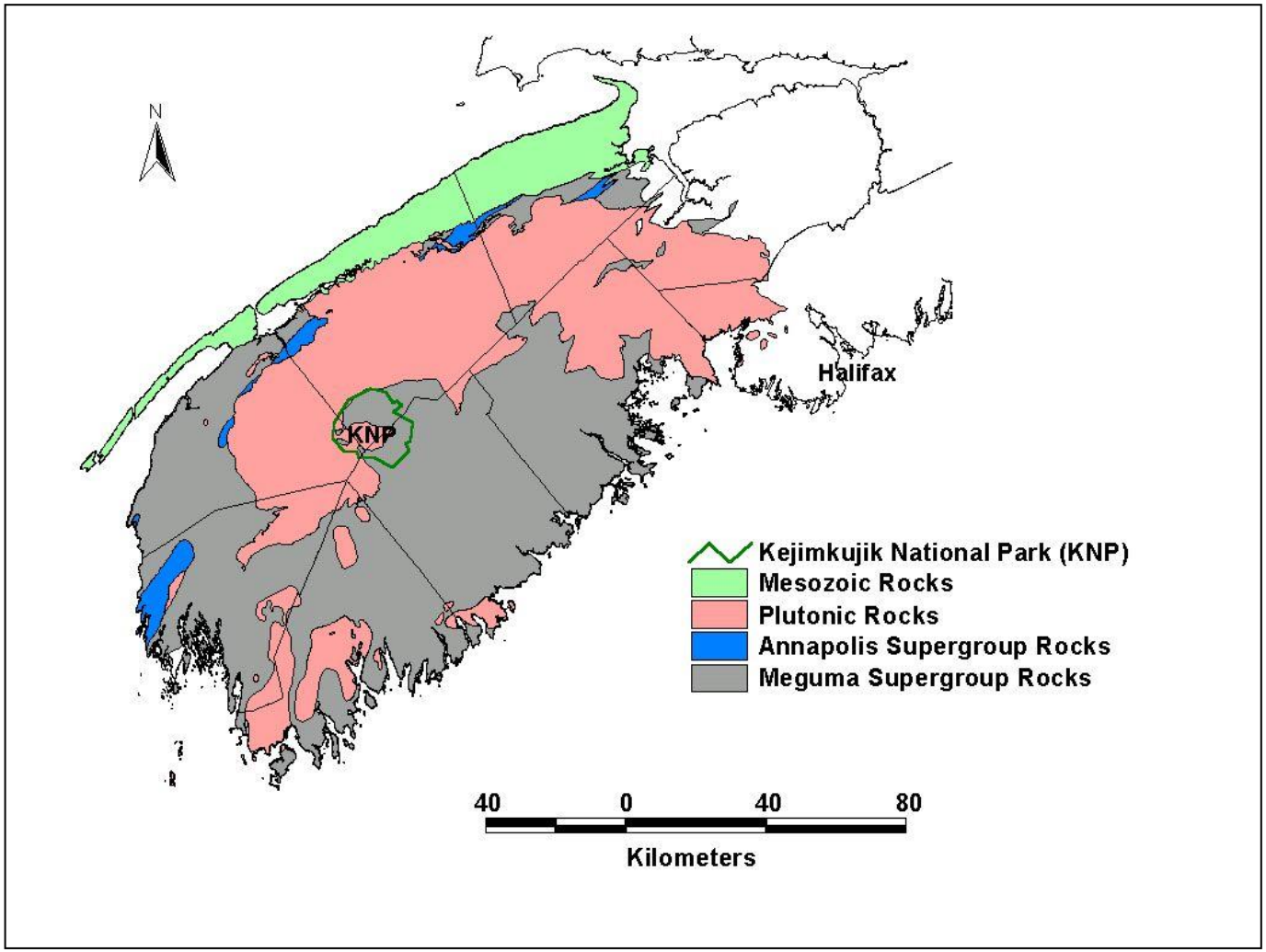


Figure 2.1. Southwest Nova Scotia is underlain by four rock units: (1) Late Cambrian –Early Ordovician Meguma Supergroup, (2) Early Ordovician – Early Devonian Annapolis Supergroup, (3) Devonian plutonic rocks, and (4) Triassic – Early Jurassic Mesozoic rocks. Later igneous activity and sedimentation produced the plutonic and Mesozoic rocks. Map modified from Keppie (2000, http).

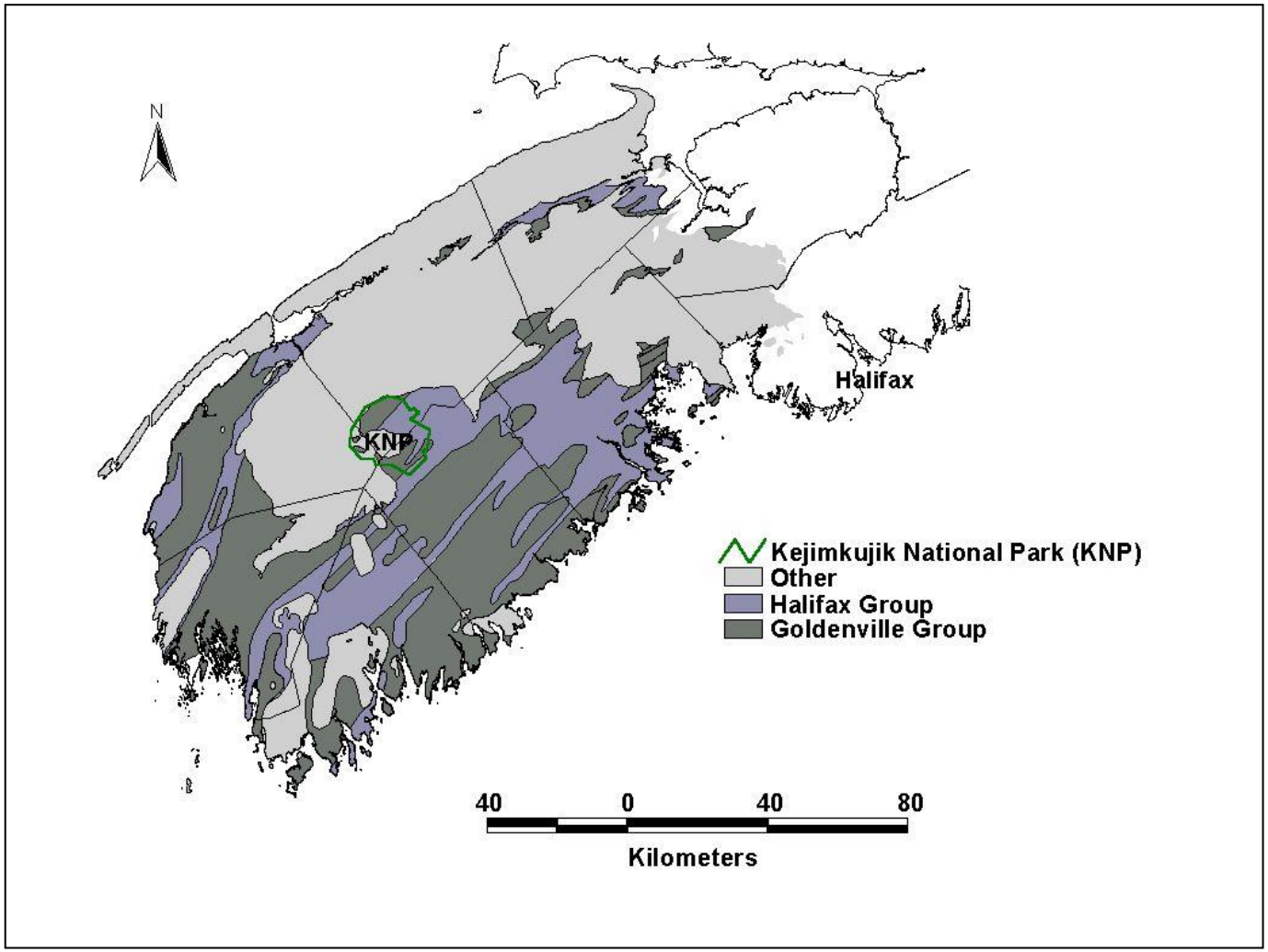


Figure 2.2. The Meguma Supergroup is divided into two groups: (1) Goldenville Group and (2) Halifax Group. Map modified from Keppie (2000, http).

The Halifax Group is divided into five formations: (1) Mosher's Island, (2) Cunard, (3) Feltzen, (4) Delanceys, and (5) Rockville Notch. Schenk (1995a) provides an up to date summary of these eight formations.

A poorly exposed package of lithologies at the transition from the upper part of the Goldenville Group to the lower part of the Halifax Group is termed the Goldenville-Halifax Transition Zone (GHT). The GHT is a sedimentary transition zone (Zentilli et al., 1986; Graves and Zentilli, 1988) that has received great attention for it's distinct lithologies and abundant mineralization. Of particular relevance to this thesis is the large amount of sulphides that are present in the GHT (predominately pyrrhotite and pyrite with lesser amounts of galena, sphalerite, and chalcopyrite). The abundance of sulphide minerals and their ability to oxidize quite readily (producing large amounts of acid and sulphate) have been the focus of acid rock drainage studies in Nova Scotia (e.g. Fox et al., 1997; Fox, 1999). Redox conditions and the cycling of sulphur in a lake are two of the major factors that affect Hg levels in fish and loons (e.g. Porcella, 1994).

The association between mercury (Hg) and sulphides has been discussed in a number of studies (e.g. Krupp, 1988). Mercury enrichment is present in some sulphide-rich layers of the GHT, however enrichment is not a ubiquitous characteristic of sulphide-rich layers in southwest Nova Scotia (P. K. Smith, personal communication, May 2, 2001). If anomalous Hg levels are associated with sulphides in some areas, oxidation of these minerals might release Hg to the surrounding environment (M. Zentilli, personal communication, April 5, 2001).

2.1.1.2. Annapolis Supergroup

The Meguma Supergroup is overlain by the Annapolis Supergroup, which predominately consists of thick sequences of fine-grained subaerial to shallow marine siliciclastic sedimentary and volcaniclastic rocks ranging in age from Late Ordovician - Early Devonian that was deposited on a continental margin (Keppie, 1979; Schenk, 1995b). The Annapolis Supergroup is divided into three groups (Figure 2.3): (1) the Late Ordovician White Rock Group, which is composed of quartzite, slate, siltstone, rhyolite, basalt, and andesite, (2) the Silurian age Kentville Group, which is composed of shale,

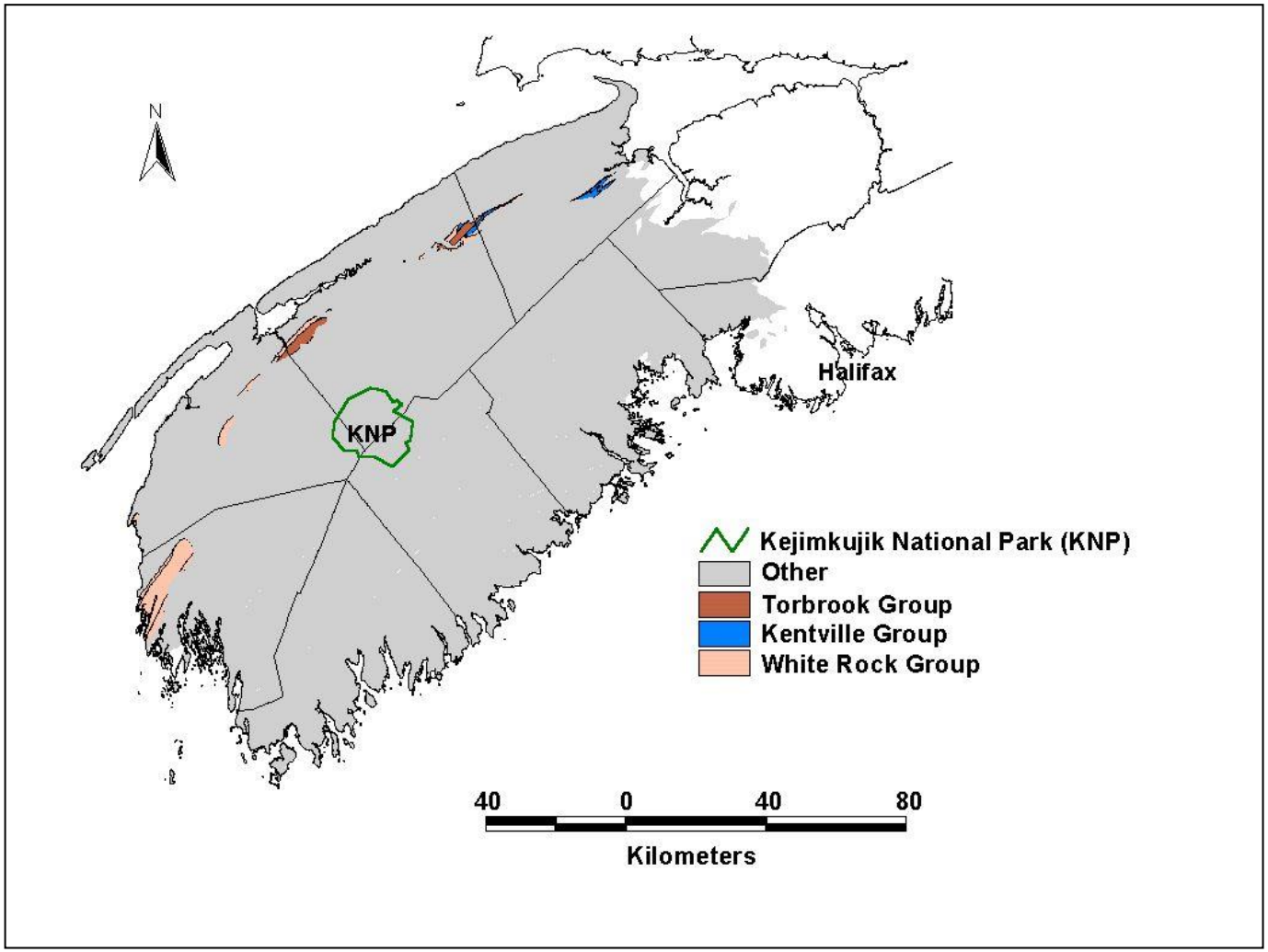


Figure 2.3. The Annapolis Supergroup is divided into three groups: (1) White Rock Group, (2) Kentville Group, and (3) Torbrook Group. Map modified from Keppie (2000, http).

siltstone, and slate, and (3) the Devonian age Torbrook Group, which is composed of shale, siltstone, and quartzite with minor shaly and/or fossiliferous limestone and iron formations (MacDonald, 1994). Each of these three groups represent a major transgressive cycle; each cycle beginning with a basal sandstone, followed by a black shale, then siltstone and/or sandstone, and ending with igneous activity, usually in the form of subaerial volcaniclastics (Schenk, 1995b).

In southwest Nova Scotia, the White Rock Group is divided into three formations. In ascending order these are: (1) Nictaux Volcanics, (2) Fales River, and (3) Deep Hollow. The Kentville Group is divided into two formations: (1) Elderkin and (2) Tremont. The Torbrook Group is divided into five informal formations (Schenk, 1995b). A detailed description of these ten formations is found in Schenk (1995b).

2.1.1.3. Acadian Orogeny

The Meguma and Annapolis supergroups were deformed, metamorphosed, and intruded by voluminous granitoid bodies during the Middle - Late Devonian Acadian orogeny (Schenk, 1995b; Wililams, 1995).

Deformation: Three sets of folds affect the Meguma terrane: (1) first generation shallowly plunging, upright folds that trend northeasterly in southwest Nova Scotia, (2) second generation steeply plunging cross-folds in the Halifax Group that trend north to northeast, and (3) third generation kink-folds and kink-bands that trend northwesterly and plunge steeply to the southeast. The first two generations of folds are older than the granitoid bodies and the third generation is younger (Fyson, 1966 in Schenk, 1995b).

Metamorphism: The Meguma terrane shows both regional and contact metamorphism. In southwest Nova Scotia, Late Silurian – Early Devonian regional metamorphism occurred before granite intrusion (Reynolds and Muecke, 1978) and produced greenschist and amphibolite facies metamorphism (Keppie and Muecke, 1979). The granite intrusions produce contact aureoles, which overprint these regional isograds and produced hornblende-hornfels facies rocks (Taylor and Schiller, 1966 in Schenk, 1995b).

Plutonism: One-third of the Meguma terrane is underlain by Devonian plutonic rocks (Figure 2.1), termed the South Mountain Batholith (SMB). The SMB, a composite pluton, is the largest igneous body in the entire Appalachian Orogen (McKenzie and Clarke, 1975). According to Benn et al. (1997) it is a syntectonic, epizonal granitoid that was emplaced during the late stages of collision between the Meguma and Avalon terranes. It is composed of a number of plutons that range in composition from muscovite leucogranite to biotite granodiorite (MacDonald, 1994; Clarke et al., 1997). The SMB is discussed further in Chapter 5.

Shear Zones: A number of shear zones transect southwest Nova Scotia. Of particular relevance to this thesis is two mineralized northeast-trending shear zones associated with anomalously intense brittle-ductile deformation. These zones, which crosscut the metasedimentary and granitoid rocks, are the East Kemptville (O'Reilly, 1988) and Tobeatic (Corey, 1994) shear zones. The East Kemptville Shear Zone transects the northern part of KNP, and the Tobeatic Shear Zone is located in the southern part of the park (see Section 2.2). The shear zones are believed to be pre- or syn-intrusion features (Horne et al., 1992; Keppie and Dallmeyer, 1995). From at least the Early Carboniferous to the Permian, these northeast-trending epithermal shear zones have been sites of extensive activity, fluid flow, and metal deposition (Graves, 1995). These zones are discussed further in Chapter 6.

2.1.2. Mesozoic Geology

In southwest Nova Scotia, Mesozoic rocks are found primarily to the north, flanking the Bay of Fundy (Figure 2.1). These rocks, which are Triassic to Early Jurassic in age, are mainly red continental clastic rocks, tholeiitic basalts, and mafic dykes (Greenough, 1995). Mesozoic rocks in southwest Nova Scotia are generally interpreted to reflect an early phase in the opening of the Atlantic Ocean (Keen et al., 1991). Greenough (1995) describes in detail the formation of these rocks; a summary is presented here. During the Permian, uplift of eastern Canada was associated with widespread erosion and small amounts of alkaline volcanism (McHone and Butler, 1984; Manspeizer et al., 1978). During the Middle to Late Triassic, a period of lithospheric extension and collapse

occurred which caused the reactivation of Paleozoic faults, forming the Fundy Graben (Swanson, 1986). The Fundy Graben contains a major synclinal structure, with its axis located in the middle of the Bay of Fundy (Keen et al., 1991). During the Early Jurassic, continental sediments were deposited in the graben and large volumes of magma produced extensive dyke swarms (e.g. the Shelburne Dyke) and flood basalt sequences (e.g. North Mountain Basalt) (various authors in Greenough, 1995). During the Middle Jurassic, North Africa separated from eastern North America, and volcanism and onland basin subsidence ceased (Keen et al., 1991).

In southwest Nova Scotia, three sequences of Mesozoic rocks overlie the Meguma terrane. In ascending order these are the: (1) Wolfville Formation, (2) Blomidon Formation, and (3) North Mountain Basalt (Figure 2.4; Keppie, 1979). The Wolfville Formation is Triassic in age and is composed of a sequence of red coarse breccias, conglomerates, mudstones, and poorly sorted to well-sorted sandstone. The formation is interpreted as an alluvial fan deposit, with braided river and eolian sand dune settings (Hubert and Mertz, 1980; Klein, 1962). The Blomidon Formation is Upper Triassic in age and is composed of planar, crossbedded, and crosslaminated sandstones with horizontal and crosslaminated siltstones, mudstones, and claystones. The formation represents the distal sheet-flood deposits of alluvial fans, sand flats, playa mud flats, and lacustrine deposits (Mertz and Hubert, 1990; Hubert and Hyde, 1982). The North Mountain Basalt is an Early Jurassic - Middle Jurassic quartz-normative tholeiitic basalt. It is composed of upper and lower massive, coarse-grained, columnar-jointed, single flow units and a number of thin amygdaloidal flows in the middle (Greenough, 1995).

2.1.3. Cenozoic Geology

2.1.3.1. Phases of Glaciation

There have been at least four glacial advances and retreats in Nova Scotia over the last 75 thousand (ka) years. These four phases are described in detail in Stea et al. (1998) and are summarized in Stea (2001, http). From oldest to youngest these phases are the (1) Caledonia Phase, (2) Escuminac Phase, (3) Scotian Phase, and (4) Chignecto Phase. Each

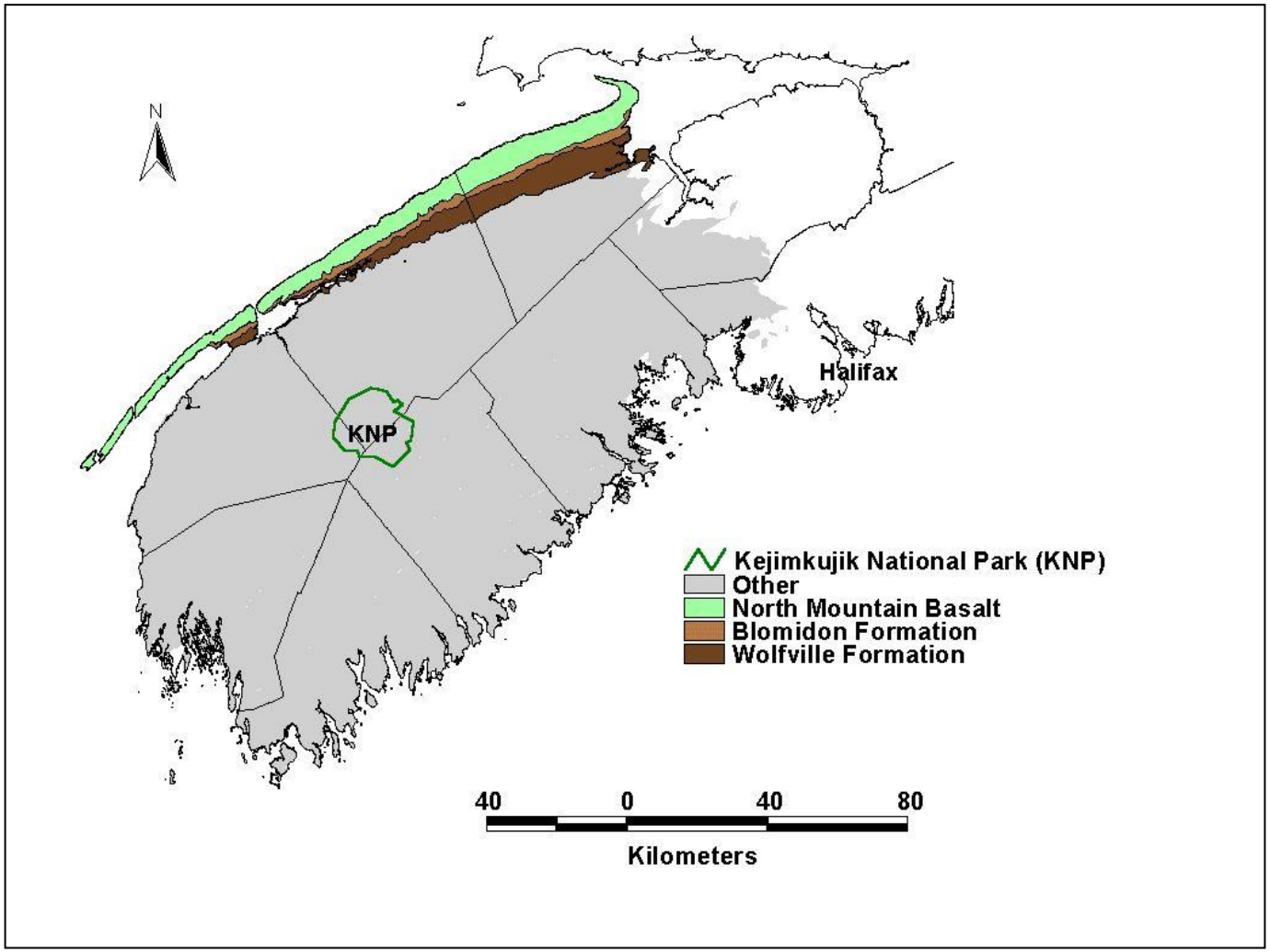


Figure 2.4. In southwest Nova Scotia, the Mesozoic rocks are divided into three units: (1) Wolfville Formation, (2) Blomidon Formation, and (3) North Mountain Basalt. Map modified from Keppie (2000, http).

of these phases had ice sheets that advanced from different directions, depositing distinct till assemblages with each event.

The Caledonia Phase is dated at 75-40 ka, and it is the oldest dated ice flow in Nova Scotia (Stea et al., 1998 and authors therein). The ice sheet, termed the Gaspereau Ice Center, developed north of New Brunswick. It crossed the Bay of Fundy and Nova Scotia in an eastward direction and then changed its course to the southeast and terminated offshore (Stea and Grant, 1988).

The Escuminac Phase is dated at 22-18 ka (Stea et al., 1998 and authors therein). The ice sheet, termed the Escuminac Ice Center, developed in the center of the Northumberland Strait. It crossed mainland Nova Scotia in a southwest to southeast direction and terminated offshore (Stea and Grant, 1988).

The Scotian Phase is dated at 18-15 ka (Stea et al., 1998 and authors therein). During this time an ice divide, termed the Scotian Ice Divide, developed down the axis of Nova Scotia. Ice flow patterns from the divide were northward into Georges Bay and the Cape Breton Channel and northwestward into the Bay of Fundy (Stea, 2001, http). Nova Scotia was cut off from the Gaspereau and Escuminac ice sheets and the ice divide may have extended out to the Sable Island Bank (Stea, 2001, http).

The Chignecto Phase is dated at 13-12.5 ka (Stea et al., 1998 and authors therein). Several small ice caps were left behind after the Scotian Ice Divide. Two of these ice caps were located in mainland Nova Scotia, one over the SMB and one over the Antigonish Highlands. Northwestward and westward flow patterns are observed along the Bay of Fundy and southwestward patterns are observed flowing from the Antigonish ice cap over southwestern Nova Scotia (Stea, 2001, http).

By 11 ka, global-scale warming resulted in the termination of glacial activity (Stea, 2001, http).

2.1.3.2. Till Deposits

A number of tills have been deposited over southwest Nova Scotia by these various ice sheets. Tills that were deposited in the Caledonia and Escuminac phases tend to be dominated by matrix rather than clasts and have more far-traveled components (Stea et

al., 1989). Tills that were deposited in the Scotian and Chignecto phases tend to be dominated by clasts rather than matrix and contain more local components (Stea et al., 1989). A number of surficial maps have been created for Nova Scotia. A 1:500,000 (500K) scale digital map is available for the entire province (Stea et al., 1992), a 250K scale paper map is available for the SMB (Finck et al., 1992), and a number of 50K scale paper maps are available for the SMB (e.g. Finck et al., 1994). All maps have been classified based on glacier origin and associated landforms according to a system developed by Goldthwait (1988). The 500K map is divided into very broad categories, whereas the 250K and 50K scale maps show more detail. The different till assemblages listed for the 250K and 50K maps include: (1) pre-Wisconsinan glacially scoured and chemically altered bedrock, (2) Early Wisconsinan Hartlen Till, (3) Late - Middle Wisconsinan Lawrencetown Till, Beaver River Till, and Shelburne River Till, and (4) Holocene - Late Wisconsinan ice contact, marine-alluvial, and outwash deposits (Finck et al., 1992). Table 2.1 provides a detailed description of each of these tills based on descriptions found in Fink et al. (1992).

2.2. LOCAL GEOLOGY – KEJIMKUJIK NATIONAL PARK

2.2.1. Bedrock Geology

According to bedrock geological maps (Horne and Corey, 1994), KNP is underlain by rocks of the Goldenville Group, Halifax Group, and granitoid rocks of the South Mountain Batholith (Figure 2.5).

The park is underlain primarily with rocks from the Goldenville and Halifax groups. Very little bedrock is exposed in the park, therefore geological contacts between these two groups are classified either as mostly “approximate” or “assumed”; most contacts have been delineated by aeromagnetic data (Horne and Corey, 1994). Although most of the contacts between the Goldenville and Halifax groups in the park are assumed to be stratigraphic (i.e. GHT; M. Zentilli, personal communication, May 17, 2001), in at least one location recent field work indicates that there is one contact that is a shear zone (Figure 2.5; P. K. Smith, personal communication, May 2, 2001).

Table 2.1. Description of the till assemblages found in southwest Nova Scotia after Finck et al. (1992).

AGE	DEPOSIT	DESCRIPTION	
Holocene-Late Wisconsinan	Marine-Alluvial and Outwash Deposits	texture: silty clay, sand, and gravel; can be massive to horizontally bedded occurrence: estuarine, alluvial floodplain, alluvial channel, and terraced deposits; channel sequences; flat plains	
	Ice Contact Deposits	texture: silty sand, gravel, and boulders; abrupt grain size transition between shallow to steeply dipping beds occurrence: kames, kame terraces, ice contact deltas, and eskers thickness: 1-15 m derived: clasts reflect provenance of surrounding till other: faulting is common; may be interstratified with till	
Late-Middle Wisconsinan	Shelburne River Till	lithological facies: granite and greywacke/slate texture: sandy matrix-rich to stony clast supported, crudely stratified color: white to very pale brown occurrence: hummocks, ridges, rolling ground moraine renewal distance: 0.1 to > 5 km thickness: 1-3 m (ground moraine), 10-15 m (hummocks and ridges) transport direction: major – southeast, minor – south and west association: kames and eskers derived: matrix may be from up-ice lithologies, pebbles local other: extensive onlap of clasts down-ice onto adjacent bedrock units	
	Beaver River Till	Ablation Moraine	lithological facies: granite, greywacke, slate texture: matrix supported color: very pale brown to yellowish-brown occurrence: hummocks and ridges renewal distance: 0.1 to 6 km thickness: 1-10 m transport direction: southeast and south derived: local other: may exhibit extensive onlap of clasts and matrix down-ice onto adjacent rock types
		Ground Moraine	lithological facies: granite and greywacke-slate texture: structureless stony matrix, sandier varieties with minor washed zones around boulders are common color: light yellowish-brown to dark yellowish-brown (granite facies), light olive-brown (greywacke and slate facies) occurrence: featureless ground moraine renewal distance: tens to hundreds of meters thickness: 1-6 m transport direction: difficult to determine, southeastward across most of SMB, however northward, northwestward and westward directions mapped in northern and western margins of the SMB association: kames and eskers derived: > 90% of clasts transported less than 1 km other: rapid lithological change down-ice from bedrock contacts

Table 2.1. (Continued)

		Drumlin Moraine	lithological facies: non-granitic lithologies are incorporated from stratigraphically older tills texture: medium to coarse grained sandy matrix, moderately stony, minor washing; matrix composition partly dependant on composition of reworked older till color: brown to dark yellowish-brown occurrence: till mantles and forms a ground moraine between drumlins thickness: 1-4 m transport direction: same as ground moraine unit, however a strong southeast transport was inherited from older reworked southeast-transported till (s)
	Lawrencetown Till	lithological facies: clast vary from 10-90% local bedrock to 10-90% non-granitic clasts derived from as far as 90 km texture: muddy to sandy till, moderately compact, jointed, greenish mottling in the weathered zone color: dark reddish-brown to strong brown occurrence: ground moraine and drumlins renewal distance: hundreds of meters to tens of kilometers thickness: 1-2 m (ground moraine), 4-30 m (drumlins) transport direction: vary from southward in the eastern SMB to southeastward in the western part of the SMB derived: distal sources are the metasedimentary/volcanic massif complex of the Cobequid Highlands, Meguma Group, metasedimentary and volcanic rocks of the White Rock, New Canaan, Kentville, and Torbrook formations, Windsor Sub-basin, and North Mountain Basalt other: includes areas previously mapped as undivided till that contain exposures of Hartlen, Beaver River, and Lawrencetown tills; due to limited areal extent individual tills do not form mappable units
Early Wisconsinan	Hartlen Till	lithological facies: granite and slate texture: sandy compact till, clast-rich, fissile color: strong brown (granite facies), olive (slate facies) occurrence: forms or cores drumlins thickness: 1-10 m transport direction: major – southeast, minor – east-southeast derived: clast lithology dominated by local bedrock lithologies, 10-35% of clasts transported 20-25 km
Pre-Wisconsinan	Residuum	lithological facies: chemically weathered bedrock texture: commonly develops a soil-like consistency due to in situ weathering followed by glacial mixing; may retain hypidiomorphic granular texture of parent granite, preservation of K-fspar megacrysts and hydrothermally altered fracture zones thickness: a thin veneer to > 3 m other: restricted to the topographically higher regions of the SMB
	Bedrock	lithological facies: glacially scoured bedrock texture: areas of discontinuous till veneer and B-horizon soil developed to bedrock other: bedrock structure and large scale features of glacial erosion are easily discernable on aerial photographs

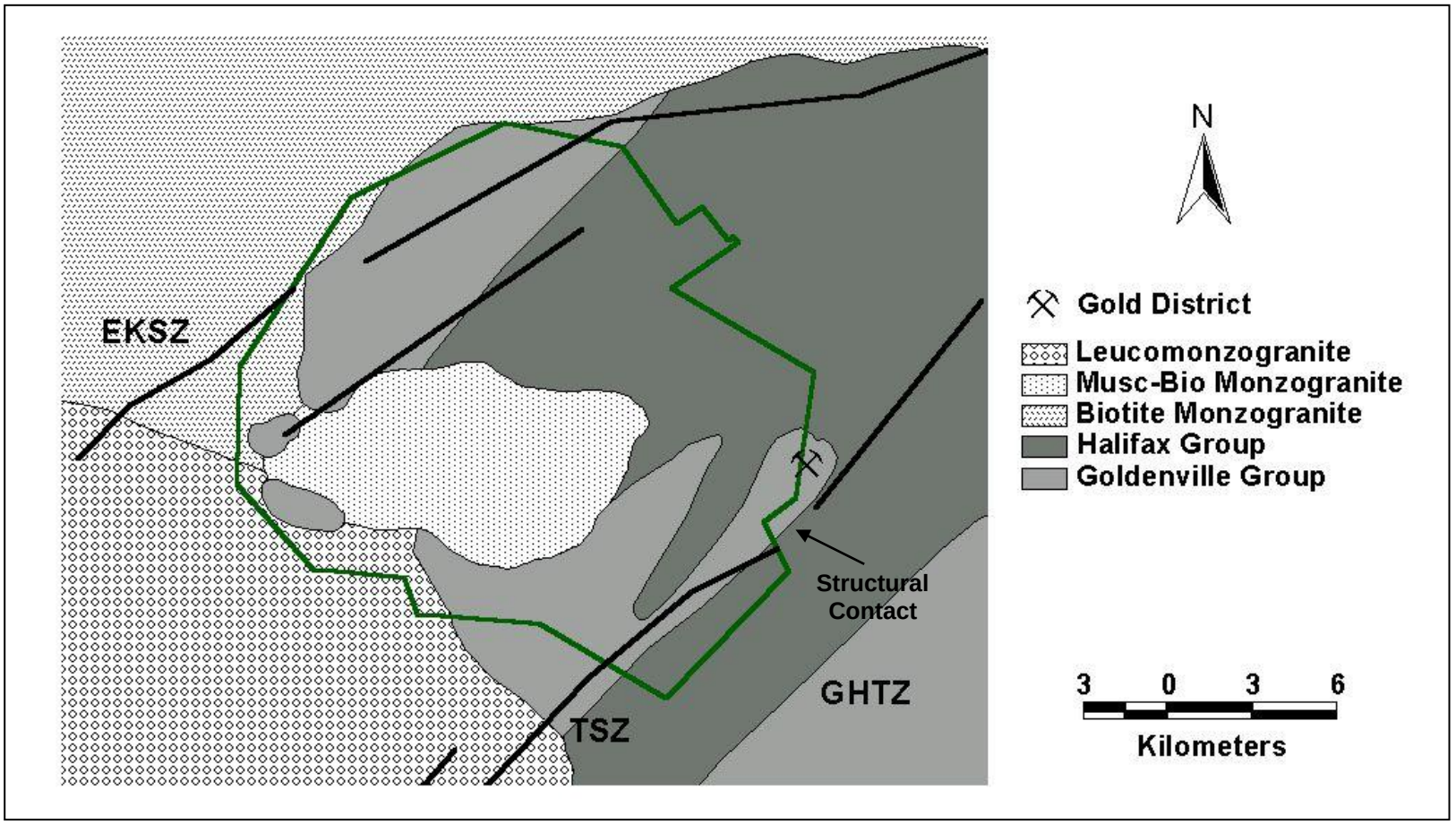


Figure 2.5. Bedrock geology map of Kejimkujik National Park. EKSZ – East Kemptville Shear Zone, TSZ – Tobeatic Shear Zone, GHTZ – Goldenville-Halifax Transition Zone. Map modified from Keppie (2000, http). The structural contact is adapted from P. K. Smith (personal communication, May 2, 2001). The leucomonzogranite constitutes the Davis Lake pluton; the muscovite-biotite monzogranite the Kejimkujik Pluton, and the Biotite Monzogranite the Scrag Lake pluton.

Three distinct types of granite constitute the highest elevations in the park: (1) biotite monzogranite, which underlies the extreme northern and western parts of the park, (2) muscovite-biotite monzogranite, which underlies the central-western part of the park, and (3) leucomonzogranite, which underlies the extreme southwest part of the park. This distribution is important, as the highest Hg values in the park are found in the lakes that overly the muscovite-biotite monzogranite (see Chapter 4). Horne and Corey (1994) refer to the biotite monzogranite as the Scrag Lake monzogranite, the muscovite-biotite monzogranite as the Kejimkujik monzogranite, and the leucomonzogranite as the Davis Lake leucomonzogranite. According to these authors, the Scrag Lake pluton is medium grey, medium- to coarse-grained, megacrystic (10%), has 14-18% biotite, trace muscovite and cordierite, and is characterized by xenoliths. The Kejimkujik pluton is medium grey, fine- to coarse-grained, megacrystic (10%), has 11-16% biotite, trace (1%) muscovite, trace (1%) cordierite (locally 2-3%), and xenoliths. The Davis Lake pluton is whitish-grey to locally blue-grey, medium- to coarse-grained, highly megacrystic (20-30%), has 6-9% biotite, trace (2%) muscovite, 1-3% cordierite, and very few xenoliths (Horne and Corey, 1994).

2.2.2. Surficial Geology

The surficial geology of KNP is composed of: (1) the Beaver River Till ground moraine and ablation moraine (predominately composed of granite lithological facies), located in the extreme northern and eastern parts of the park, (2) the Beaver River Till ground moraine and ablation moraine (predominately composed of slate and greywacke lithological facies), located in the central part of the park, (3) ice-contact deposits that extend E-W through the northern and central parts of the park, and (5) the Shelburne River Till, which is found throughout most of the park (Finck et al., 1994). Overall the till clasts are composed of (1) Scrag Lake, Little Round Lake, and Kejimkujik monzogranite in the southern part of the park (granite facies) and (2) Meguma metasediments in the northern part of the park (slate and greywacke facies). Generally, the till clasts are representative of the underlying lithologies (Finck et al., 1994). The granite clasts are medium grey, fine- to coarse-grained, megacrystic, have 8-18% biotite, with minor

(<1%) amounts of muscovite and cordierite (Finck et al., 1994). The slate and greywacke facies are finely laminated slate, siltstone, and greenish-grey metawacke (Finck et al., 1994).

Chapter 3: Mercury (Hg) in the Environment: An Overview

The following chapter is a literature review on the typical behavior of mercury (Hg) in the environment.

3.1. GENERAL PROPERTIES

Mercury (Hg) is a naturally occurring silver-white metal that is liquid at room temperature (Mineral Gallery, 1998, http). Mercury has a high surface tension, high density, excellent electrical conductivity, will form alloys with most metals, and is chemically stable (NPI, 1999). Mercury is not soluble in water or most other liquids but it will dissolve in lipids, such as fats and oils (NPI, 1999). A table, describing some chemical and physical properties of mercury, is presented in Table 3.1.

3.2. CHEMICAL FORMS AND TRANSFORMATIONS

3.2.1. Forms

Although Hg exists in a number of chemical forms, there are only three forms that significantly contribute to the distribution of Hg in the environment: (1) elemental or metallic mercury (Hg^0), (2) inorganic, divalent mercury (Hg^{2+}), and (3) organic or methylmercury (CH_3Hg^+; abbr. MeHg). *Elemental mercury* is stable, volatile, sparingly soluble in water and is quite easily transported long distances in the atmosphere (Carpi, 1997). *Inorganic mercury* is stable, far more soluble than Hg^0, and has a strong affinity for many inorganic and organic ligands, especially sulphur (Carpi, 1997; Ebinghaus et al., 1999). *Organic mercury* is toxic, fairly soluble in water, and strongly accumulates in living organisms (Mercury: Chapter 2, 1996, http; Ebinghaus et al., 1999). The conversion between these three forms provides the basis of mercury's complex distribution in nature (Ebinghaus et al., 1999) and will be the focus of this chapter.

3.2.2. Transformations

Table 3.1. General overview of the chemical and physical properties of Hg. Taken from Chesterman (1995), Mineral Gallery (1998, http), and Banfield (2001, http).

Chemistry	Hg, Elemental Mercury (Hg0)
Periodic Table Group	IIB, transition metals (shares this group with zinc and cadmium)
Atomic Number	80
Atomic Weight	200.59
Color	Bright Silvery-white Metallic
Luster	Metallic
Transparency	Opaque
Associated Minerals	Cinnabar (HgS – mercury sulphide), Calomel (HgCl - mercury chloride)
Mineral Occurrence	Cinnabar – formed at low temperatures, usually near hot springs or where there has been volcanic activity; also forms in epithermal veins, associated with opal, chalcedony, and dolomite Calomel – a rare mineral that is never found in large quantities; most often a secondary mineral that forms from the alteration of cinnabar or other mercury minerals; can be deposited from hot underground solutions
Specific Gravity	13.5+

Mercury undergoes two very important chemical transformations: (1) oxidation-reduction and (2) methylation-demethlylation (Figure 3.1). In terms of living organisms, the latter transformation is more significant (Mercury: Chapter 2, 1996, http). Methylated Hg (MeHg) is the most dangerous form of Hg: (1) it is a neurotoxin for vertebrate species, (2) it may inhibit enzyme activity in the brain, and (3) prolonged exposure may cause mental retardation (Gabriel, 1998). In general, the transformation of Hg to MeHg, and subsequent demethylation, is poorly understood (Parkman et al., 1994). However, it has been shown that methylation and demethylation can take place by biotic and abiotic processes (various authors in Godbold, 1994; various authors in Parkman et al., 1994; Mercury: Chapter 2, 1996, http). In terms of methylation, biotic processes (conversion by microorganisms) play an important role.

Many types of microorganisms can turn Hg^{2+} into MeHg, however, it is sulphate reducing bacteria that are responsible for most of these conversions (e.g. Branfireun et al., 1999). These conversions take place in the soil, sediment, and water (Mercury: Chapter 2, 1996, http). Most Hg^{2+} is converted to MeHg in anoxic lake sediments or in the most oxygen depleted parts of a lake (e.g. Mercury: Chapter 2, 1996, http; Winfrey and Rudd, 1990 in Branfireun et al., 1999).

3.3. NATURAL SOURCES OF HG

All of the Hg that is present in the environment today originated in the lithosphere (Ebinghaus et al., 1999). Since the origin of the earth, this Hg has been circulated throughout the environment. Most of the Hg that is released to the environment from natural sources is in the elemental form (various authors in Ebinghaus et al., 1999). Natural sources of Hg include: (1) erosion and weathering of rocks, minerals, and mineral deposits, (2) volcanic eruptions, (3) volatilization from the ocean (which receives Hg from mid-ocean ridges and continental rift systems), and (4) degassing of natural geothermal and geological crevices (Environmental Geochemistry, 1994, http; Mercury: Chapter 2, 1996, http; Krabbenhoft and Rickert, 1995, http; Ebinghaus et al., 1999). Other natural sources of Hg include the evasion of Hg from water, soil, and vegetation

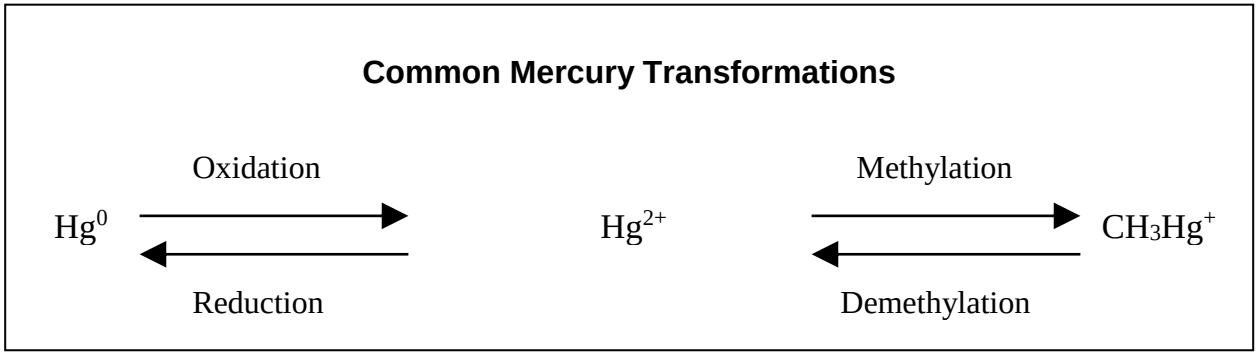


Figure 3.1. Common Hg transformations in the environment. Oxidation and reduction reactions result in changes in valence states. Methylation is the addition of a "methyl group" or a hydrocarbon group (CH_3). Demethylation is the removal of this group. Figure and definitions modified from Mercury: Chapter 2, 1996, http.

(Schroeder, 1994; Ebinghaus et al., 1999), however these sources could represent anthropogenically deposited Hg that is being re-emitted to the atmosphere.

3.4. ANTHROPOGENIC SOURCES OF HG

Different studies have attempted to estimate the ratio of anthropogenic Hg to naturally occurring Hg in the environment, with little agreement as to whether the ratio is <1 or >1 (e.g. various authors in Benoit et al., 1994; Mercury: Chapter 2, 1996, http). Although the ratio is controversial, it is estimated that 200,000 tons of Hg have been emitted by anthropogenic sources since 1890 (Ebinghaus et al., 1999), resulting in a 1.5-3 fold increase of Hg in the atmosphere (Benoit et al., 1994).

Anthropogenic sources of Hg include: (1) burning of fossil fuels (coal, oil, wood) to produce heat, steam, and electricity, (2) chlorine alkali processing plants, (3) waste incinerators, (4) metal processing, (5) mining, which accelerates weathering, and (6) agriculture (Mercury: Chapter 2, 1996, http; Krabbenhoft and Rickert, 1995, http; Ebinghaus et al., 1999).

Unlike natural sources of Hg, which contribute mainly Hg^0 to the environment, anthropogenic sources contribute large amounts of Hg^{2+} to the air (Porcella, 1994). For example, coal combustion is estimated to emit 20-50% Hg^0 and 50-80% Hg^{2+}, and waste incinerators are estimated to emit 10-20% Hg^0 and 75-85% Hg^{2+} (Carpi, 1997). Since Hg^{2+} is water soluble, most of the Hg emitted from anthropogenic sources is removed from the atmosphere by precipitation close to the source (Carpi, 1997). Most of this Hg ends up in the soil (Ebinghaus et al., 1999), where it can remain for years before being completely redistributed to the environment.

3.5. EXTERNAL SOURCES OF HG TO LAKES

3.5.1. Atmospheric Input

Hg levels in the Atmosphere: Average Hg concentrations in the atmosphere are very low (i.e. parts per trillion; Keeler et al., 1994). Background Hg levels are typically between 10-20 ppt (Mercury, 1992, http) and only rarely exceed 100 ppt (Winter, 2001, http).

Hg Forms in the Atmosphere: 95-98% of the Hg in the atmosphere is Hg^0; the other 2-5% is vapor-phase Hg^{2+}, gaseous MeHg, and/or particulate Hg (Porcella 1994; Ebinghaus et al., 1999). The residence time for Hg^0 in the atmosphere can range from 5 days to 3 years (various authors in Mercury: Chapter 2, 1996, http), and it can travel up to 2000 km from its source (Lindqvist, 1994).

Since Hg^0 is stable in the atmosphere, anthropogenically (or naturally) emitted Hg will contribute to the global background levels, hence influencing the deposition at every location, even in remote areas (Lindqvist, 1994). Recently, environmental studies have shown that fish in remote lakes have high levels of Hg. The main source of the Hg in these lakes is commonly attributed to an increase in atmospheric Hg levels, as a result of increased anthropogenic emissions. (Krabbenhoft and Rickert, 1995, http).

MeHg constitutes 1-5% of total Hg in precipitation (e.g. various authors in Hudson et al., 1994; Peterson et al., 1996 in Ebinghaus et al., 1999), however the source of this Hg in not known. There is some evidence that MeHg is emitted from marine and continental sources (various authors in Ebinghaus et al., 1999) and other evidence suggesting that MeHg might actually form in the atmosphere (Munthe, 1994).

Atmospheric deposition of MeHg, however, is typically insufficient to account for the levels of MeHg found in lake organisms (Gilmour and Henry, 1991 in Branfireun et al., 1999). The general consensus is that most MeHg is derived from in-lake and in-catchment processes (e.g. Fitzgerald et al., 1994; Porcella, 1994).

Hg Input – From Atmosphere to Lakes: The ultimate fate of Hg in the atmosphere is wet or dry deposition (Munthe, 1994). Dry deposition is a physical removal process that does not involve precipitation (e.g. gravitational settling, impaction, and adsorption). Wet deposition is the removal processes associated with precipitation (e.g. dissolving in raindrops or incorporation into raindrops; Mercury: Chapter 2, 1996, http). Mercury is primarily deposited by wet deposition, however in some situations, dry deposition can become very important (various authors in Munthe, 1994). Inorganic Hg can be removed from the atmosphere by either wet or dry deposition (Ebinghaus et al., 1999), whereas Hg^0 can only be removed by dry deposition (Carpi, 1997). Water insoluble Hg^0 must first be converted to Hg^{2+} (generally through an oxidation reaction with ozone, O_3) before it

can be deposited by wet deposition (Munthe, 1994). Although the deposition of MeHg from the atmosphere is rarely discussed in the literature, a number of studies suggest that precipitation inputs of MeHg can contribute a significant fraction of the total MeHg accumulated annually by fish (various authors in Watras et al., 1994).

3.5.2. Terrestrial Input

3.5.2.1. Rocks

Hg Levels in Rocks: Anderson (1979) and Jonasson and Boyle (1972) give an excellent overview of recorded Hg levels in bedrock up to the mid 70's. Typical average values for some of the lithologies that are relevant to this study are shown in Table 3.2. Estimates for the amount of Hg in the earth's crust vary from about 80 to 500 ppb (Manahan, 1994; Mercury, 2000, http). The difficulty in using these numbers is that accurate Hg measuring techniques have only developed in the last 10-15 years (Hudson et al., 1994). In historical data, sample contamination can account for up to 500% error (Fitzgerald and Watras, 1989 in Watras et al., 1994). For example, the same lake in Wisconsin yielded a water value of 200 ppt Hg in 1983, 50 ppt Hg in 1985, and 0.5 ppt Hg in 1986 (Mercury: Chapter 2, 1996, http). Modern sampling techniques for Hg analysis have become more sensitive and contamination-free. The difficulty now lies in comparing present day data to historical data. Unfortunately, there is very little published data on typical Hg levels in rocks for the last decade, as most environmental studies on Hg behavior have not evaluated any sort of geological component for their analysis. Therefore, determining Hg levels for rocks in Nova Scotia has been an important part of the TSRI project. As stated above (see Chapter 1, section 1.3.1), an average value of 3.3 ppb Hg (n = 146) has been established for rocks in southwest Nova Scotia (Smith, 2000). This value may be modified as new rock samples are collected and analyzed in the province.

Hg Forms in Rocks: The only common ore of Hg is the mineral cinnabar (HgS), and the Hg content in cinnabar exceeds 86% (Mercury: Chapter 2, 1996, http). There are three varieties of cinnabar ore: (1) compact masses of cinnabar, (2) cinnabar in veins, and (3) quartz sandstone impregnated with cinnabar (Mercury, 2000, http). In southwest Nova

Table 3.2. All data taken from various authors in Anderson (1979).

Lithology	**Hg (ppb)**
Igneous Rocks	Generally < 50 ppb, most of the time < 10 ppb (a number of studies)
Diabase	0.2-17.7 ppb, with an average around 3.5 ppb (two studies)
Gabbro	79 ppb (one study)
Diorite	0.4 – 19.7 ppb, with an average around 5.0 ppb (one study)
Slate/Shales	0.9 – 513 ppb (a number of studies)
Sandstone	0.8 – 30 ppb (a number of studies)

Scotia, only one possible occurrence of cinnabar has been noted about 15 km east of the park (P. K. Smith, personal communication, June 20, 2001). Instead, Hg^0 and Hg^{2+} are found as trace components of many minerals. For example, Smith (2000) consistently noted above average Hg levels in biotite separates taken from the South Mountain Batholith in Nova Scotia.

Hg Input – From Rocks to Lakes: Hg in rocks steadily contributes small amounts of Hg to the atmosphere (Hg^0) and waters (Hg^{2+}) by weathering (Mercury: Chapter 2, 1996, http). This process is sometimes enhanced by acid rain, which leaches Hg from the minerals. In most regions, background Hg inputs from the local bedrock are considered to be minor when compared to atmospheric inputs (Swain and Engstrom, 2001, http).

3.5.2.2. Soil

Hg Levels in Soil: Mercury levels in the soil typically range from 20-625 ppb (Mercury, 1992, http).

Hg Input into Soil: Basically, Hg enters the soil from (1) the atmosphere (via wet and dry deposition), (2) anthropogenic wastes (e.g. sewage sludge, landfilling of solid wastes, and agricultural use of pesticides containing Hg), and (3) from the natural degradation of till and bedrock. Once Hg enters the soil, it is strongly bound to the organic matter in the A-horizon (also termed the humic layer, Figure 3.2; Johannson and Iverfelt, 1994). Even a small amount of humus content in the A-horizon is enough to adsorb large amounts of Hg, resulting in an accumulation in the upper part of the soil (Lodenius et al., 1987 in Cocking et al., 1994; Lee et al., 1994). Mercury that is not adsorbed by the soil is eventually volatilized, precipitated, leached, or taken up by plants (Adriano, 1986 in Cocking et al., 1994).

Hg Forms in Soil: In the soil, Hg is mainly present as Hg^{2+} (Mercury: Chapter 2, 1996, http), however all forms of Hg can be found in the humic layer of the soil (Godbold, 1994). MeHg can be abiotically produced in the humic layer, and the amount of MeHg produced depends on the oxygen levels (↓ O ↑ MeHg), sulphur levels (↑ sulphur ↑ MeHg), and pH (↓ pH ↑ MeHg) (Rogers, 1976 in Cocking et al., 1994; Mercury: Chapter 2, 1996, http). One study suggests that MeHg might have a weaker bond with

Figure 3.2. Soil profile showing the A-horizon, the leached out grey zone, and the B-horizon.

soil organic matter than Hg^{2+} (Lee et al., 1994). If this is the case, MeHg can be mobilized and transported much more readily than Hg^{2+} (Mercury: Chapter 2, 1996, http).

Hg Input – From Soil to Lakes: The mobilization of Hg from the soil is generally promoted by: (1) microbial activity, (2) organic poor soil, and (3) high pH values (Mercury: Chapter 2, 1996, http). High pH values will actually promote the solubility of Hg, whereas low pH values will cause a stronger bond with the organic matter (Cocking, et al., 1994).

Because of the strong binding of Hg to organic matter, only a small percentage (<0.1%) of Hg in the soil will ever reach lakes via runoff. However, this small amount can make up to 25-75% of the Hg reaching the lakes (various authors in Lee et al., 1994). Mercury generally travels to streams and lakes with dissolved humic matter (i.e. dissolved organic content, DOC), which acts as a carrier of Hg from soils to inland waters (various authors in Johansson and Iverfelt, 1994).

3.5.2.3. Till

According to Finck et al. (1994), the tills in KNP are primarily derived from underlying bedrock. However, the distribution of Hg in tills is poorly understood. In order to assess the potential for tills as a source of Hg, till samples have been collected in southwest Nova Scotia by T. Goodwin (Nova Scotia Department of Natural Resources). The average value for 59 samples is 59.77 ppb (min = 6.4, max = 158.5, sd = 40.07; T. Goodwin, written communication, May 2, 2001). Since Hg is adsorbed in the humic layer of the soil and shows no evidence of downward migration, the amount of Hg in the till is probably a reflection of the underlying geology, rather than a reflection of atmospheric conditions. As with soil, Hg^{2+} is probably the main type of Hg found in the till. Because these tills have low organic content (T. Goodwin, personal communication, May 2, 2001), methylation in the till is probably unlikely, as most methylation takes place in organic rich conditions. However, methylation rates and Hg mobility in the till have never been investigated, therefore these questions remain unanswered.

3.5.2.4. Terrestrial Plants

Hg levels in Terrestrial Plants: Background concentrations of Hg in terrestrial plants typically range from 3 to 100 ppb (Lodenius, 1994).

Hg Input into Terrestrial Plants: Plants can incorporate Hg into their systems in a number of ways: (1) Binding of free Hg^{2+} ions by precipitation on plant surfaces. However most Hg in precipitation is dominated by particulate phase Hg (Lindberg et al., 1994). (2) Absorption of Hg^0, Hg^{2+}, and MeHg through the leaves at elevated atmospheric concentrations. However, there is also a re-emission of the Hg (or conversion of Hg into volatile compounds and release), which greatly reduces the concentration in leaves (Lodenius, 1994; Ebinghaus et al., 1999). Any part of the plant that is in direct contact with the air is capable of releasing Hg as a vapor (Aula et al., 1994). (3) Direct uptake from Hg enriched soil (Mercury, 1992, http). Although the humic layer in soils is an important rooting zone for plants (Godbold, 1994), the uptake of Hg by plants in enriched soils seems to be very limited (various authors in Lindberg et al., 1994). Most plants uptake metals that have been mobilized by low pH values. However, as stated above, Hg is strongly bound to the organic matter in the soil, especially at low pH values.

Affects of Hg on Terrestrial Plants: Although plants only uptake small amounts of Hg (Lodenius, 1994), high Hg levels in the soil or the atmosphere can have adverse affects on the plants. These affects include a reduction in: (1) photosynthesis and transpiration, (2) water uptake, (3) chlorophyll synthesis, and (4) root growth (various authors in Godbold, 1994).

Hg Input – From Terrestrial Plants to Lakes: Plants do store some Hg in their plant structure, and upon decay this Hg can be released into the watershed (Ebinghaus et al., 1999). For example, leaves that fall onto lakes in the autumn can contribute large amounts of Hg to a lake. One study in Wisconsin showed total Hg values between 46-48 ppb, and MeHg values between 0.25-0.07 ppb, for red maple and white pine leaves that fell onto a lake (Watras et al., 1994).

3.5.2.5. Forests

Hg Input into Forests: The accumulation and translocation of Hg in forests and the movement to the lakes and streams is poorly understood (Grigal et al., 1994). However, most studies agree that there is more Hg in a forest than there is in surrounding areas for three reasons: (1) large surface areas of forest canopies tend to extract Hg from the atmosphere via dry deposition, although very little is known about this process (Lindberg et al., 1994), (2) the wet canopy of a forest can provide a large surface area for the oxidation of Hg^0 and hence the removal of Hg from the atmosphere (Godbold, 1994), and (3) Hg stored in forest plants deposit their leaves and needles on the forest floor, adding additional Hg to the soils (Godbold, 1994).

Hg Input – From Forests to Lakes: Since the forest soils are potentially a large sink for Hg, clear cutting (Benoit et al., 1994), forest fires (Ebinghaus et al., 1999), and the creation of reservoirs (Aula et al., 1994) all release large amounts of Hg to the atmosphere and the surrounding watershed. Normally, this Hg would be bound and immobilized in the soil.

3.5.2.6. Wetlands

Definition: A wetland is a dynamic ecosystem with complex interrelationships between hydrology, soils, and vegetation (Carter, 1982). These environments are usually considered to be transitional between aquatic and terrestrial environments, where the water table is generally at or near the surface (Carter, 1982). Wetlands contain large amounts of clays and humic substances; therefore they can quite readily remove metals (including Hg) from surface and ground water (Osmond, 1995, http). Metals can be removed in a number of ways: (1) precipitation of the metal as an inorganic compound, (2) adsorption of the metal to precipitated hydrous oxides, (3) complexation of the metals with humic substances, or (4) binding of metals with clay particles (Osmond, 1995, http). For example, clays often obtain a negative charge by ion replacement, where Si^{4+} and Al^{3+} ions are replaced by metal ions of similar size but lesser charge (Manahan, 1994). This produces an overall negative charge on the clay particle. Therefore, clay-rich

wetlands become very effective at removing positively charged metal ions from the water (Osmond, 1995, http).

Hg Input – From Wetlands to Lakes: Wetlands, which have high total Hg concentrations, also tend to have high pore water MeHg concentrations (Branfireun et al., 1999). This is probably a result of increased methylation due to the presence of abundant organic material. Various studies show that wetlands are a large source of MeHg to the downstream lakes (various authors in Branfireun et al., 1999). These studies show a 4-15 times greater yield of MeHg from watersheds containing wetlands than from watersheds without wetlands. Hurley et al. (1995 in Branfireun et al., 1999) showed a positive correlation between the percent of wetland surface area in a watershed to MeHg yield.

On the other hand, wetlands are efficient at retaining Hg in their top layer, and transport of humic matter (the carrier of Hg from soils to lakes) through wetlands to the streamwaters can be very slow. Therefore, lower Hg levels in the run-off water from watersheds, where there are a large percentage of wetlands, is also possible (Johansson and Iverfelt, 1994).

More likely, the amount of Hg present in a watershed is a function of the types of wetlands present in a watershed (see Chapter 4, section 4.2.2.2) as opposed to the percentage of wetlands. Some wetlands retain Hg efficiently, whereas others release Hg.

3.5.2.7. Watersheds

Although it is thought that most MeHg is produced within the lake, there is also an input from the terrestrial watershed. For example, many studies have shown that lakes with large drainage areas (high land-to-lake ratios) are very sensitive to MeHg inputs from the watershed (Hultberg et al., 1994; various authors in Verta et al., 1994). In addition, several studies show higher Hg levels in drainage lakes as oppose to seepage lakes (i.e. lakes that do not receive drainage) (e.g. Grieb et al., 1990 in Verta et al., 1994).

There are a number of environments found in the terrestrial watershed that can potentially store and release Hg to the environment: (1) rocks, (2) soil, (3) till, (4) terrestrial plants, (5) forests, (6) and wetlands. The amount of Hg (and more importantly MeHg) that is made available to the lakes from these environments is an important part of

the lake's Hg budget. There are obviously other settings that have not been considered (e.g. groundwater and shear zones), however limited research has been done in these areas.

3.6. INTERNAL DISTRIBUTION OF HG IN LAKES

3.6.1. Lake Sediment

Hg levels in Lake Sediment: Canadian Environmental Guidelines for the limit of acceptable Hg concentrations in lake sediments are 0.17 ppm (Canadian Environmental, 2000, http).

Hg Input into Lake Sediment: Hg gets incorporated into the lake sediment in a number of ways: (1) settling out of Hg from the water column (Mercury, 1992, http), (2) release of Hg from dead and decaying microorganisms and organic matter (Krabbenhoft and Rickert, 1995, http), and/or (3) input from underlying bedrock and soils (Swain and Engstrom, 2001, http).

Hg Mobilization Between Lake Sediment and Lake Water: The upper layer of lake sediments can extract Hg from the water, leaving less Hg for the organisms in the water column (Mercury: Chapter 2, 1996, http). This Hg can then be released subsequently by diffusion or re-suspension (Krabbenhoft and Rickert, 1995, http). However, some studies suggest that once the Hg is buried below the sediment/water interface, it is very unlikely that the Hg will be remobilized (e.g. Watras et al., 1994).

The amount of Hg that settles to the bottom of a lake appears to be a function of lake color and stratification. One study showed that most Hg in clear water lakes gets deposited in the sediment whereas in dark water lakes (humic lakes) most of the Hg is retained in the water column (Meili, 1991 in Haines et al., 1994). A short epilimnetic Hg residence time results in the removal of Hg from the water column into lake sediment, whereas a long epilimnetic Hg residence time results in high evasion (Watras et al., 1994).

Typical Properties of Hg in Lake Sediment: There are two typical properties of lake sediments: (1) There is no correlation between Hg concentrations in fish and Hg concentrations in lake sediment (various authors in Meili, 1994). It has been suggested

that the variability takes place at the abiotic/biotic transition zone (Meili, 1994). Another possible explanation could be that the amount of Hg in the sediment more closely reflects the amount of Hg in the underlying geology rather than the amount of Hg in the overlying water column. For example, lakes may form in the topographic depressions above shear zones, and Hg-bearing minerals in these shear zones may be related to Hg in lake sediments. (2) The lake sediment is a huge reservoir for Hg (e.g. Watras et al., 1994). Sediments typically have Hg levels that are six orders of magnitude higher than the atmosphere and water.

Lake Sediment and Bioavailability: Regardless of Hg levels in lake sediment, sedimentation transports Hg^{2+} to the oxic/anoxic water boundary and into the lake sediment, where resident bacteria may facilitate methylation (Watras et al., 1994; Oremland, 2001, http). As MeHg is formed, it is not strongly adsorbed to sediments because it is somewhat soluble in water, therefore it is available for biological uptake (DaCosta, 1999).

3.6.2. Lake Water

Hg levels in Lake Water: Mercury levels in natural uncontaminated surface waters generally range from 0.1-20 ppt, with most less than 5 ppt (Mastrine et al., 1999 in Environmental Geochemistry, 2001, http). General guidelines set a limit of 2 ppb for drinking water (CERHR, 1999, http).

Hg Forms in Lake Water: Mercury is found in a number of forms in natural waters, however the most common forms are (1) dissolved Hg^{2+} and (2) Hg^{0} that is absorbed to particles of Fe and Al oxides and clay minerals (Environmental Geochemistry, 2001, http). Some studies show that particulate (suspended or insoluble) Hg levels are 5-25 times higher than dissolved Hg (e.g. Hinkle and Learned, 1969 in Benes and Havlik, 1979).

MeHg generally accounts for a small percentage (1.5-20%) of the total Hg in the water column (Bloom et al., 1994 and various authors in Hudson et al., 1994). As stated above, most MeHg is formed at the oxic/anoxic boundary in a lake. Therefore, MeHg concentrations are the highest near the bottom of the lake. These concentrations seem to

be linked to high sulphide and low oxygen concentrations (Porcella, 1994). Total Hg levels and the pH values in the lake probably play a secondary role, as MeHg is still produced in lakes with low total Hg concentrations and high pH (>6) values (Cossa, 1994).

Hg Behavior in Lake Water: Within a lake, Hg inputs follow three main pathways: (1) particle scavenging and transport toward sediments, (2) conversion from Hg^{2+} to Hg^{0} and subsequent evasion, and (3) methylation and subsequent uptake by organisms and/or demethylation (Watras et al., 1994). These processes compete for the Hg, and the outcome is dependant on a number of variables, such as (1) oxygen content, (2) sulphur content, (3) pH, and (4) dissolved organic matter concentration (DOC; which is linked to lake color).

3.6.3. Fish

Hg levels in Fish: MeHg usually accounts for 95-99% of the total Hg found in fish (Wiener, 2001, http). MeHg levels for most fish range from <0.01-0.5 ppm and most fish consumption advisories are set at 1 ppm Hg (CERHR, 1999, http).

Bioavailability: In order for fish to incorporate Hg into their systems, the Hg must be in the methylated form (MeHg). As stated above, most MeHg is created within a lake by methylating bacteria (e.g. Branfireun, et al., 1999). MeHg-rich bacteria are then either (1) consumed by organisms and transmitted to higher levels in the food chain and/or (2) MeHg is released from the bacteria into the water column where it quickly adsorbs to plankton, which is then consumed by the next higher level in the food chain (Krabbenhoft and Rickert, 1995, http). Fish incorporate MeHg into their systems by (1) eating MeHg rich organisms and/or (2) uptake of MeHg from the water as it passes over their gills (CERHR, 1999, http). Most studies agree that methylation and demethylation do not occur within the fish (e.g. Huckabee et al., 1979). Fish probably take in Hg^{2+}, but release it again to the water (Huckabee et al., 1979).

Hg Behavior in Fish: MeHg assimilates across the fish gut, binds to red blood cells, and is rapidly transported via the circulatory system to all internal organs, readily crossing internal cellular membranes (Wiener, 2001, http). Most MeHg ends up in the

skeletal muscle and not in the skin and fat (in contrast with most PCB's and other organic contaminants; Krabbenhoft and Rickert, 1995, http). Therefore, the Hg present in fish cannot be removed by cooking or cleaning the fish (Mercury in the Environment, 2001, http).

The problem with MeHg is that it bioaccumulates (i.e. the fish take up the contaminant more readily than their bodies can eliminate it; Krabbenhoft and Rickert, 1995, http). Therefore, small amounts of Hg in the water can cause significant accumulation in the fish. Bioaccumulation factors (the ratio of Hg levels in fish to Hg levels in water) can reach up to 225,000 (e.g. fish 0.45 ppm, water 2 ppt; Mercury in the Environment, 2001, http).

In addition to bioaccumulation, Hg also biomagnifies as it moves up the food chain (i.e. there is a significant increase in the concentration of Hg at each level of the food chain). MeHg builds up in the food chain, starting from bacteria, to small fish, then to larger fish (Figure 3.3; Mercury in the Environment, 2001, http). Therefore, because of bioaccumulation and biomagnification effects, older fish tend to have higher concentrations of Hg than younger fish, especially as older fish switch their diets from a low MeHg anthropod diet to a high MeHg fish diet (Huckabee et al., 1979).

Several studies show high Hg concentrations in fish from lakes with any one of a combination of (1) low pH, (2) low alkalinity, (3) high dissolved organic content, (4) dark color, (5) newly flooded reservoirs, (6) nutrient poor, and (7) lakes that receive drainage from wetlands (e.g. Krabbenhoft and Rickert, 1995, http; Wiener, 2001, http; Colman et al., 2001, http).

Most lakes that have fish consumption advisories are only lightly contaminated ecosystems. However, their physical and chemical conditions are such that Hg^{2+} is readily converted to MeHg, and then the MeHg can enter the food chain (Wiener, 2001, http). Mercury levels in fish are generally low in lakes with low methylation rates, even in lakes with a large inventory of Hg^{2+} (Wiener, 2001, http).

3.6.4. Loons

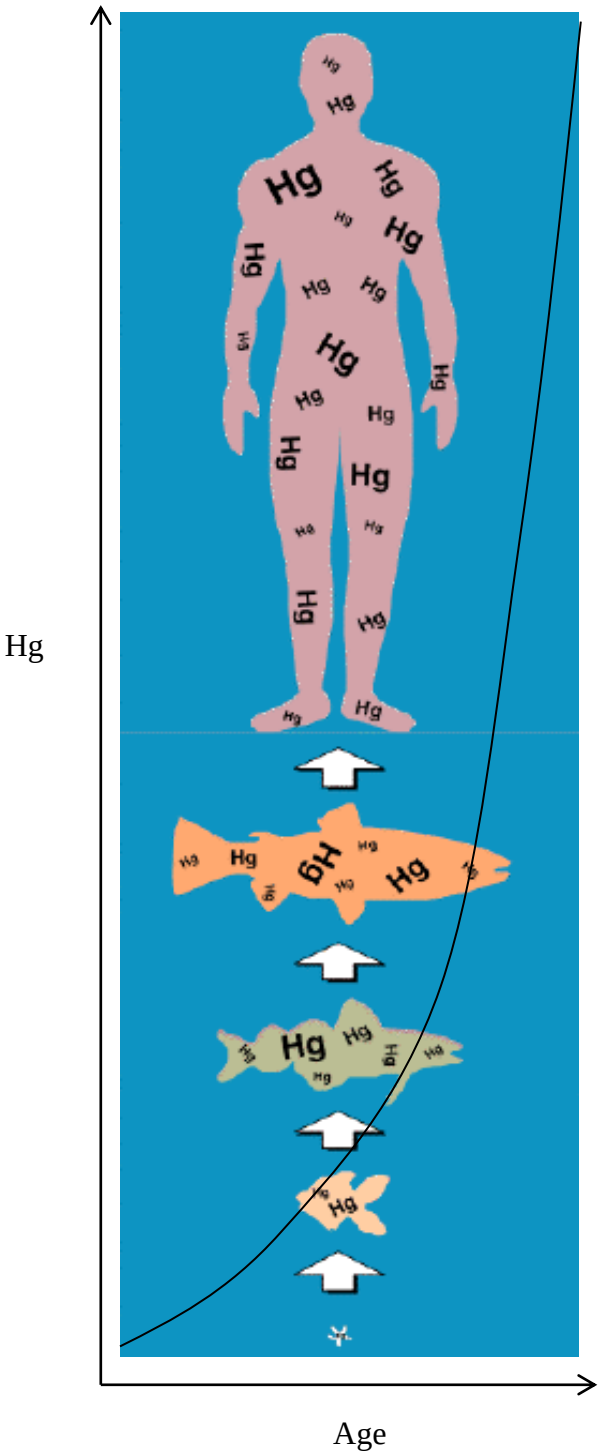


Figure 3.3. MeHg biomagnifies up the food chain, starting with microorganisms up to big predatory fish, and finally to humans. Figure modified from Krabbenhoft and Rickert (1995, http).

The loons in Kejimkujik National Park accumulate Hg primarily by eating MeHg-rich fish (mainly perch; Figure 3.4). A strong correlation between blood Hg levels within families and the high levels of Hg found in loon feathers at the end of the summer, after a full molt in the spring, suggests that this Hg is being accumulated in the park (Beauchamp et al., 1997). High Hg levels can produce a number of adverse affects on the loons: (1) decreased chick brooding (back-riding) time, (2) reduced productivity through the lack of nesting attempts, (3) lower nest attentiveness, (4) aberrant breeding responses, and (5) affects on avian behavior (various authors in Nocera and Taylor, 1998, http). In addition to the loons eating MeHg-rich fish, one study in the United States suggests that loons prefer to nest on acidic lakes, where fish MeHg levels tend to be the highest (Meyer, 2001, http).

3.7. SUMMARY

Figure 3.5 provides a simplified overview of Hg sources, sinks, and species for a remote watershed based on the information presented above. Basically, Hg can enter a lake in two ways, via (1) atmospheric deposition and/or (2) terrestrial input. However, in terms of Hg contamination in fish and loons, (1) MeHg input into a lake and (2) methylation rates seem to be more important than the total amount of Hg in any given watershed.

Figure 3.4. The loon's diet consists primarily of fish.

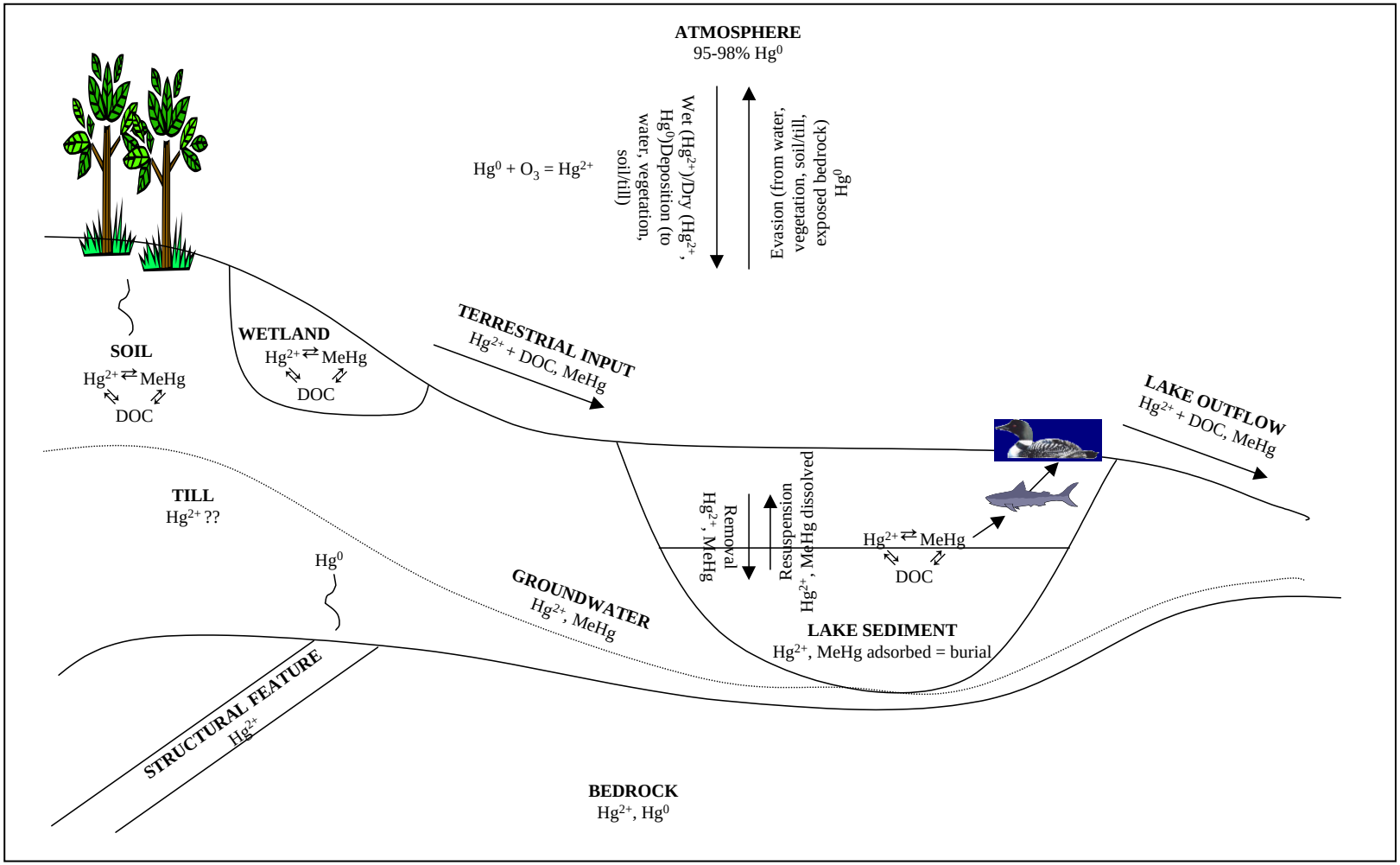


Figure 3.5. Overview of Hg sources, sinks, and species for a remote watershed.

Chapter 4 – The GIS Database

4.1. INTRODUCTION

Geographic Information Systems (GIS) are useful tools that facilitate the display and analysis of multiple layers of spatially related data. Over the past 25 years, a variety of data have been collected in the vicinity of Kejimkujik National Park (KNP) that pertain to the origin of the mercury (Hg) anomalies, especially in the past 2-3 years, as a result of a multi-disciplinary project entitled "The Toxic Substance Research Initiative (TSRI) Mercury Project". GIS is an ideal tool for analyzing and interpreting these data sets and the relationship between them.

In July 2000, the TSRI team released a CD-ROM containing a compilation of data sets that have been gathered in KNP for the Hg project over the last number of years (Rencz, 2000, CD-ROM). This CD-ROM includes data on lake physical characteristics and Hg in loons, fish, insects, lakes, and terrestrial plants. Other data sets that are not on the CD-ROM (e.g. wetland surface area and bedrock geology) have also been made available by the Centre of Geographic Sciences (COGS), Nova Scotia Department of Natural Resources (NSDNR), and Nova Scotia Department of the Environment (NSDOE) for this thesis.

In order to determine relationships between the various data sets, a synthesis of the data into the same reference geographic layer is necessary. For example, in order to compare the relationship between Hg in fish to Hg in surface water at a given locality, each parameter needs to be linked to a common geographic unit. The lakes were chosen as the reference geographic layer because most data sets are lake-based (e.g. fish and lake surface water). The data sets that are not lake-based (e.g. terrestrial plants) can be indirectly tied to the lakes via their watershed. This process is discussed below.

The final product is a GIS database, called **KEJI DATASETS COMBINED** (UTM NAD83 coordinates). The full database is provided in Appendix 4.1 and is included in digital format as XLS and DBF files on the CD-ROM in the back cover (Note: values of '9999' indicate 'no data'). A description of each field in the database is included in Appendix 4.2. The **KEJI DATASETS COMBINED** database can be directly linked to 24 lakes in KNP

(Figure 4.1). These lakes were chosen based on data availability. The software used to create the GIS database includes: (1) SPANS®, (2) ARC/INFO® v.7.2.1, (3) ArcView GIS® v.3.2, and (4) Microsoft Excel® 97. This chapter describes in detail (1) the methods used to generate the GIS database, (2) the results of the GIS database, (3) and a discussion of these results.

4.2. METHODS

Sixteen data sets were incorporated into the GIS database (Table 4.1). From these sixteen data sets, 122 fields (excluding LAKE NAME, EASTING, and NORTHING) were derived (Figure 4.1 and Appendix 4.2). Some of the original data sets have more than one value for each lake; some of the data sets have points that fall outside of the lake; and some of the data sets have fields that are irrelevant for this project. For this reason, most data sets had to be *modified* before they could be incorporated into the GIS database. In this thesis, the term *modified* means 'the steps necessary in order for each field in each data set to yield one value for each lake'. A description of the modifications made to each data set is included in this section. The original and modified databases are included in digital format on the CD-ROM in the back cover.

This section has two parts: (1) a description of how each lake-based data set was incorporated into the GIS database and (2) a description of how each non lake-based data set was incorporated into the GIS database. In the second part, there are two further subdivisions: (1) a description of how the non lake-based *point* data was incorporated into the GIS database and (2) a description of how the non lake-based *polygon* data was incorporated into the GIS database. Point and polygon data are two very distinct data types (Bonham-Carter, 1994). *Point* data is anything that occurs in one geographic location on the ground (e.g. location of a vegetation sample or location of a water sample). Point data have zero area and zero length. *Polygon* data is anything that covers a geographic area (e.g. a wetland or a geological unit). Polygon data have nonzero area and nonzero perimeter.

4.2.1. Incorporating Lake-Based Data

Figure 4.1. All data sets are combined based on these 24 lakes. This is an example of the values available for the attributes at Big Dam West Lake. Each of the 24 lakes has these attributes linked to them. The relationship between each attribute (e.g. Hg in fish and Hg in water) can now be established. Note: 9999 indicates no value available. The fields that have 'avg wshed' or '% wshd' after them were incorporated into the GIS database via the watershed. Abbreviations: SW – Surface Water; AR – A. Rencz Water Data; PC – Lake Physical Characteristics; Lks77 – NSDNR Lake Sediment Data 1977.

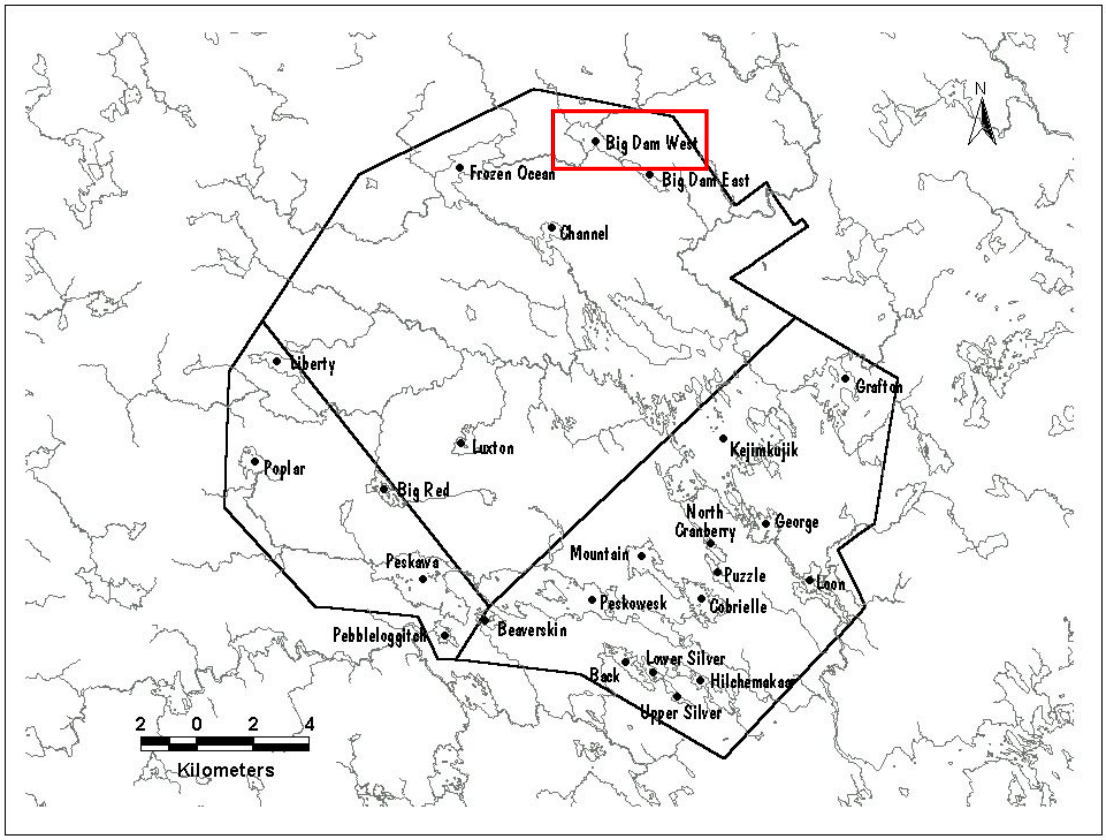


Figure 4.1. (Continued)

ATTRIBUTE	VALUE
Lake Name	**Big Dam West**
Easting Nad83	317825
Northing Nad83	4925517
Adult Loon Blood (ug/g)	4.56
Juvenile Loon Blood (ug/g)	9999.00
Adult Loon Feathers (ug/g)	9.25
Wperch Avg Conc/Wt (%)	9999.000
Wperch Avg Conc/Lgth (%)	9999.000
Yperch Avg Conc/Wt (%)	1.467
Yperch Avg Conc/Lgth (%)	1.886
Trout Avg Conc/Wt (%)	0.121
Trout Avg Conc/Lgth (%)	1.023
Perch Tot Hg (10cm)	0.1687917
Perch Tot Hg (20cm)	0.7178786
SW Alkalinity (mg/L)	0.07
SW pH	5.0
SW Color (Hazens)	94
SW Specific Conductance (uS/cm)	30.1
SW Total Organic Carbon (mg/L)	10.5
SW Dissolved Cl (mg/L)	4.84
SW Dissolved SO4 (mg/L)	1.69
SW Total N2 (mg/L)	0.111
SW Dissolved Na (mg/L)	3.52
SW Dissolved K (mg/L)	0.307
SW Dissolved Ca (mg/L)	0.641
SW Dissolved Mg (mg/L)	0.364
SW Extractable Al (mg/L)	0.198
SW Extractable Fe (mg/L)	0.165
SW Extractable Mn (mg/L)	0.015
SW Total Hg - unfiltered (ng/L)	5.01
Lake Sediment Hg (mg/kg)	0.06
PC Lake Elevation (m)	120
PC Surface Area (hectares)	105.0
PC Total Catchment Area (km2)	40.0
PC Volume (m3)	2593000
PC Mean Depth (m)	2.5
PC Max Depth (m)	9.5
PC Shoreline Length (km)	6.1
PC Flushing Rate (times/yr)	13.1
Tot Hg dragonfly larvae (ug/g)	0.042
Tot Hg Unfiltered (ng/L)	2.93
Tot Hg Filtered (ng/L)	2.49
MeHg Unfiltered (ng/L)	0.113
MeHg Filtered (ng/L)	0.084
AR H2O Date	11/4/1997
AR H2O Time	morning
AR H2O Color	clear
AR H2O Temp	9.1
AR H2O pH	5.20
AR H2O DO	11.05
AR H2O Conductivity	0.025
AR H2O Alkalinity	1.0
AR H2O Turbulence	3
AR H2O DOC ppm	5.60
AR H2O Hg ppb	0.003
AR H2O Al27 ppb	112.2
AR H2O Fe54 ppb	115
AR H2O Mn55 ppb	11.85
AR H2O Co59 ppb	0.058
AR H2O Cu65 ppb	0.38
AR H2O Zn66 ppb	2.59
AR H2O As75 ppb	0.35
AR H2O Rb85 ppb	1.221

ATTRIBUTE	VALUE
AR H2O Sr88 ppb	3.81
AR H2O Y89 ppb	0.062
AR H2O Ag107 ppb	9999.000
AR H2O Cd114 ppb	9999.000
AR H2O Pb208 ppb	0.214
AR H2O U238 ppb	0.0314
Lks77 Copper (ppm)	6.00
Lks77 Nickel (ppm)	12.00
Lks77 Lead (ppm)	3.60
Lks77 Zinc (ppm)	40.00
Lks77 Cobalt (ppm)	1.00
Lks77 Iron (%)	0.60
Lks77 Manganese (ppm)	200.00
Lks77 Calcium	760.00
Lks77 Magnesium	1800.00
Lks77 Molybdenum (ppm)	1.00
Lks77 Mercury (ppm)	0.40
Lks77 Uranium (ppm)	2.40
Lks77 Arsenic (ppm)	3.00
Wpine Mo ppm (avg wshed)	0.6700
Wpine Cu ppm (avg wshed)	2.9950
Wpine Pb ppm (avg wshed)	1.0850
Wpine Zn ppm (avg wshed)	27.8500
Wpine Ag ppb (avg wshed)	16.0000
Wpine Mn ppm (avg wshed)	128.5000
Wpine Fe % (avg wshed)	0.0100
Wpine As ppm (avg wshed)	0.2500
Wpine U ppm (avg wshed)	5.0000
Wpine Au ppb (avg wshed)	2.7500
Wpine Th ppm (avg wshed)	2.0000
Wpine Ca % (avg wshed)	0.2300
Wpine Hg ppb (avg wshed)	20.5000
Wpine W ppm (avg wshed)	2.0000
Rmaple Mo ppm (avg wshed)	0.3650
Rmaple Cu ppm (avg wshed)	6.8000
Rmaple Pb ppm (avg wshed)	0.7100
Rmaple Zn ppm (avg wshed)	40.6500
Rmaple Ag ppb (avg wshed)	17.0000
Rmaple Mn ppm (avg wshed)	309.0000
Rmaple Fe % (avg wshed)	0.0100
Rmaple As ppm (avg wshed)	0.2500
Rmaple U ppm (avg wshed)	5.0000
Rmaple Au ppb (avg wshed)	1.0000
Rmaple Th ppm (avg wshed)	2.0000
Rmaple Ca % (avg wshed)	0.6800
Rmaple Hg ppb (avg wshed)	16.5000
Rmaple W ppm (avg wshed)	1.0000
Deep Marsh (% wshd)	0.29
Shallow Marsh (% wshd)	0.00
Seasonally Flooded Flats (% wshd)	0.00
Meadow (% wshd)	0.00
Shrub Swamp (% wshd)	0.02
Wooded Swamp (% wshd)	0.00
Lakeshore Wetland (% wshd)	0.00
Bog (% wshd)	1.65
Fen (% wshd)	3.06
Total (% wshd)	5.04
Goldenville (% wshd)	48.00
Halifax (% wshd)	1.46
Biotite Monzogranite (% wshd)	50.55
Leucomonzogranite (% wshd)	0.00
Musc Biot Monzogranite (% wshd)	0.00

Figure 4.1. (Continued)

Table 4.1. Sixteen data sets were incorporated into the GIS database. Twelve of these data sets were incorporated on a lake basis, and four were linked to lakes via their watershed (using the lake name as the common field). The data were provided from five sources: (1) TSRI CD-ROM (Rencz, 2000, CD-ROM), (2) S. O'Grady, Kejimkujik National Park, written communication, April 13, 2000, (3) A. Rencz, Geological Survey of Canada, written communication, January 24, 2000, (4) Nova Scotia Department of Natural Resources (NSDNR, 2000, http), and (5) Centre of Geographic Sciences (COGS) – original data source NSDNR.

Data Set (Layer)	Method of Incorporation	Data Provider
Mercury in Kejimkujik Loons	Lake	TSRI CD-ROM (Rencz, 2000, CD-ROM)
Mercury in Yellow Perch	Lake	TSRI CD-ROM (Rencz, 2000, CD-ROM)
Mercury in White Perch	Lake	S. O'Grady, Kejimkujik National Park
Mercury in Trout	Lake	S. O'Grady, Kejimkujik National Park
Mercury in Perch (10cm & 20 cm)	Lake	TSRI CD-ROM (Rencz, 2000, CD-ROM)
Surface Water Lake Chemistry	Lake	TSRI CD-ROM (Rencz, 2000, CD-ROM)
Mercury in Lake Sediment	Lake	TSRI CD-ROM (Rencz, 2000, CD-ROM)
Lake Physical Characteristics	Lake	TSRI CD-ROM (Rencz, 2000, CD-ROM)
Mercury in Dragonfly Larvae	Lake	TSRI CD-ROM (Rencz, 2000, CD-ROM)
Mercury/Methylmercury in Lake Water	Lake	TSRI CD-ROM (Rencz, 2000, CD-ROM)
Lake Water Chemistry	Lake	A. Rencz, Geological Survey of Canada
Mercury in Lake Sediment 1977	Lake	NSDNR (2000, http)
Wetland Surface Area	Watershed	COGS (source NSDNR)
Bedrock Geology	Watershed	NSDNR (2000, http)
White Pine Chemistry	Watershed	A. Rencz, Geological Survey of Canada
Red Maple Chemistry	Watershed	A. Rencz, Geological Survey of Canada

The modifications made to each lake-based data set are described in flowcharts shown in Figures 4.2 to 4.13. Table 4.2 references each lake-based data set to a flowchart. For example, modifications made to the loon data set are shown in Figure 4.2. The original loon data set was divided into three separate data sets, one for Hg in adult loon blood, one for Hg in juvenile loon blood, and one for Hg in adult loon feathers. This is done because Hg levels in loons are dependent on age. There were a number of data points for each lake, so these points were averaged to obtain a characteristic value for the lake. The average value was assigned to each of the 24 study lakes (Note: if one of the 24 lakes does not have a sample point, it is assigned a value of 9999 in the GIS database).

4.2.2. Incorporating Non Lake-Based Data

Values for terrestrial based data sets cannot be directly tied to an individual lake. For example, samples taken for terrestrial plants belong to one distinct location on the ground. Similarly, wetlands do not occupy the same geographic space as a lake. For non lake-based data sets (e.g. terrestrial plants and wetlands), the data were incorporated into the GIS database using lake catchment areas (termed 'watersheds' throughout the rest of this thesis). A. Rencz (Geological Survey of Canada) digitized the watershed file used for this analysis. The watershed file was created manually using a 1:50,000 topographic sheet. One watershed was assigned to each lake, and the watershed boundary between lakes was defined by locating inflection points in the contours. Therefore, each lake in the park has one watershed that includes the lake and the immediate surrounding area (Figure 4.14). Since there are 24 study lakes in the park, only 24 watersheds from the watershed file are used. Once a value is determined for a watershed (e.g. Hg in terrestrial plants), it can be linked to the lake that the watershed represents.

The original watershed files (**KEJIAREA.VEC** and **KEJIAREA.VEH**) are included on the CD-ROM in the back cover. Since the bulk of the GIS analysis for this thesis is performed in ARC/INFO and ArcView GIS, these files, which are not ARC/INFO or ArcView files, were converted into an ArcView shapefile in SPANS. The shapefile was then converted into an ARC/INFO coverage. The name of the new coverage is **AR_KEJIAREA** (AR = A. Rencz). The steps required to create the **AR_KEJIAREA** coverage

Table 4.2. The modifications required for each lake-based data set (left column) are represented by a figure (right column).

Data Set	Figure
Mercury in Kejimkujik Loons	Figure 4.2
Mercury in Yellow Perch	Figure 4.3
Mercury in White Perch	Figure 4.4
Mercury in Trout	Figure 4.5
Mercury in Perch (10cm & 20 cm)	Figure 4.6
Surface Water Lake Chemistry	Figure 4.7
Mercury in Lake Sediment	Figure 4.8
Lake Physical Characteristics	Figure 4.9
Mercury in Dragonfly Larvae	Figure 4.10
Mercury/Methylmercury in Lake Water	Figure 4.11
Lake Water Chemistry	Figure 4.12
Mercury in Lake Sediment 1977	Figure 4.13

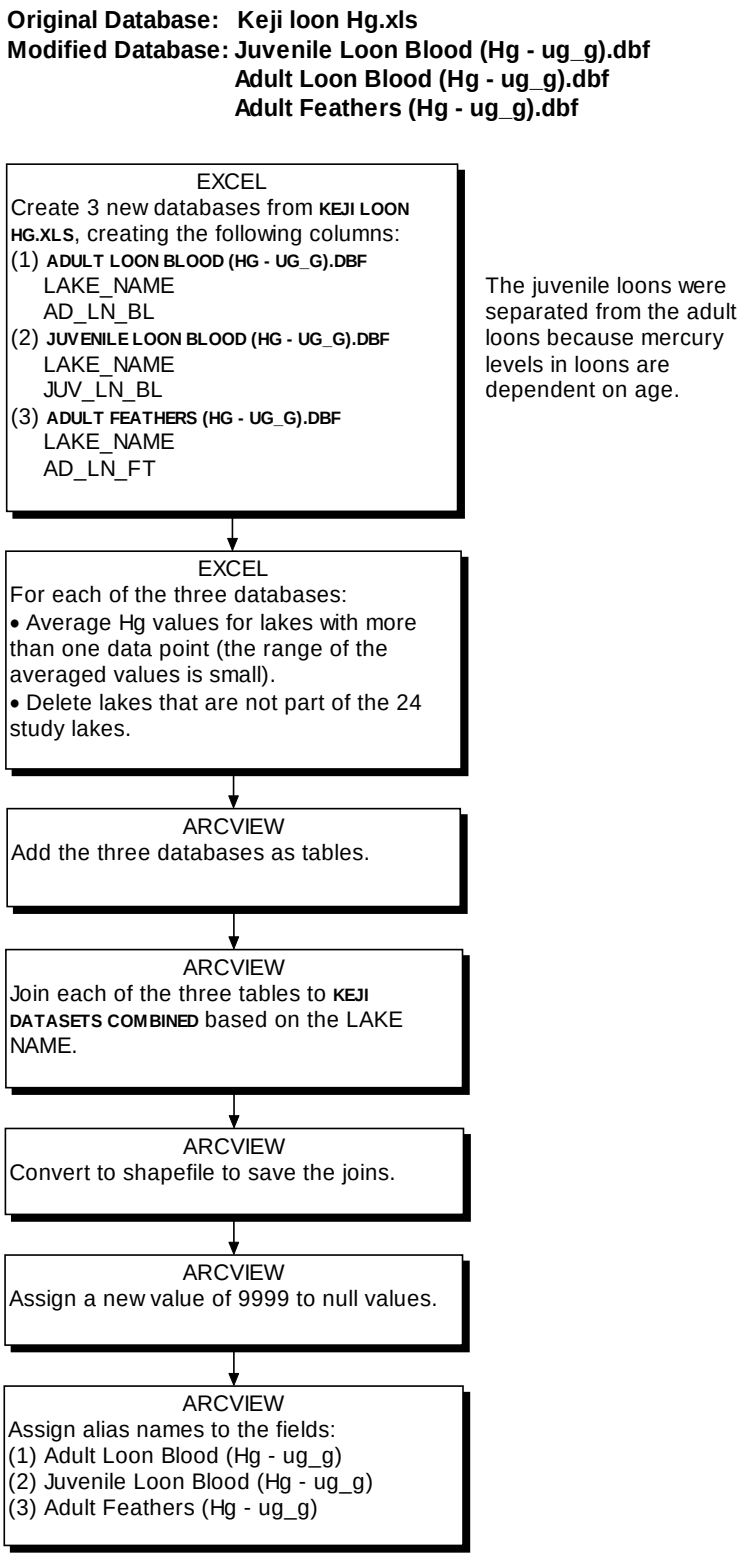


Figure 4.2. Modifications made to the Mercury in Kejimkujik Loons Data Set.

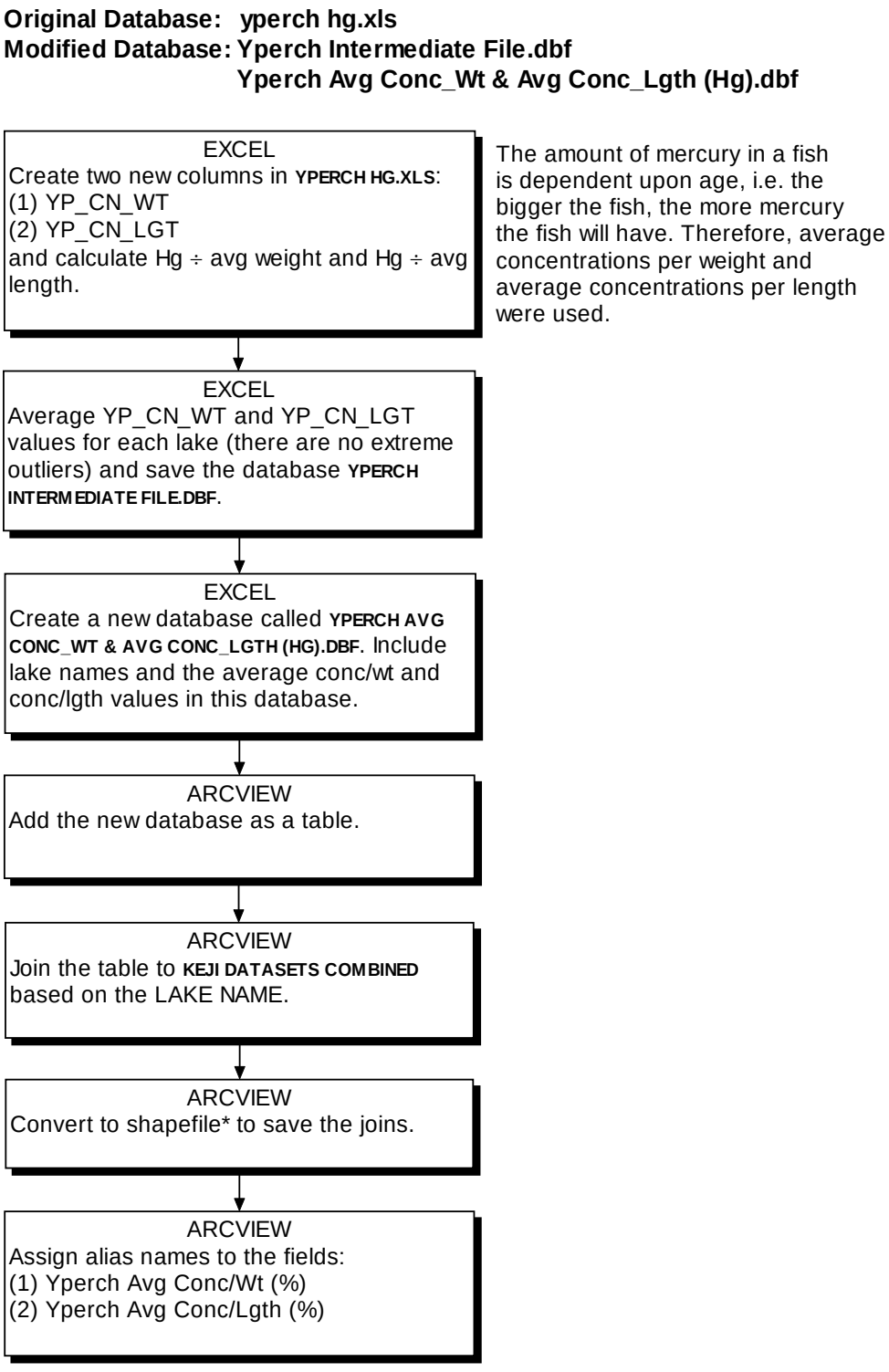


Figure 4.3. Modifications made to the Mercury in Yellow Perch Data Set. * A shapefile is a simple, non-topological format for storing the geometric location and attribute information of geographic features; it is the way that ArcView stores its geographical layers.

Original Database: white_perch.dbf
Modified Database: Wperch Intermediate File.dbf
Wperch Avg Conc_Wt & Avg Conc_Lgth (Hg).dbf

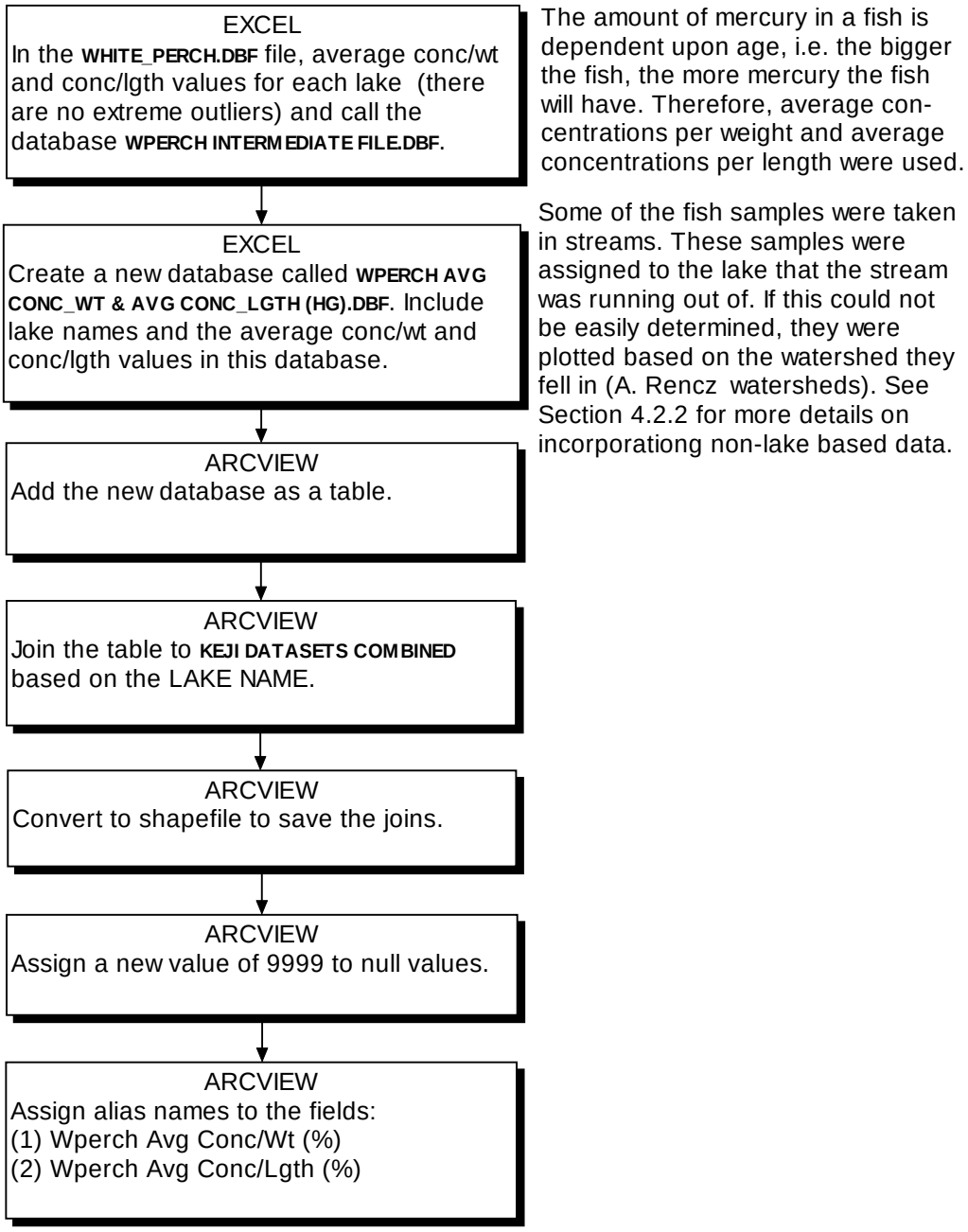


Figure 4.4. Modifications made to the Mercury in White Perch Data Set.

Original Database: trout.dbf
Modified Database: Trout Intermediate File.dbf
Trout Avg Conc_Wt & Avg Conc_Lgth (Hg).dbf

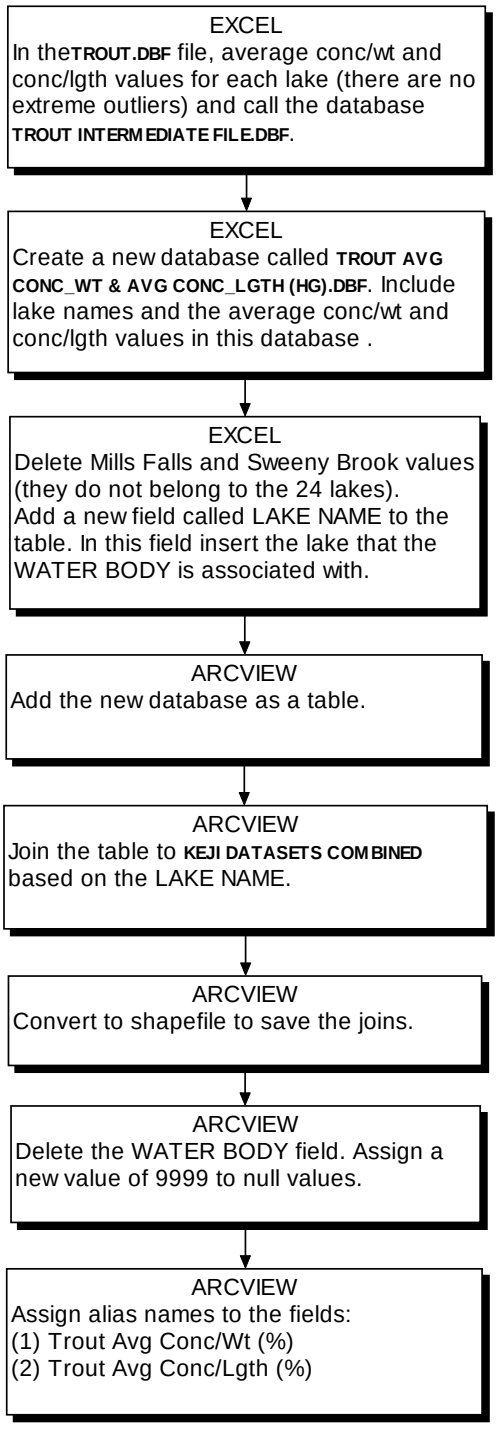


Figure 4.5. Modifications made to the Mercury in Trout Data Set.

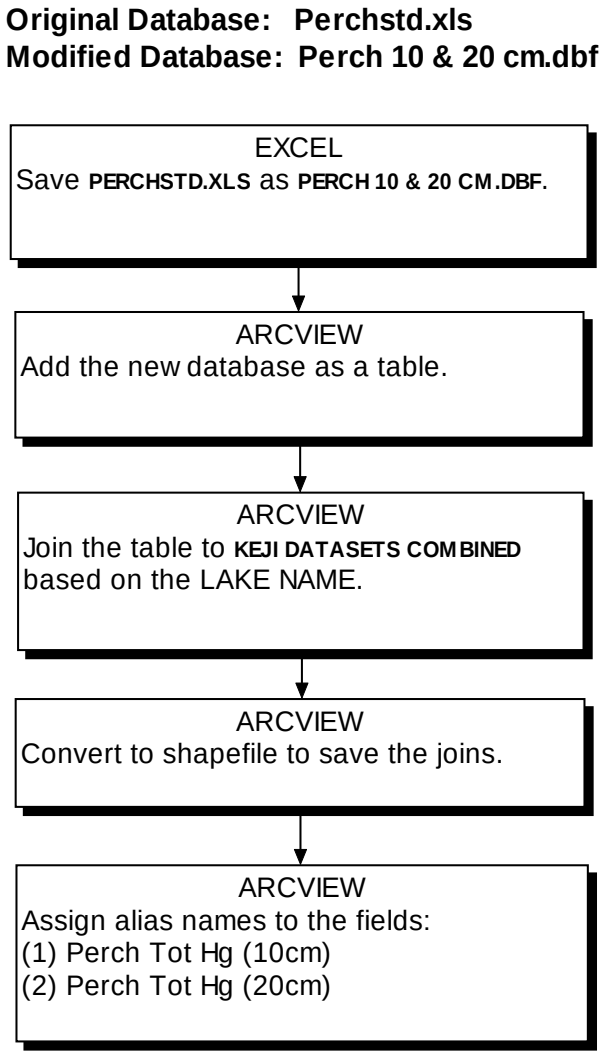


Figure 4.6. Modifications made to the Mercury in Perch (10 cm & 20 cm) Data Set.

Original Database: LAKEchem.dbf
Modified Database: Surface Water Lake Chemistry.dbf

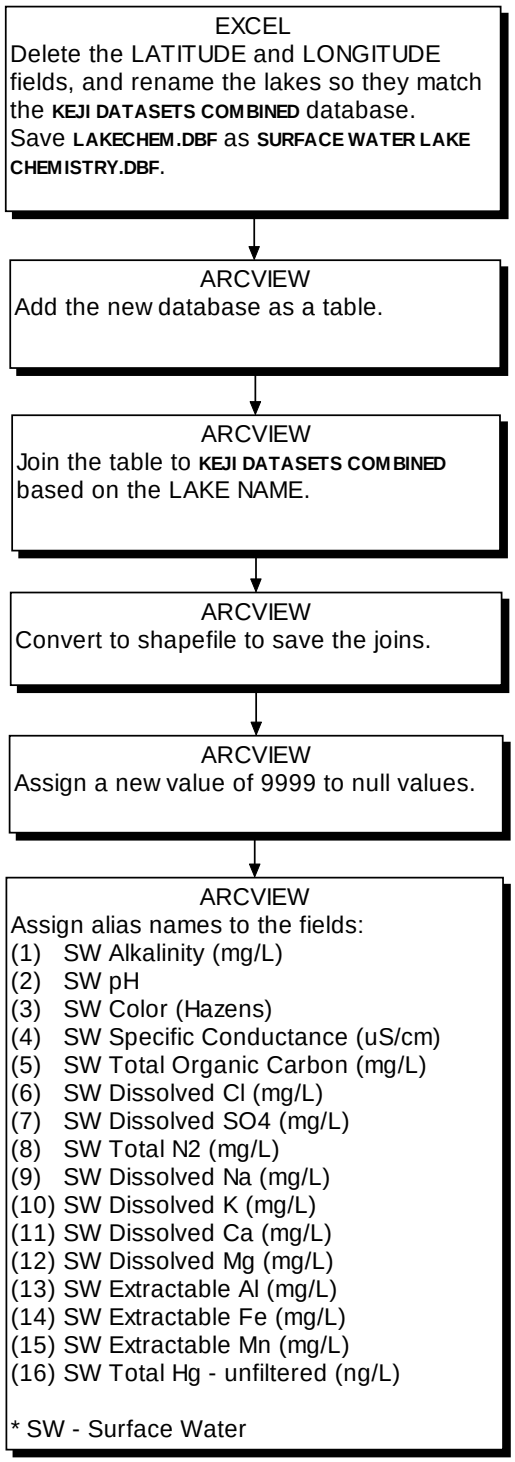


Figure 4.7. Modifications made to the Surface Water Lake Chemistry Data Set.

Original Database: LAKEsed.xls
Modified Database: Hg in Lake Sediment (mg_kg).dbf

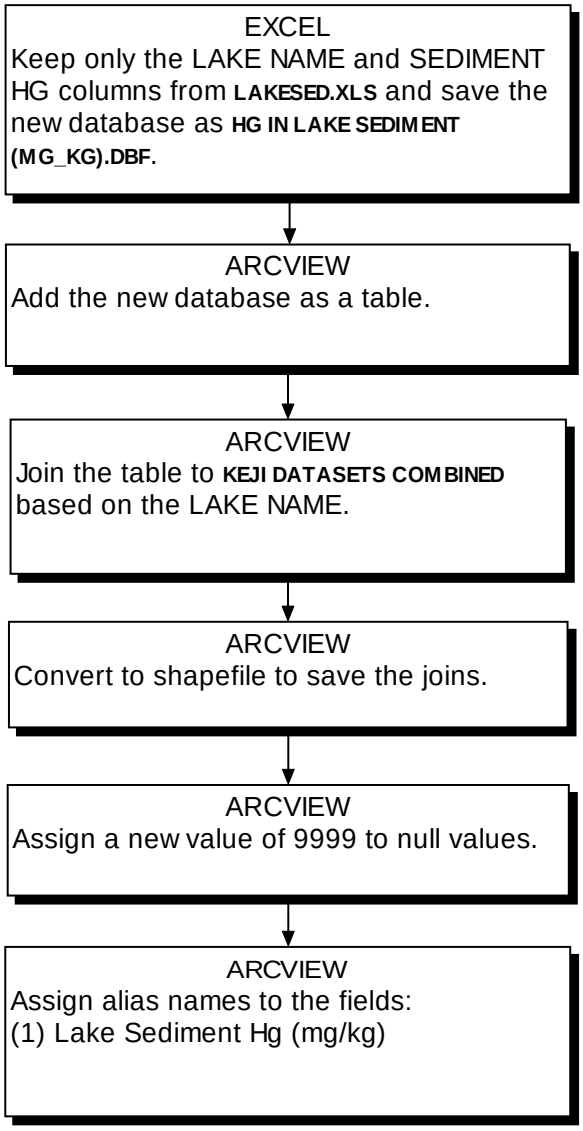


Figure 4.8. Modifications made to the Mercury in Lake Sediment Data Set.

Original Database: LAKE physical char.dbf
Modified Database: Lake Physical Characteristics.dbf

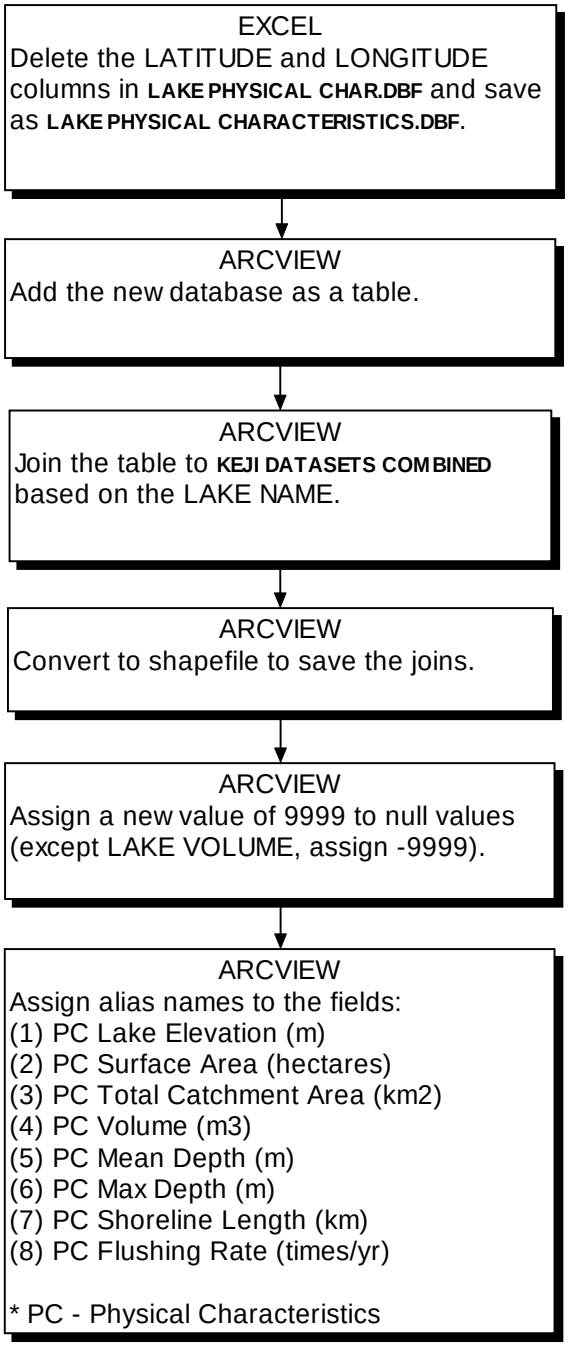


Figure 4.9. Modifications made to the Lake Physical Characteristics Data Set.

Original Database: LAKEinvr.xls
Modified Database: Hg in Dragonfly Larvae (ug_g).dbf

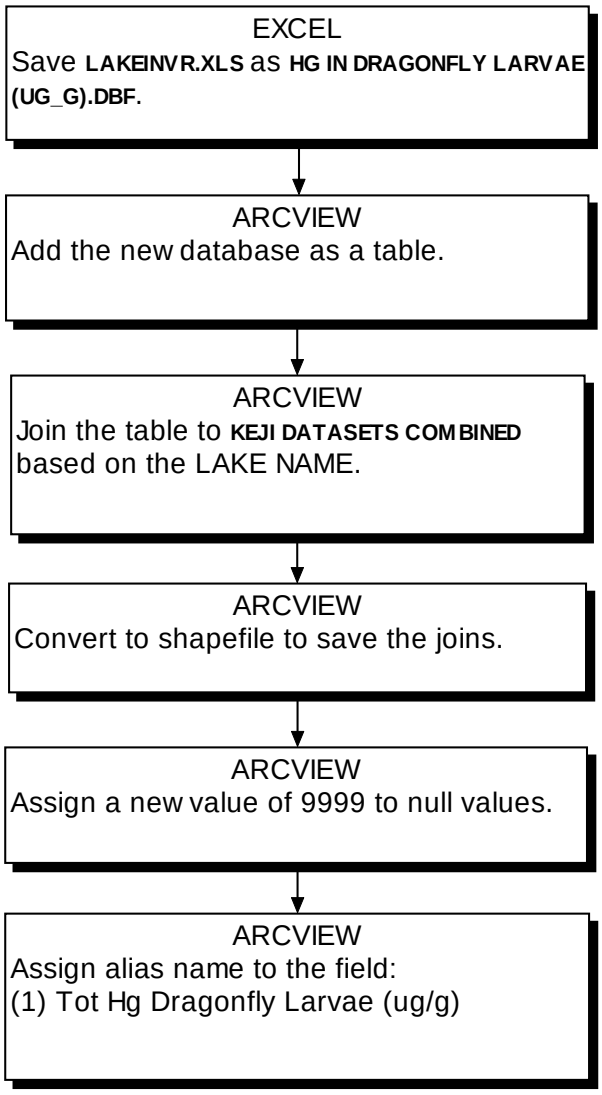


Figure 4.10. Modifications made to the Mercury in Dragonfly Larvae Data Set.

Original Database: LAKEMeHg.xls
Modified Database: MeHg Intermediate File.dbf
Hg & MeHg_Filtered & Unfiltered.dbf

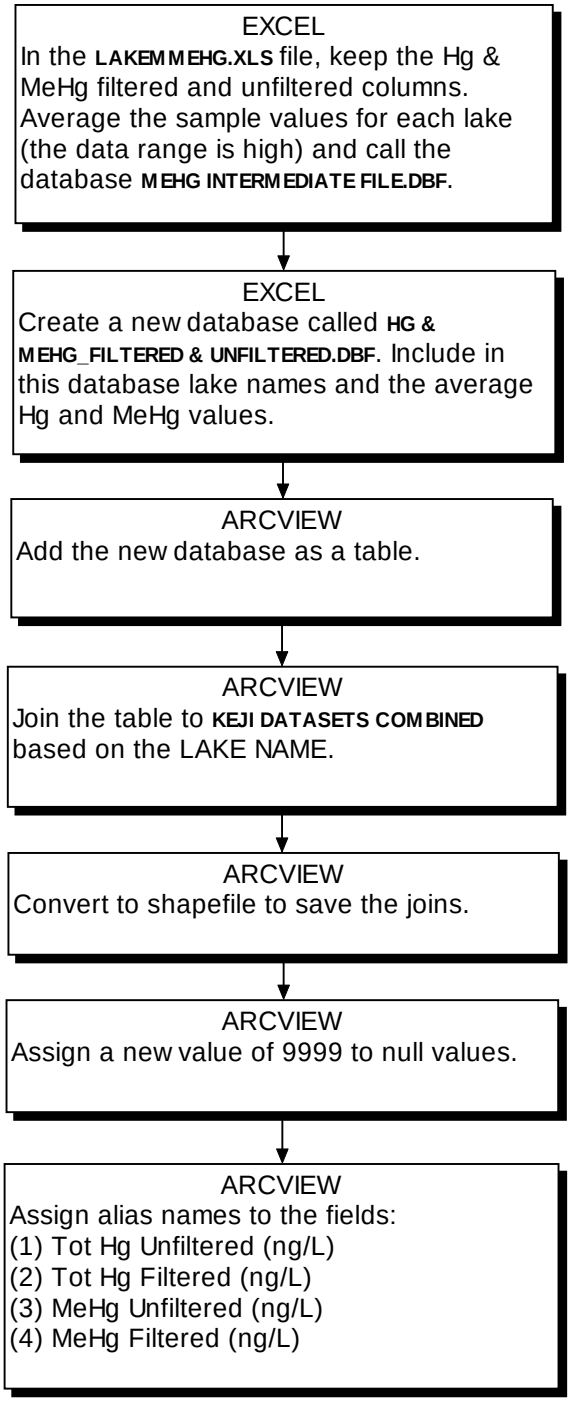


Figure 4.11. Modifications made to the Mercury/Methylmercury in Lake Water Data Set.

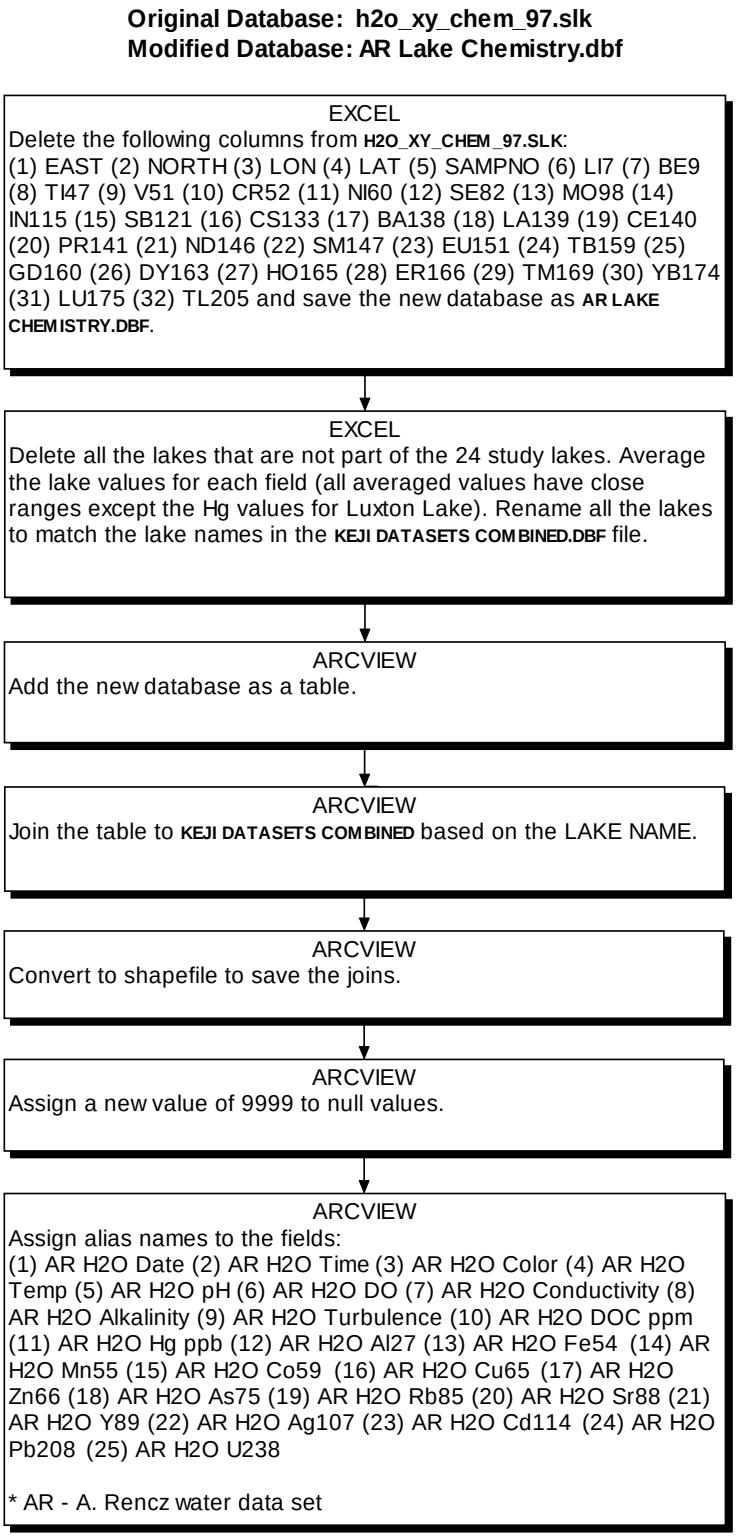


Figure 4.12. Modifications made to the Lake Water Chemistry Data Set.

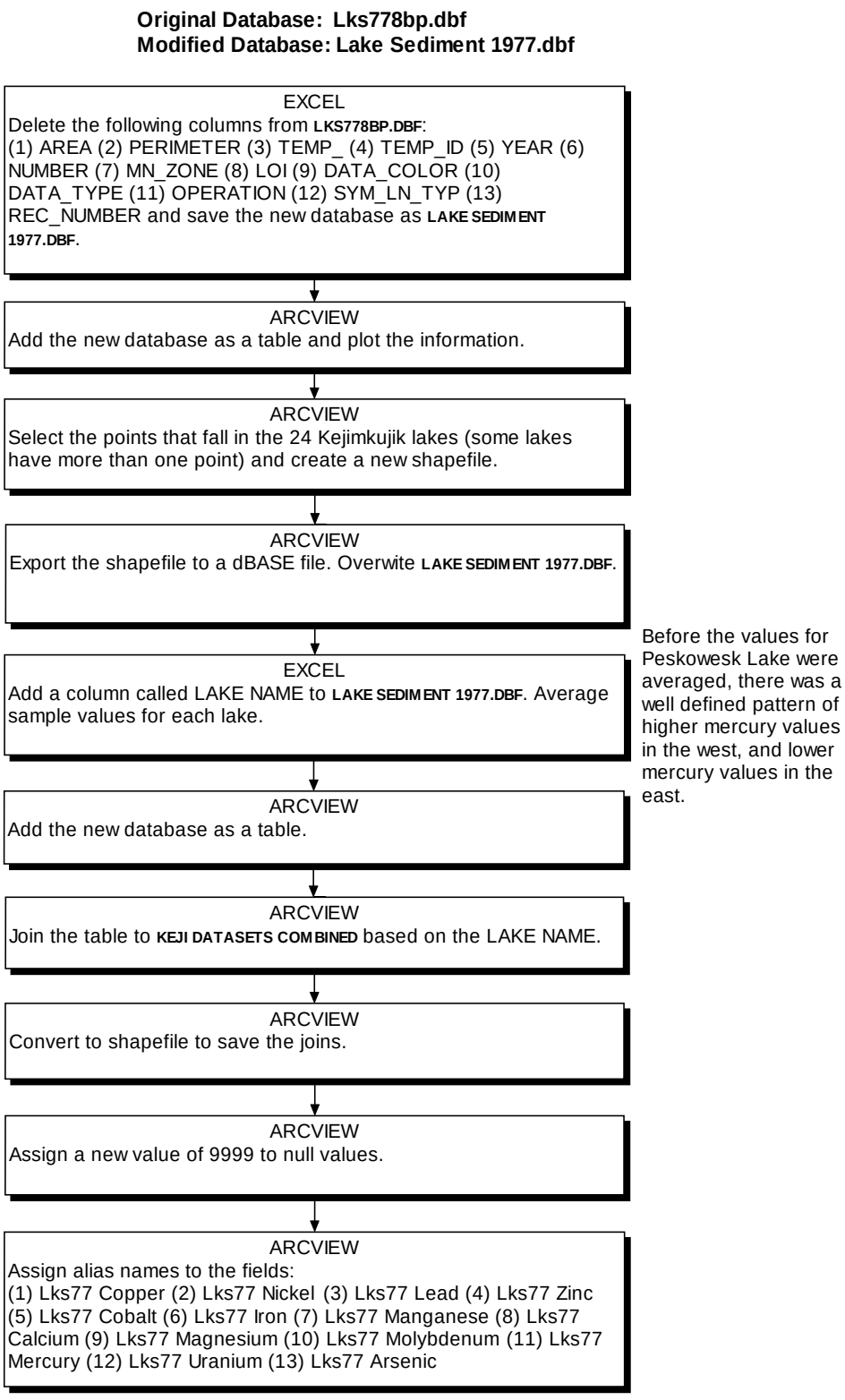


Figure 4.13. Modifications made to the Mercury in Lake Sediment 1977 Data Set.

Watershed Delineation

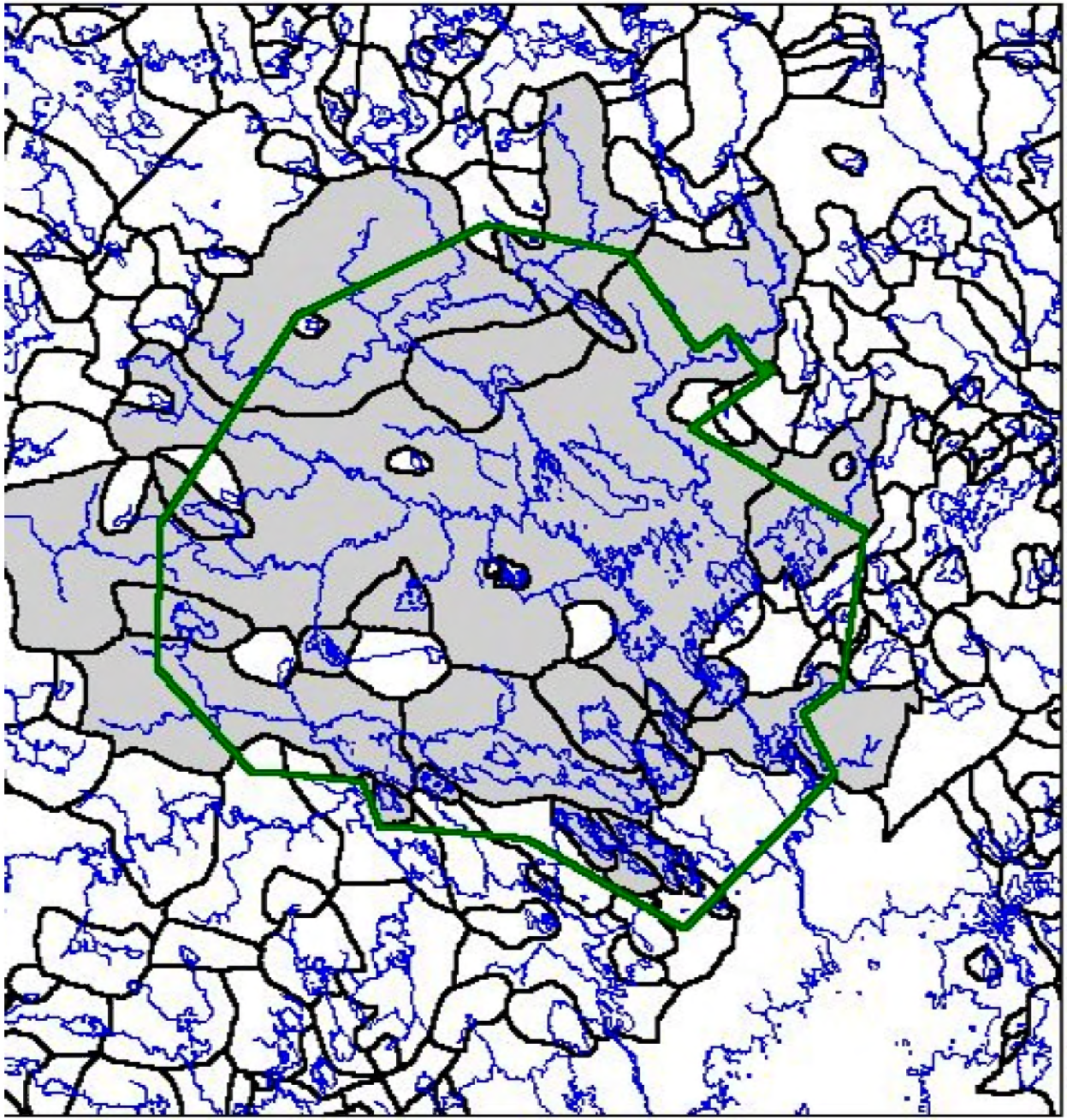


Figure 4.14. Each of the 24 lakes has one watershe Therefore, the GIS database represents data for 24 watersheds (shaded grey). Any value obtained for a watershed can therefore be directly linked to the KI DATASETS COMBINED database. Boundaries between watersheds determined by A. Rencz.

are included in Figure 4.15. In this thesis, 'the steps necessary in order to prepare a file to be used in GIS analysis (e.g. changing the file format or the projection)' are called *pre-processing*.

Four data sets were incorporated into the GIS database via the watersheds: (1) red maple – point data, (2) white pine – point data, (3) wetlands – polygon data, and (4) bedrock geology – polygon data (Table 4.1).

4.2.2.1. Incorporating Point Data (Red Maple and White Pine)

To incorporate the plant data, an average value for each plant type (white pine and red maple) was assigned to each watershed (an example of this is shown in Figure 4.16). An AML (Arc Macro Language; ARC/INFO programming language) was created to extract selected elements from the two plant data sets and assign each watershed an average, minimum, maximum, standard deviation, and count based on the point values that fall into each watershed (Appendix 4.3). For simplicity in analysis, the average values were the only values incorporated into the **KEJI DATASETS COMBINED** database. However, all of the original data is included in the **AR_KEJIAREA** database on the CD-ROM in the back cover (**AR_KEJIAREA.E00**). Once the average values for each element were calculated for each watershed, the values were extracted and entered into the **KEJI DATASETS COMBINED** database. The steps to perform this operation are outlined in Figure 4.17. Prior to running the AML, the two plant data sets and the watershed layer were pre-processed (Figures 4.18 and 4.19 respectively).

4.2.2.2. Incorporating Polygon Data (Wetlands and Geology)

To incorporate the wetland and geological data, the same principle applies. For example, in each of the 24 watersheds (which represent the 24 lakes) there are a number of wetlands. Using ARC/INFO, the percentage wetland area for each watershed is calculated and divided by the total area of the watershed. This percentage is assigned to the watershed. For geological data, such as maps, which show the distribution of surface or near-surface lithologies, each watershed is assigned the percentage of each lithology.

Original Database: kejiarea.veh; kejiarea.vec
Modified Database: ar_kejiarea (ARC/INFO coverage)

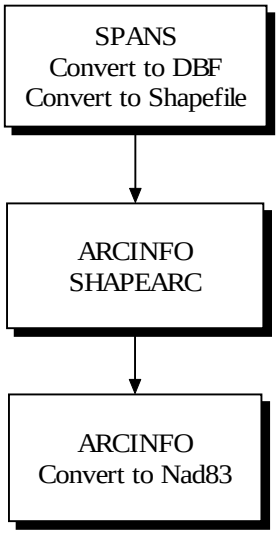


Figure 4.15. Pre-processing of the watershed data. The final version of this file is called **AR_KEJIAREA**; it is included on the CD-ROM in the back cover as an E00 file**.** Other than the title caption for each box, all capitalized words are ARC/INFO commands.

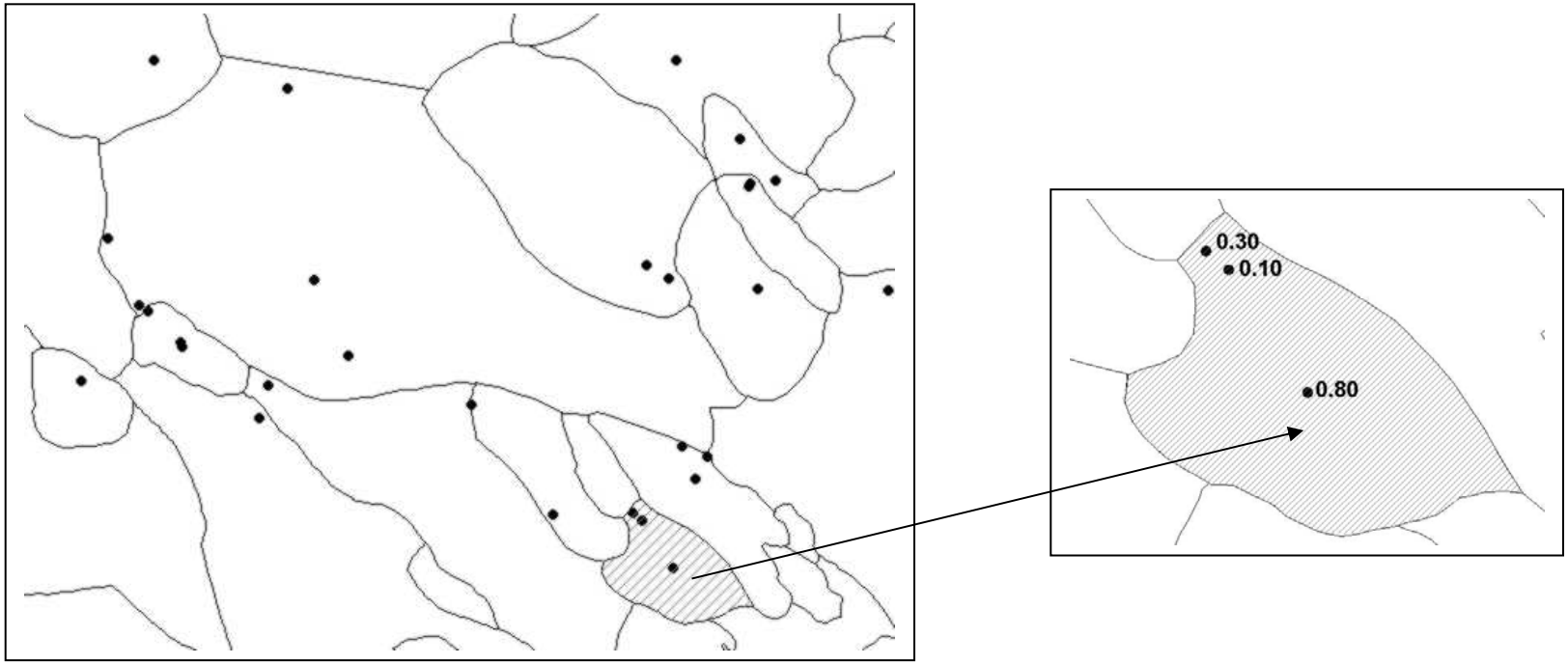


Figure 4.16. The inset shows an example of how plant data from a watershed was incorporated into the GIS database. The grey lines represent watershed boundaries and the black points represent red maple sampling locations. The selected watershed has three points. These points contain values for a number of elements. For example, the three values for molybdenum are: 0.30 ppm, 0.10 ppm, and 0.80 ppm. The average of these three values is 0.4 ppm. This is the value that is assigned to the watershed for molybdenum in red maples. The same three points also have values for mercury, calcium, gold, etc. Therefore this watershed will also be assigned an average value for each of these elements.

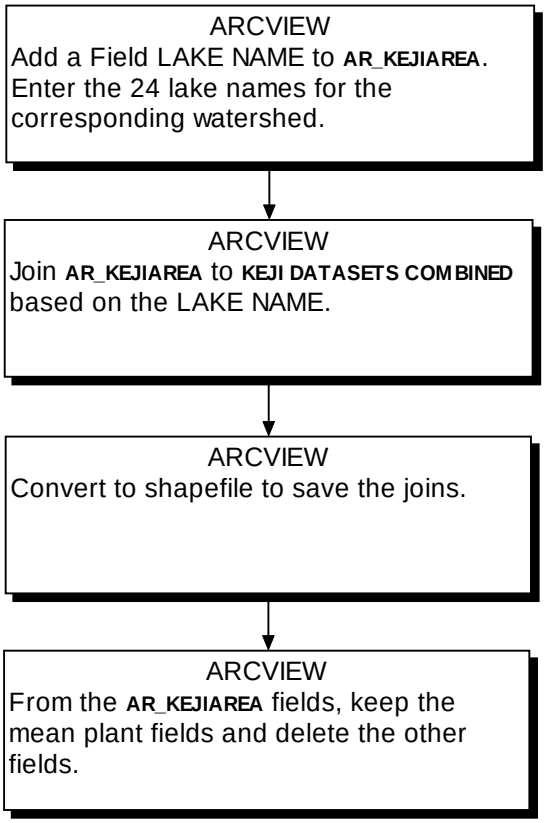


Figure 4.17. Steps required to join the plant data to the **KEJI DATASETS COMBINED** database.

White Pine Original Database: keji_98_99_wpine_lf_acme_xy.xls
Red Maple Original Database: keji_98_99_rmaple_lf_acme_xy.xls

White Pine Modified Database: ar_keji_wp (ARC/INFO coverage)
Red Maple Modified Database: ar_keji_rm (ARC/INFO coverage)

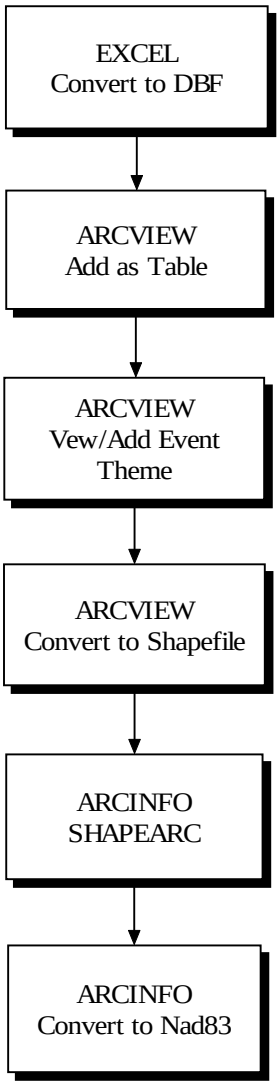


Figure 4.18. Pre-processing of the Plant Data Sets. The modified files are included on the CD-ROM in the back cover as E00 files (**AR_KEJI_WP.E00** and **AR_KEJI_RM.E00**). Other than the title caption for each box, all capitalized words are ARC/INFO commands.

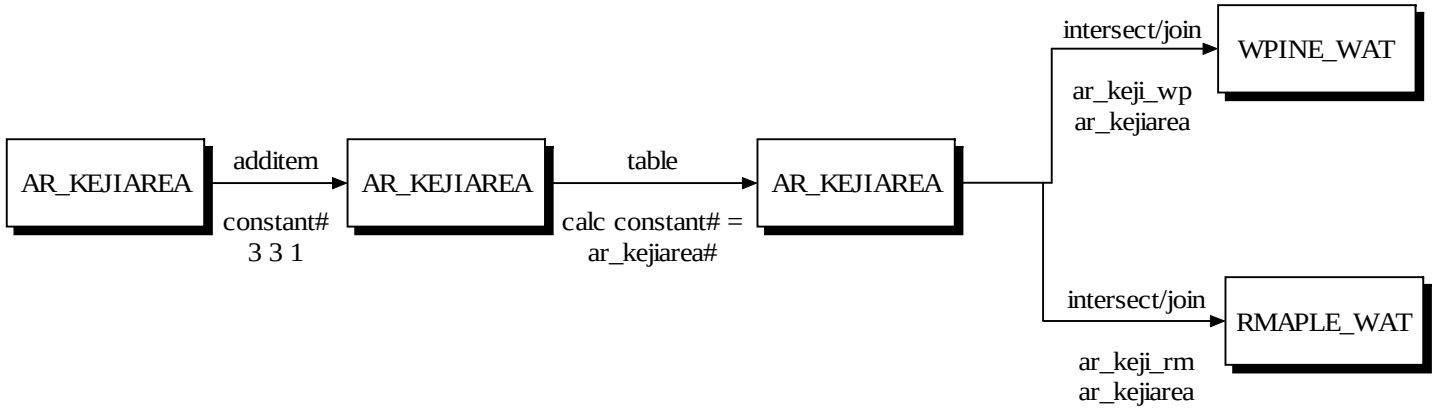


Figure 4.19. Pre-processing of the **AR_KEJIAREA** layer. **AR_KEJI_WP** and **AR_KEJI_RM** were generated in Figure 4.18. Note: the text on top of an arrow line represents an ARC/INFO command (e.g. additem); the text on bottom of an arrow line represents the parameters entered for the command (e.g. constant # 3 3 1).

This section discusses the methods used to incorporate the wetland and geology data into the integrated database.

Wetlands: The physical and chemical characteristics of a wetland influence: (1) the amount of metal (including Hg) the wetland removes from the surface and ground water, (2) the way in which those metals will be distributed in the wetland, and (3) the amount of metal that will leave the wetland and enter the watershed. For example, a wetland with more vegetation will intercept more runoff, will reduce runoff velocity, and will have more time to remove metals from the water than a wetland will less vegetation (Osmond, 1995, http). In a stagnant wetland, the metals sink to the bottom and are buried in the substrate. In a moderately flowing wetland, however, the metals are more likely to be redistributed to the adjacent watershed (Osmond, 1995, http).

In order to investigate wetland significance in a watershed, the percentage of each wetland type and the chemical and physical characteristics of each wetland type within a watershed must be known. In Nova Scotia, there are nine basic types of wetlands: (1) bogs, (2) lakeshore wetlands, (3) fens, (4) deep marshes, (5) shallow marshes, (6) seasonally flooded flats, (7) meadows, (8) shrub swamps, and (9) wooded swamps (NSDNR, 1999). A table giving a general description, common characteristics, organic content, nutrient information, wildlife descriptions, and vegetation characteristics for each generic type of wetland is included in Appendix 4.4.

The wetlands were incorporated into the watershed layer based on the nine wetland types listed above. The AML used to assign a value to each watershed for each wetland type is in Appendix 4.5. The pre-processing steps required for the wetland and watershed data are described in Figure 4.20. The wetland data belongs to NSDNR; therefore the original and modified wetland data sets are not included on the CD-ROM in the back cover. The original file can be obtained from R. Milton (miltongr@gov.ns.ca, NSDNR).

Geology: The lithology was incorporated into the watershed layer using a 1:500,000 digital geology layer available on the NSDNR website (Keppie, 2000, http). The 1:500,000 map is the only digital geology map available for the park. The AMLs used to assign lithological percentages to each watershed are in Appendix 4.6. Pre-processing steps required for the geology layer are included in Figure 4.21.

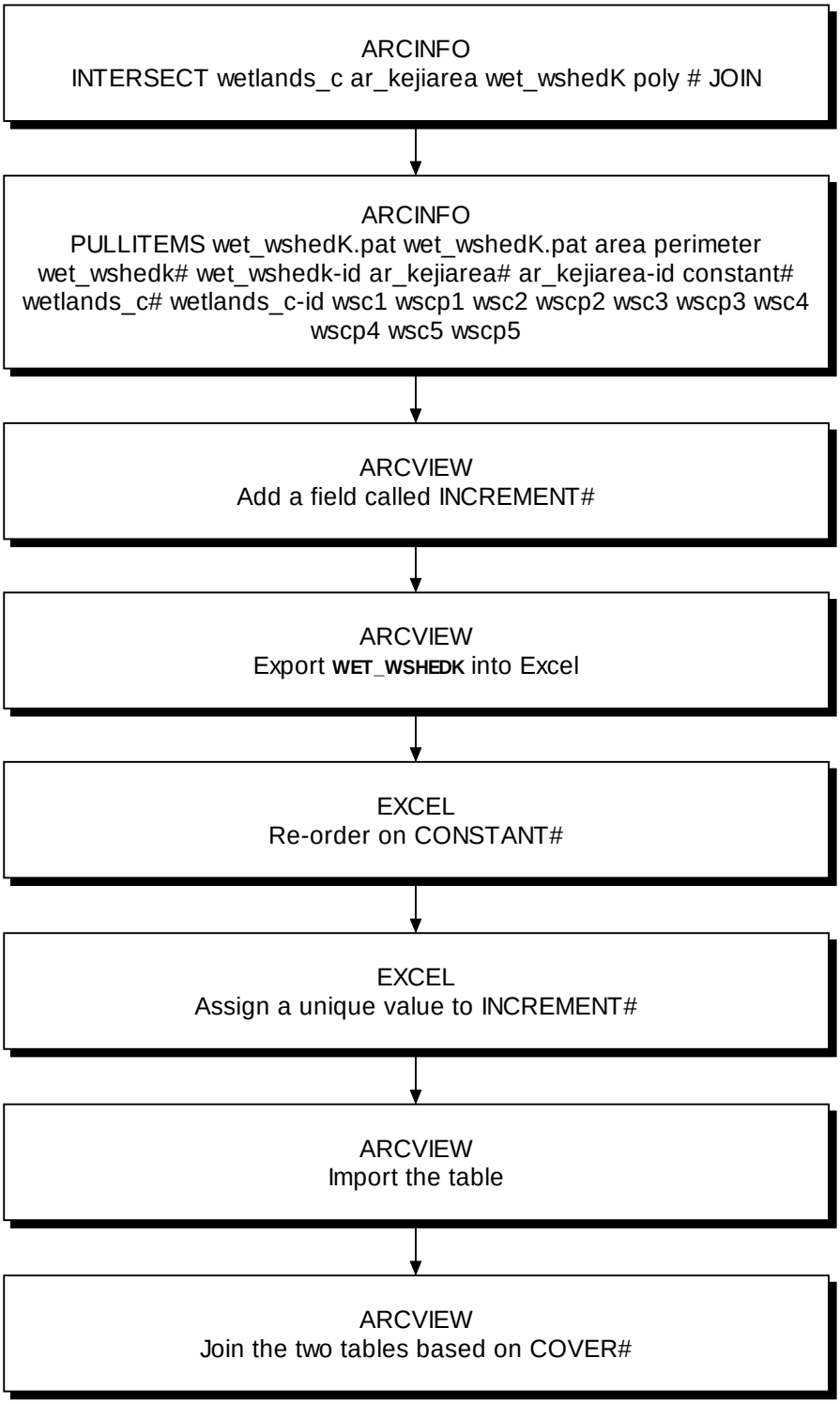


Figure 4.20. Pre-processing of the wetland and watershed data. Other than the title caption for each box, all capitalized words are either ARC/INFO commands or the name of a field.

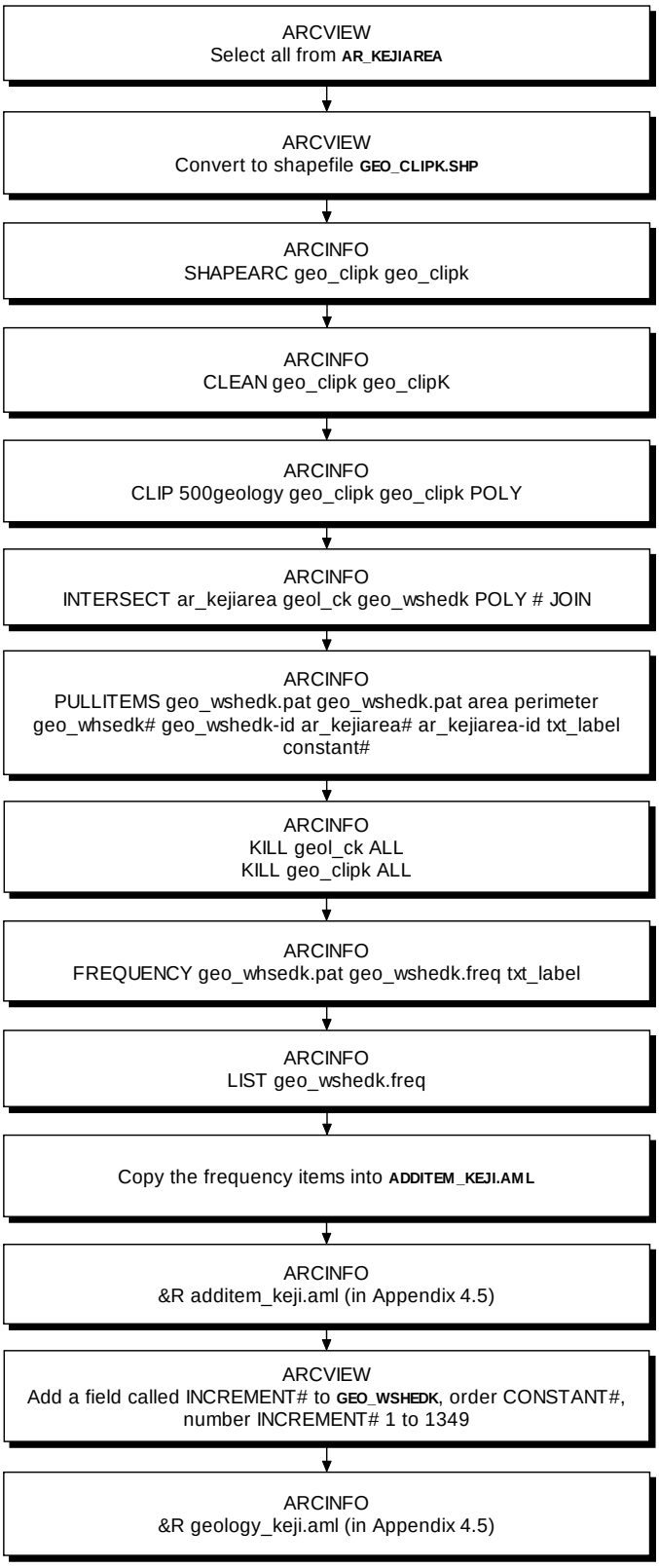


Figure 4.21. Pre-processing of the geology layer. The geology layer had a number of unidentified topological problems; therefore a number of steps, that would not normally be required, were performed (i.e. conversion to a shapefile, then back to a coverage, then rebuilding the topology). Other than the title caption for each box, all capitalized words are either ARC/INFO commands or field names.

Once the wetland and lithological percentages were calculated for each watershed, the values were extracted and entered into the **KEJI DATASETS COMBINED** database. The steps to perform this operation are outlined in Figure 4.22.

4.3. RESULTS

This section shows the results of the **KEJI DATSETS COMBINED** database. Results are presented as follows: (1) spatial relationships of Hg in the park, (2) correlations between Hg fields, (3) correlations between Hg fields and other element fields, (4) correlations between Hg fields and non-element fields, and (5) examination of the wetlands and the geology.

4.3.1. Spatial Relationships of Hg in the Park

4.3.1.1. Visual Examination of the Hg Fields

Each of the 122 fields (excluding LAKE NAME, EASTING and NORTHING) in the **KEJI DATASETS COMBINED** database has been color-coded according to their values and are included as JPEGs on the CD-ROM in the back cover. Of the 122 fields, there are only 22 fields that contain information on Hg (Table 4.3a) and only nine that represent a good geographic coverage of the park (i.e. cover about 80% of the lakes; Table 4.3b). Maps showing the geographic distribution and values for each of the 22 fields are in Figures 4.23 to 4.44, as well as on the CD-ROM in the back cover. Most fields are divided into four quantile break categories; i.e. each category contains the same number of values. In instances where there are five or less unique values, each value is represented separately on the map. The name of each map on the CD-ROM corresponds to the field name in **KEJI DATASETS COMBINED.XLS** (Appendix 4.2). All of these JPEGs were created in ArcView GIS and can be recreated in ArcView GIS using the **KEJI DATASETS COMBINED.DBF** file.

General observations made from visually examining these maps are summarized in Table 4.4. Using the color scheme described above, a '*high*' value is one that falls into the fourth class and a '*low*' value is one that falls into the first class. The second and third classes are intermediate between the first and fourth. There are five key points that can be

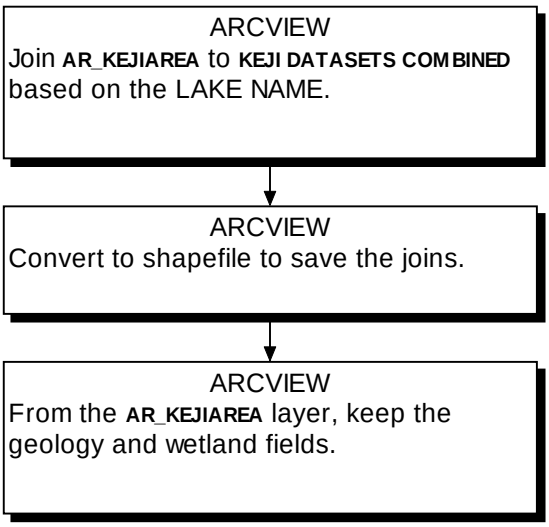


Figure 4.22. Steps required to incorporate the wetland and lithological percentages into the **KEJI DATASETS COMBINED** database. NOTE: For wetlands, George, Mountain, Loon, Peskawa, and Puzzle lakes have wetland totals that are not the sum of the other wetland columns (because in the original wetland database, not all wetlands were assigned to one of the nine basic Nova Scotia types).

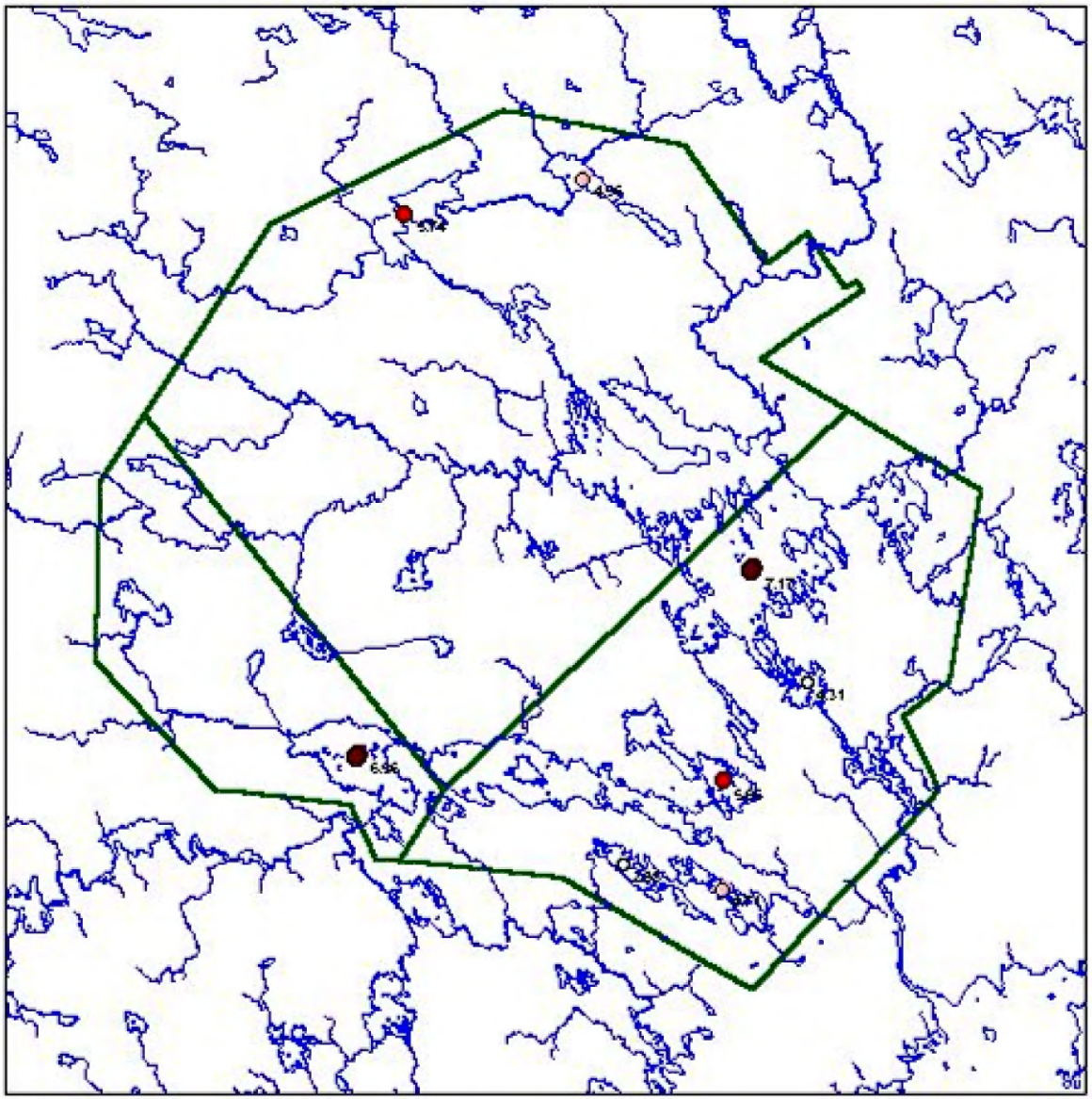
Hg Field
(1) ADULT LOON BLOOD (PPM)
(2) JUVENILE LOON BLOOD (PPM)
(3) ADULT LOON FEATHERS (PPM)
(4) WPERCH AVG CONC/WT (%)
(5) WPERCH AVG CONC/LGTH (%)
(6) YPERCH AVG CONC/WT (%)
(7) YPERCH AVG CONC/LGTH (%)
(8) TROUT AVG CONC/WT (%)
(9) TROUT AVG CONC/LGTH (%)
(10) PERCH TOT HG (10CM)
(11) PERCH TOT HG (20CM)
(12) SW TOTAL HG – UNFILTERED (NG/L)
(13) LAKE SEDIMENT HG (MG/KG)
(14) TOT HG DRAGONFLY LARVAE ((UG/G)
(15) TOT HG UNFILTERED (NG/L)
(16) TOT HG FILTERED (NG/L)
(17) MEHG UNFILTERED (NG/L)
(18) MEHG FILTERED (NG/L)
(19) AR H2O HG PPB
(20) LKS77 MERCURY
(21) WPINE HG PPB (AVG WSHED)
(22) RMAPLE HG PPB (AVG WSHED)

Table 4.3a. Out of the 125 fields in the **KEJI DATASETS COMBINED** database, there are 22 fields that pertain directly to Hg. Three relate to loons (1-3), eight relate to fish (4-11), six relate to lake water (12, 13, 15-18), two relate to lake sediment (13, 20), one relates to dragonflies (14), and two relate to vegetation (21, 22). Field descriptions are provided in Appendix 3.2; data sources are provided in Table 4.1.

Hg Field
(1) YPERCH AVG CONC/LGTH (%)
(2) YPERCH AVG CONC/WT (%)
(3) PERCH TOT HG 10CM
(4) PERCH TOT HG 20CM
(5) SW TOTAL HG – UNFILTERED (NG/L)
(6) LAKE SEDIMENT HG (MG/KG)
(7) LKS77 MERCURY
(8) WPINE HG PPB (AVG WSHED)
(9) RMAPLE HG PPB (AVG WSHED)

Table 4.3b. Out of the 22 Hg fields in the **KEJI DATASET COMBINED** database, there are only nine fields that represent a full geographic coverage of the park. Four relate to fish (1-4), one relates to lake water (5), two relate to lake sediment (6, 7), and two relate to vegetation (8, 9). Field descriptions are provided in Appendix 4.2; data sources are provided in Table 4.1.

Mercury in Adult Loon Blood (ppm)



CLASSIFICATION: Quantile Break

- 2.88 - 4.31 ppm
- 4.31 - 4.71 ppm
- 4.71 - 5.74 ppm
- 5.74 - 7.17 ppm

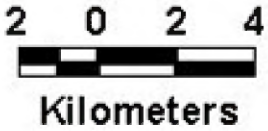
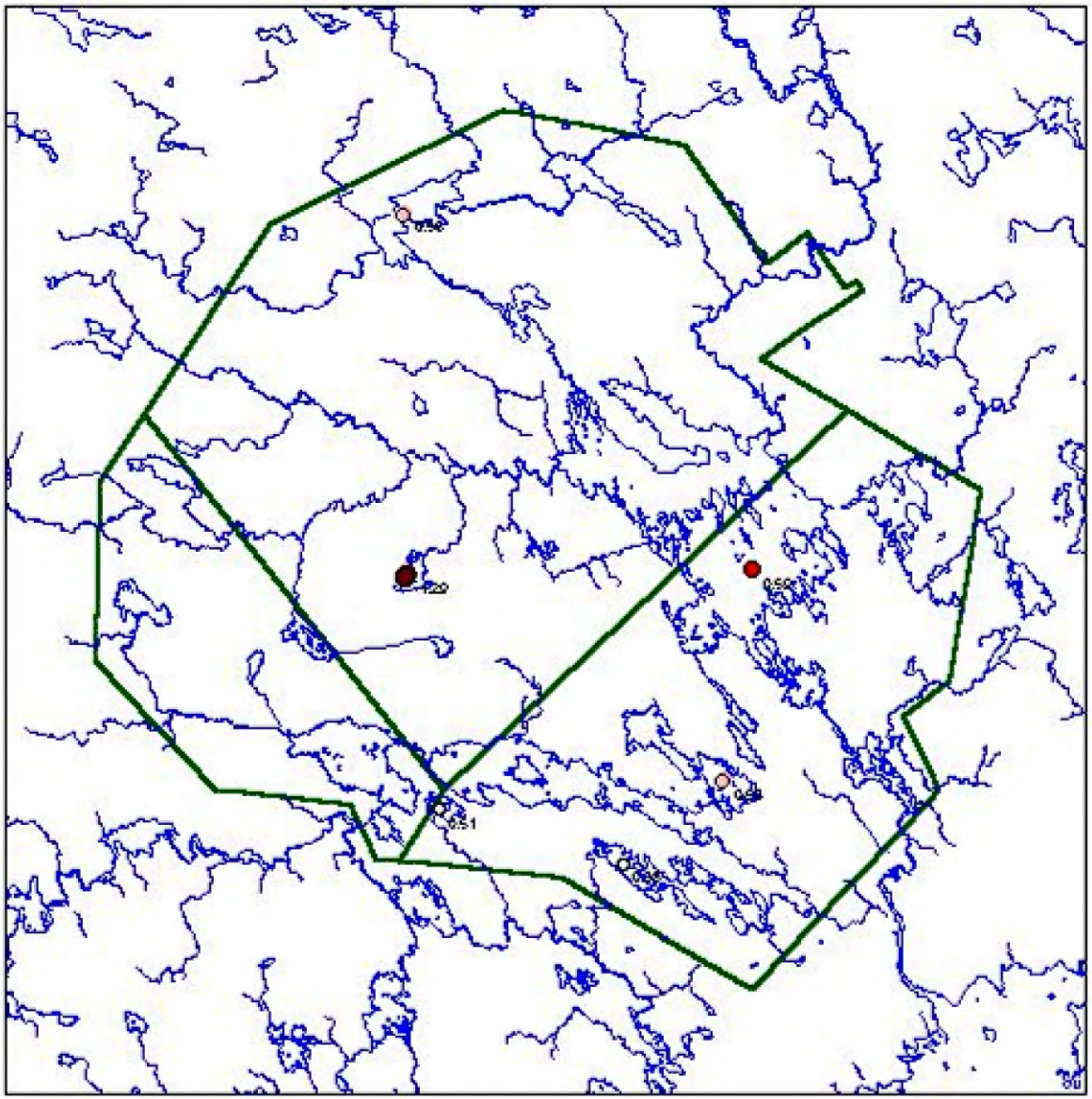


Figure 4.23.

Mercury in Juvenile Loon Blood (ppm)



N

CLASSIFICATION: Quantile Break

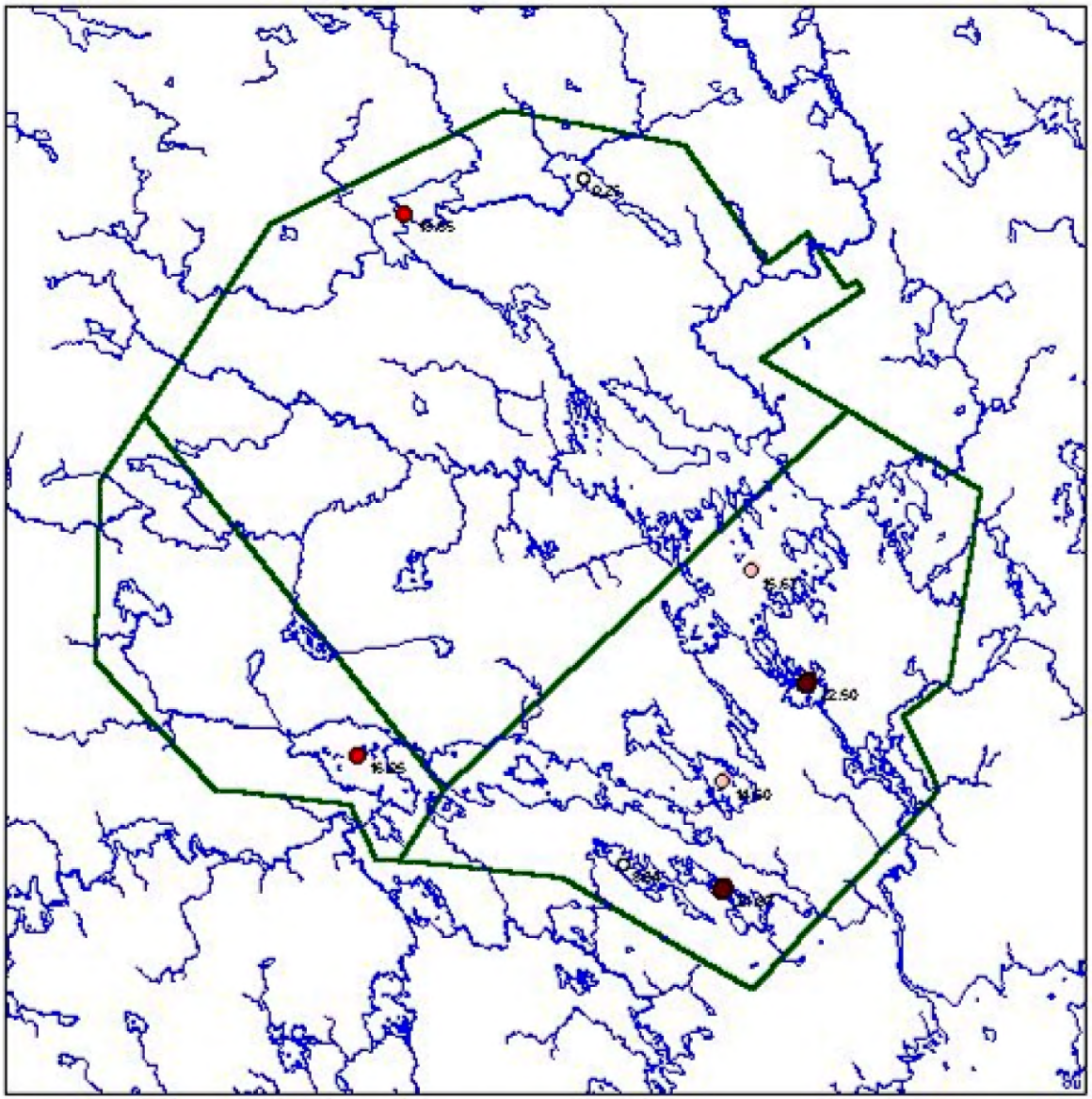
- 0.38 - 0.51 ppm
- 0.51 - 0.58 ppm
- 0.58 - 1.29 ppm
- 1.29 ppm

2 0 2 4

Kilometers

Figure 4.24.

Mercury in Adult Loon Feathers (ppm)



N

CLASSIFICATION: Quantile Break

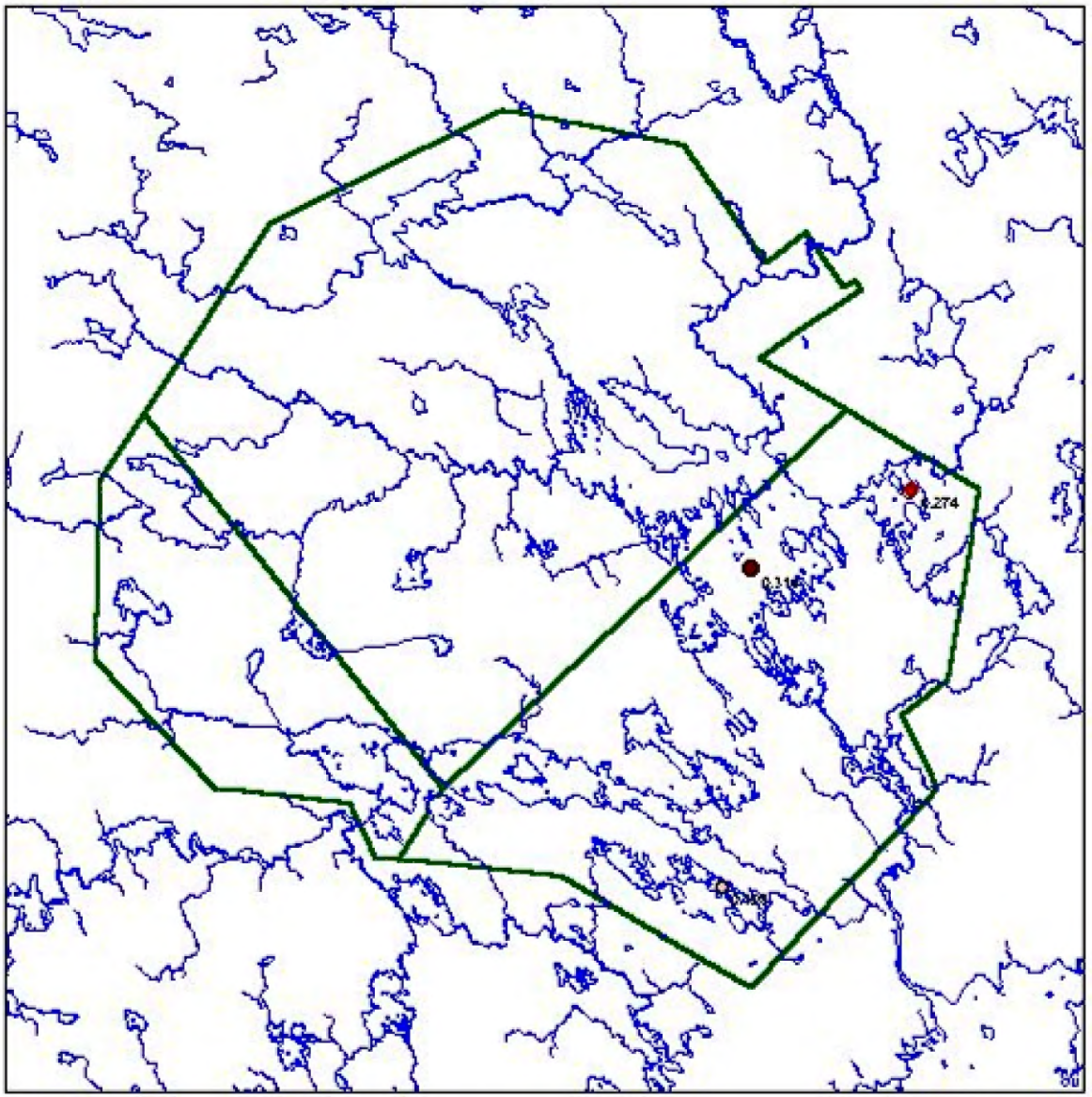
- 8.64 - 9.25 ppm
- 9.25 - 15.67 ppm
- 15.67 - 18.55 ppm
- 18.55 - 22.50 ppm

2 0 2 4

Kilometers

Figure 4.25.

Mercury in White Perch - Average Concentration / Weight (%)



N

CLASSIFICATION: Unique Value

- 0.198
- 0.274
- 0.314

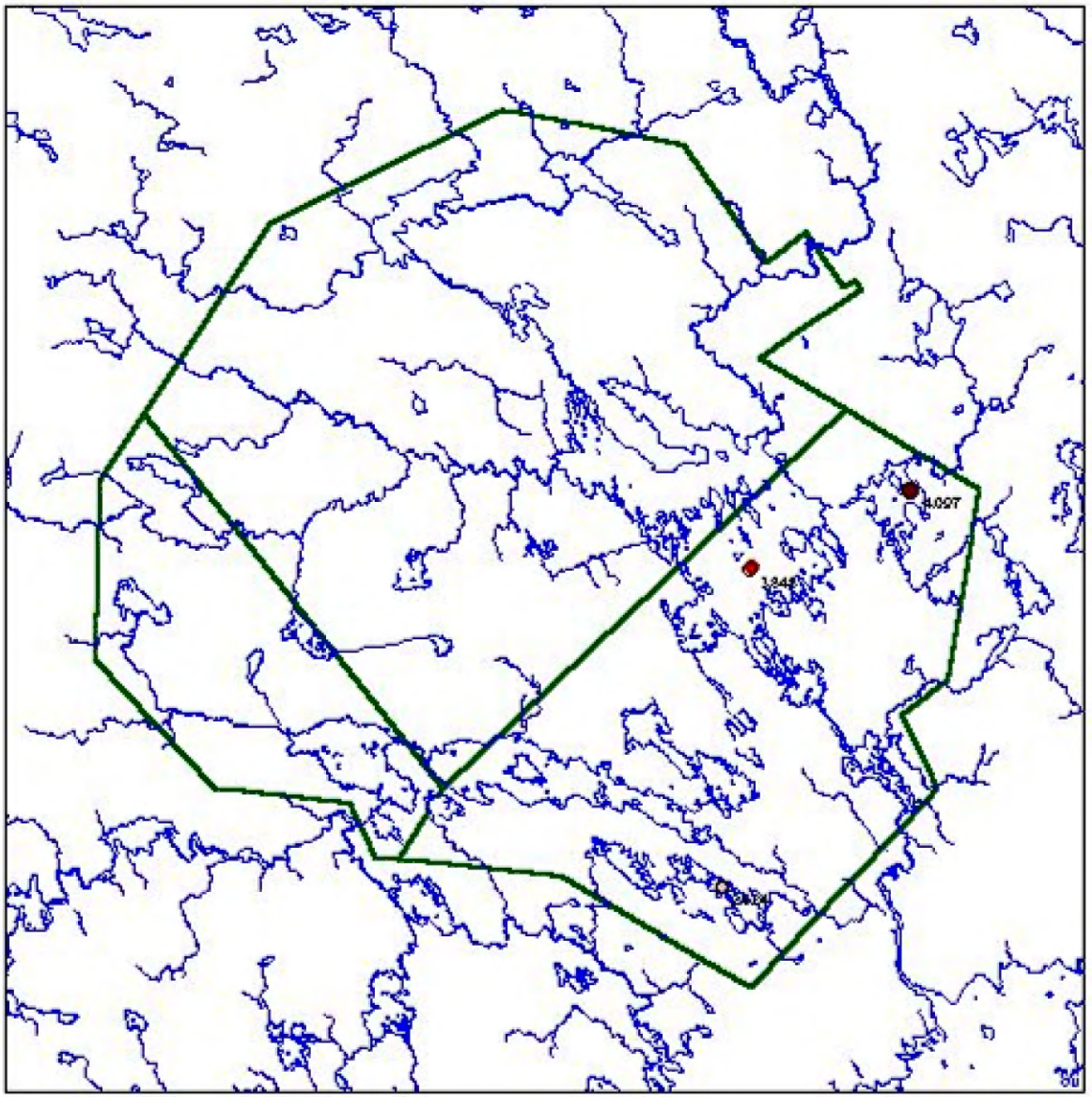
ug /g wet wt; white perch muscle tissue

2 0 2 4

Kilometers

Figure 4.26.

Mercury in White Perch - Average Concentration / Length (%)



N

CLASSIFICATION: Unique Value

- 2.624
- 3.848
- 4.097

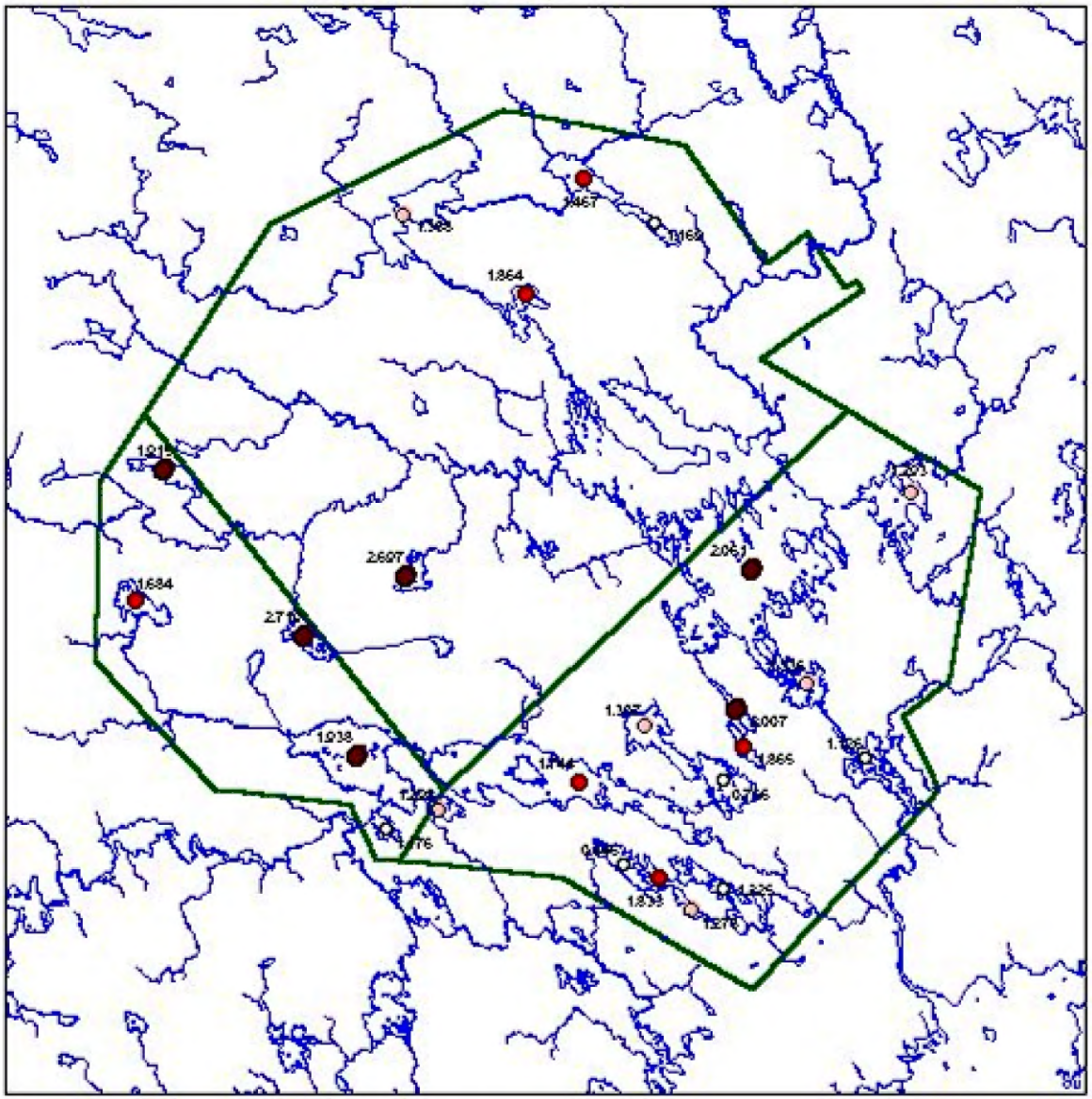
ug /g wet wt; white perch muscle tissue

2 0 2 4

Kilometers

Figure 4.27.

Mercury in Yellow Perch - Average Concentration / Weight (%)



N

CLASSIFICATION: Quantile Break

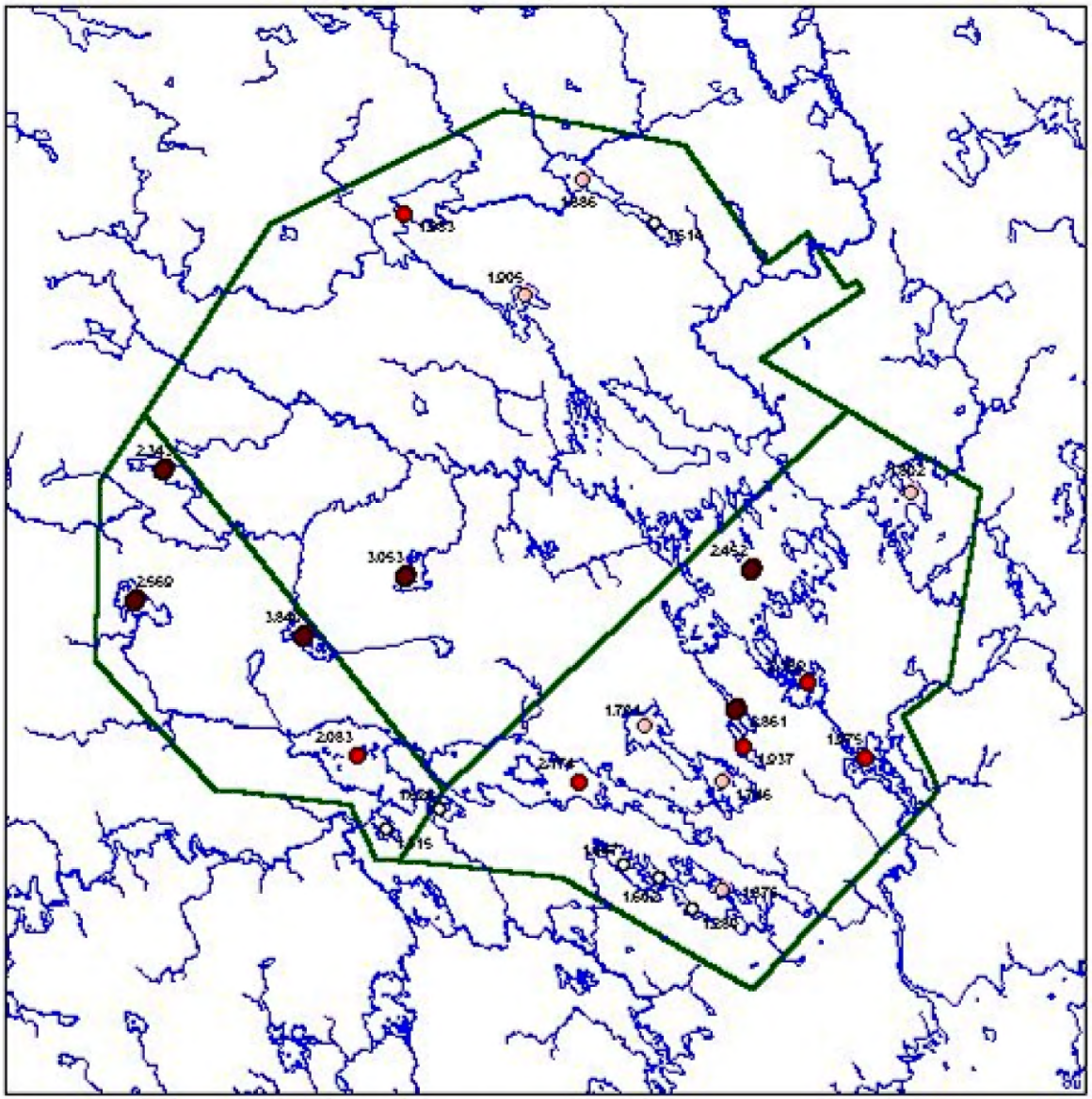
- 0.756 - 1.225 %
- 1.225 - 1.358 %
- 1.358 - 1.865 %
- 1.865 - 2.719 %

2 0 2 4

Kilometers

Figure 4.28.

Mercury in Yellow Perch - Average Concentration / Length (%)



N

CLASSIFICATION: Quantile Break

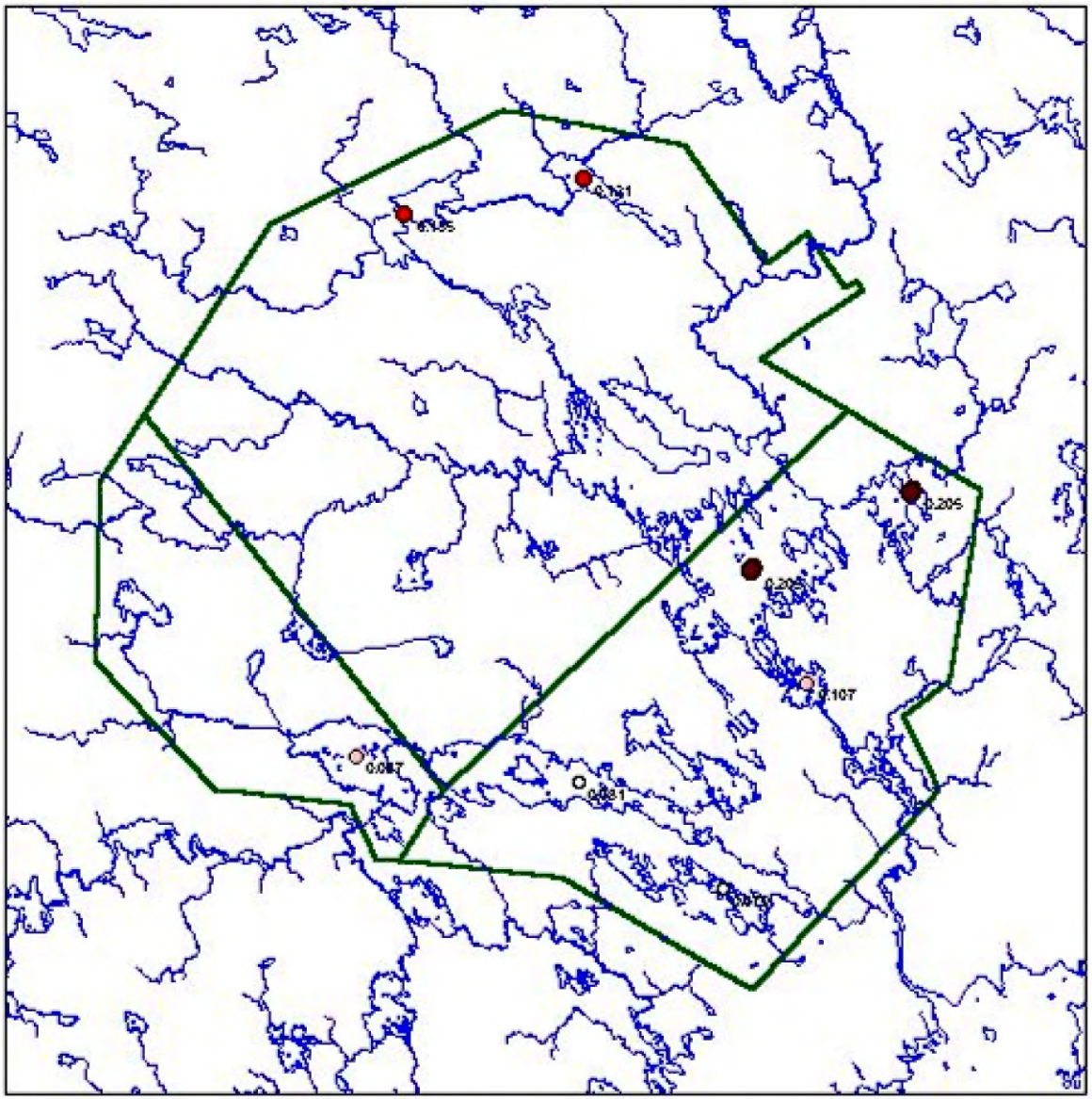
- 1.047 - 1.626 %
- 1.626 - 1.905 %
- 1.905 - 2.174 %
- 2.174 - 3.840 %

2 0 2 4

Kilometers

Figure 4.29.

Mercury in Trout - Average Concentration / Weight (%)



N

CLASSIFICATION: Quantile Break

- 0 .000 - 0.081 ug/g
- 0.081 - 0.107 ug/g
- 0.107 - 0.135 ug/g
- 0.135 - 0.205 ug/g

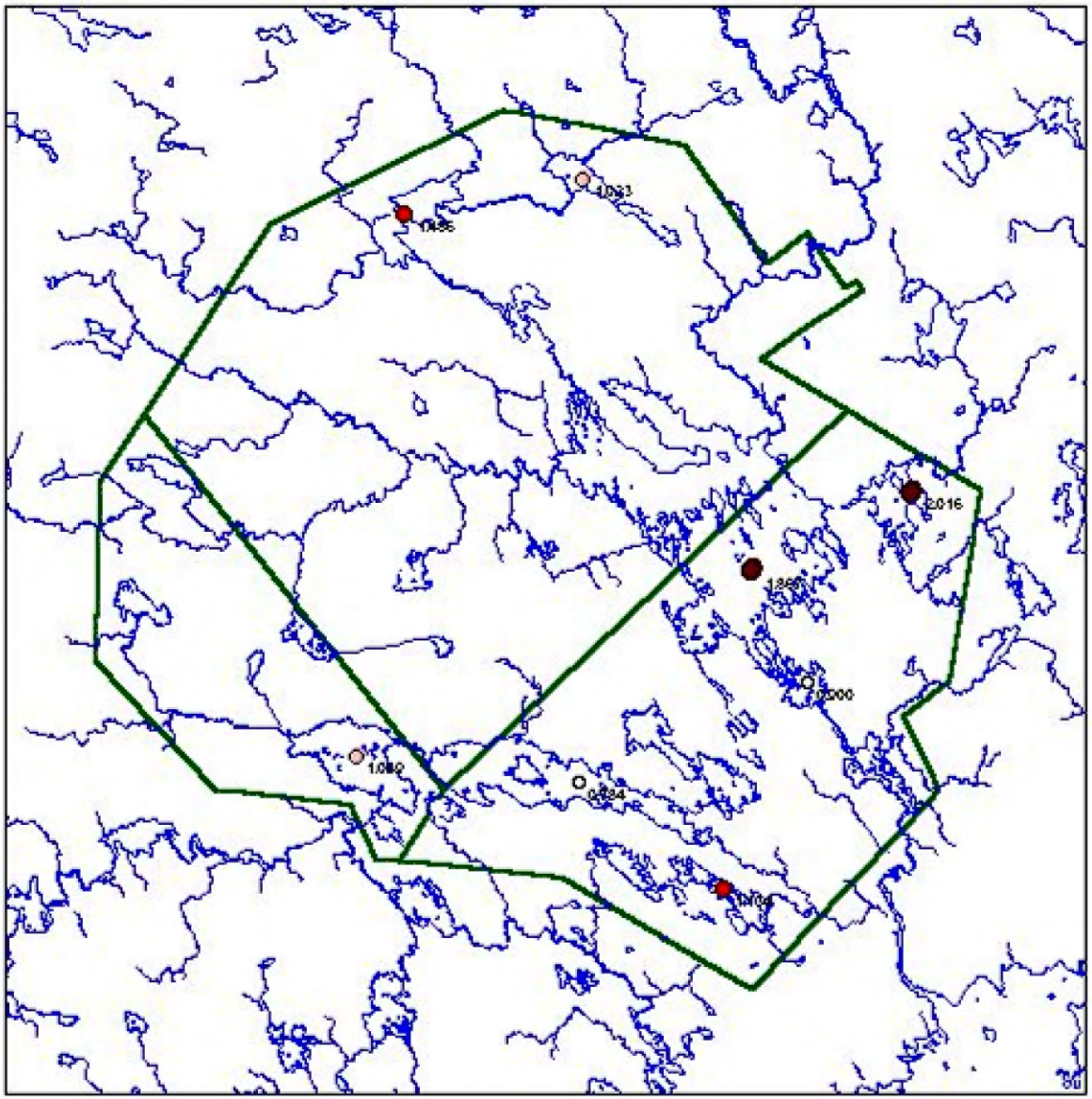
ug /g wet wt; trout muscle fissue

2 0 2 4

Kilometers

Figure 4.30.

Mercury in Trout - Average Concentration / Length (%)



N

CLASSIFICATION: Quantile Break

- 0.000 - 0.900 ug/g
- 0.900 - 1.089 ug/g
- 1.089 - 1.486 ug/g
- 1.486 - 2.016 ug/g

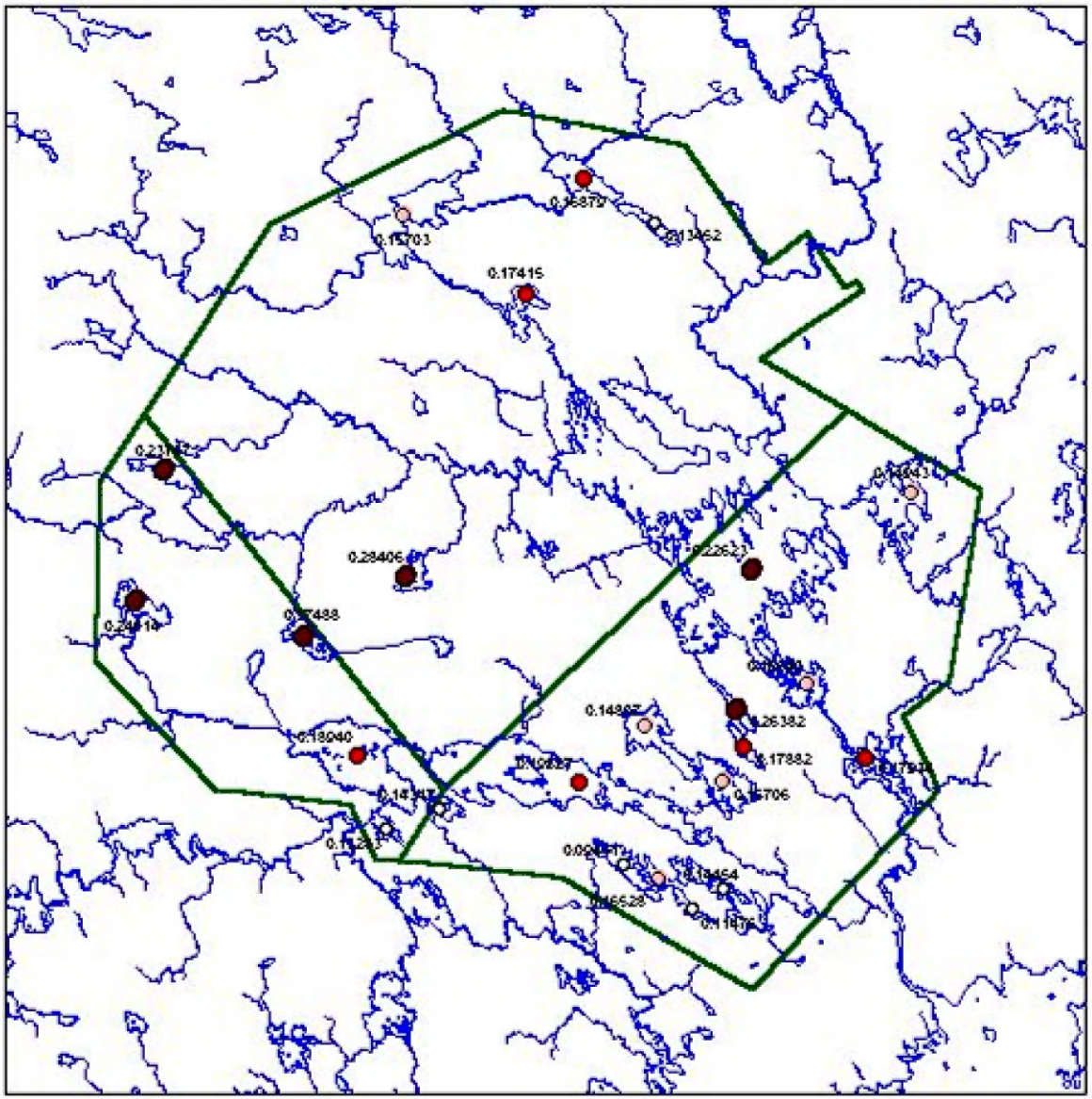
ug /g wet wt; trout muscle tissue

2 0 2 4

Kilometers

Figure 4.31.

Total Mercury in Perch 10 cm Long



N

CLASSIFICATION: Unique Value

- 0.094 - 0.145 ug/g
- 0.145 - 0.165 ug/g
- 0.165 - 0.198 ug/g
- 0.198 - 0.375 ug/g

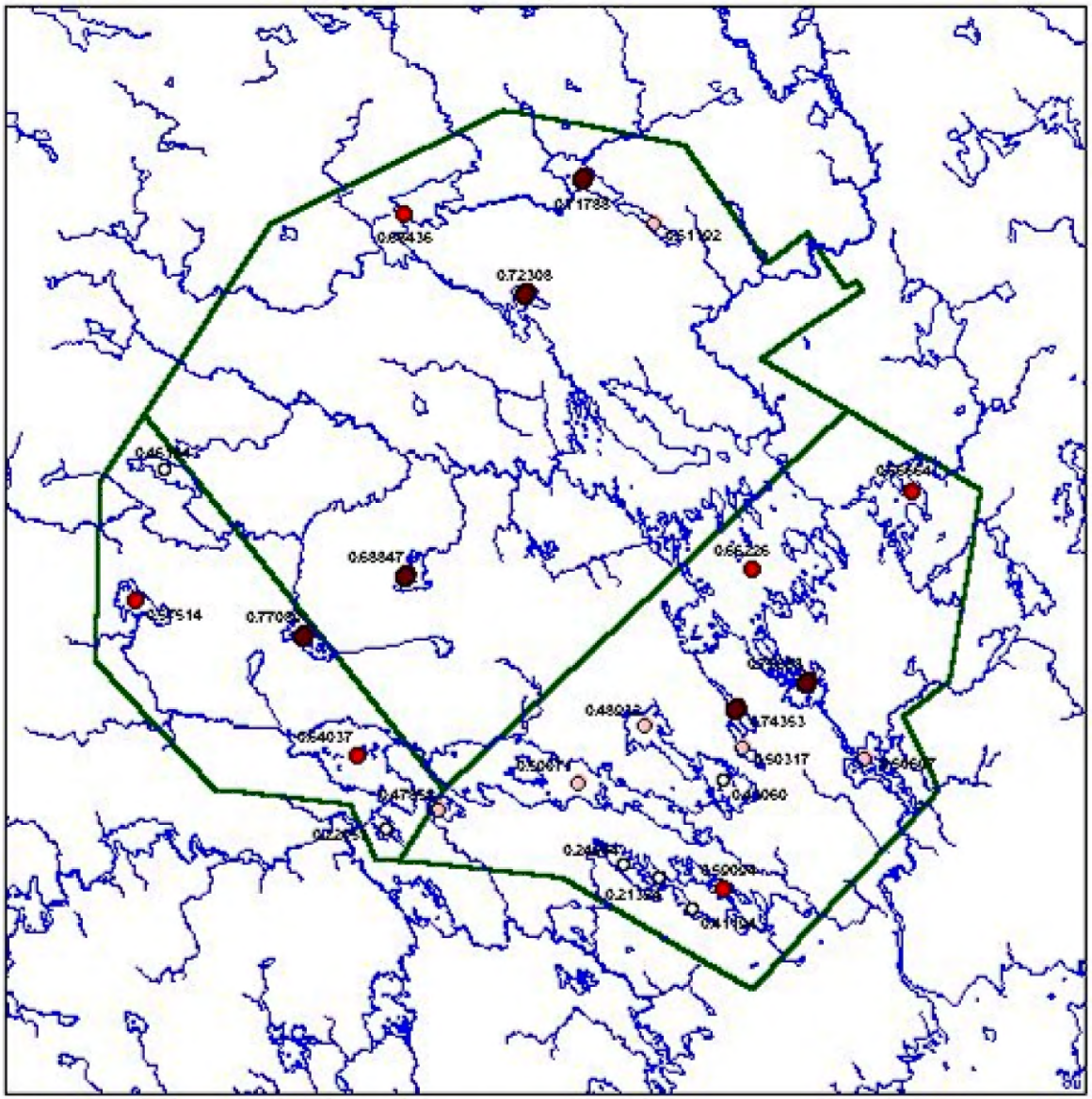
Mean Hg ug/g wet wt.
Whole Perch; given fork length.

2 0 2 4

Kilometers

Figure 4.32.

Total Mercury in Perch 20 cm Long



N

CLASSIFICATION: Quantile Break

- 0.213 - 0.462 ug/g
- 0.462 - 0.512 ug/g
- 0.512 - 0.684 ug/g
- 0.684 - 0.771 ug/g

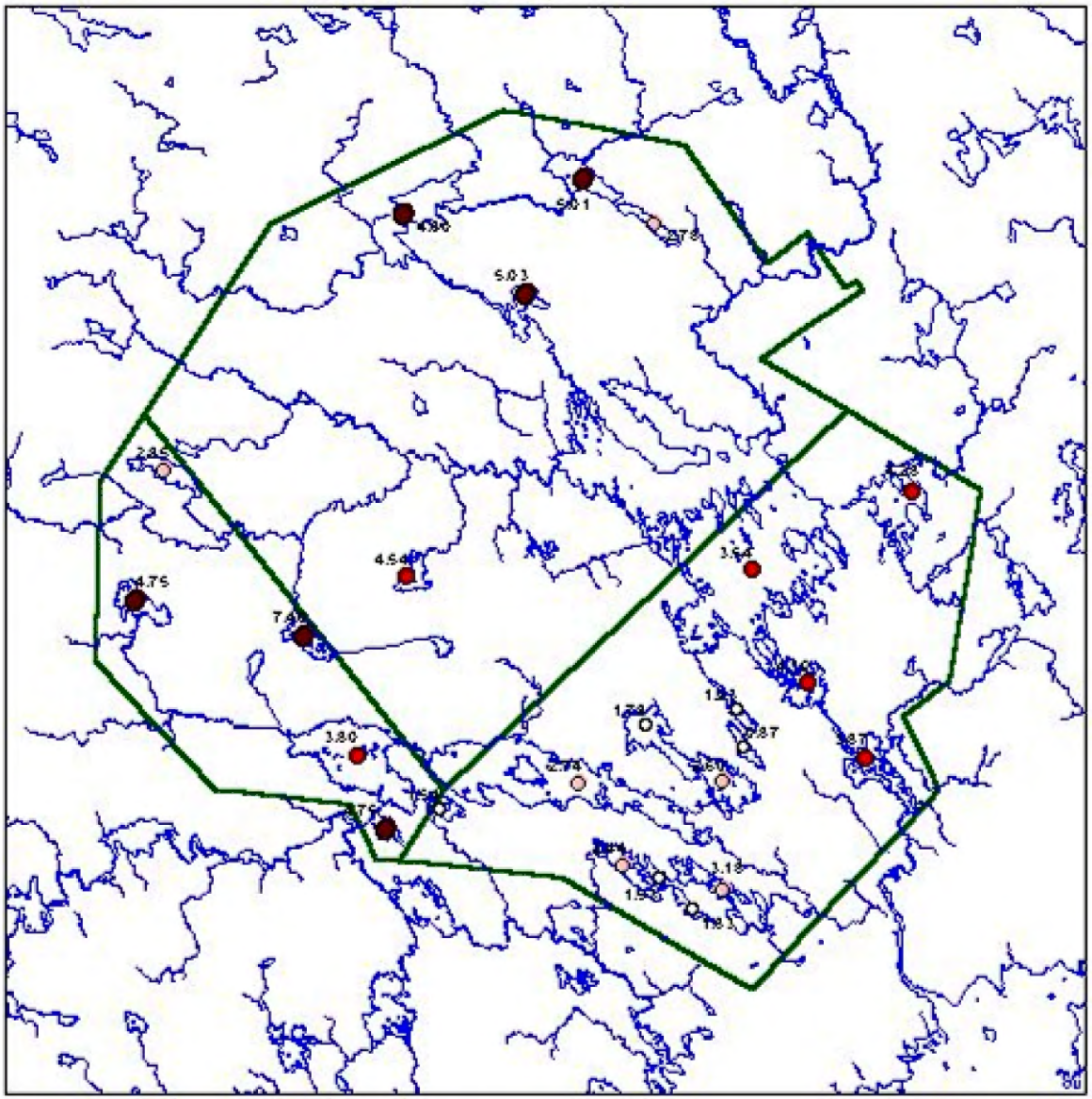
Mean Hg ug/g wet wt.
Whole Perch; given fork length.

2 0 2 4

Kilometers

Figure 4.33.

Surface Water Total Mercury Unfiltered (ng/L)



N

CLASSIFICATION: Quantile Break

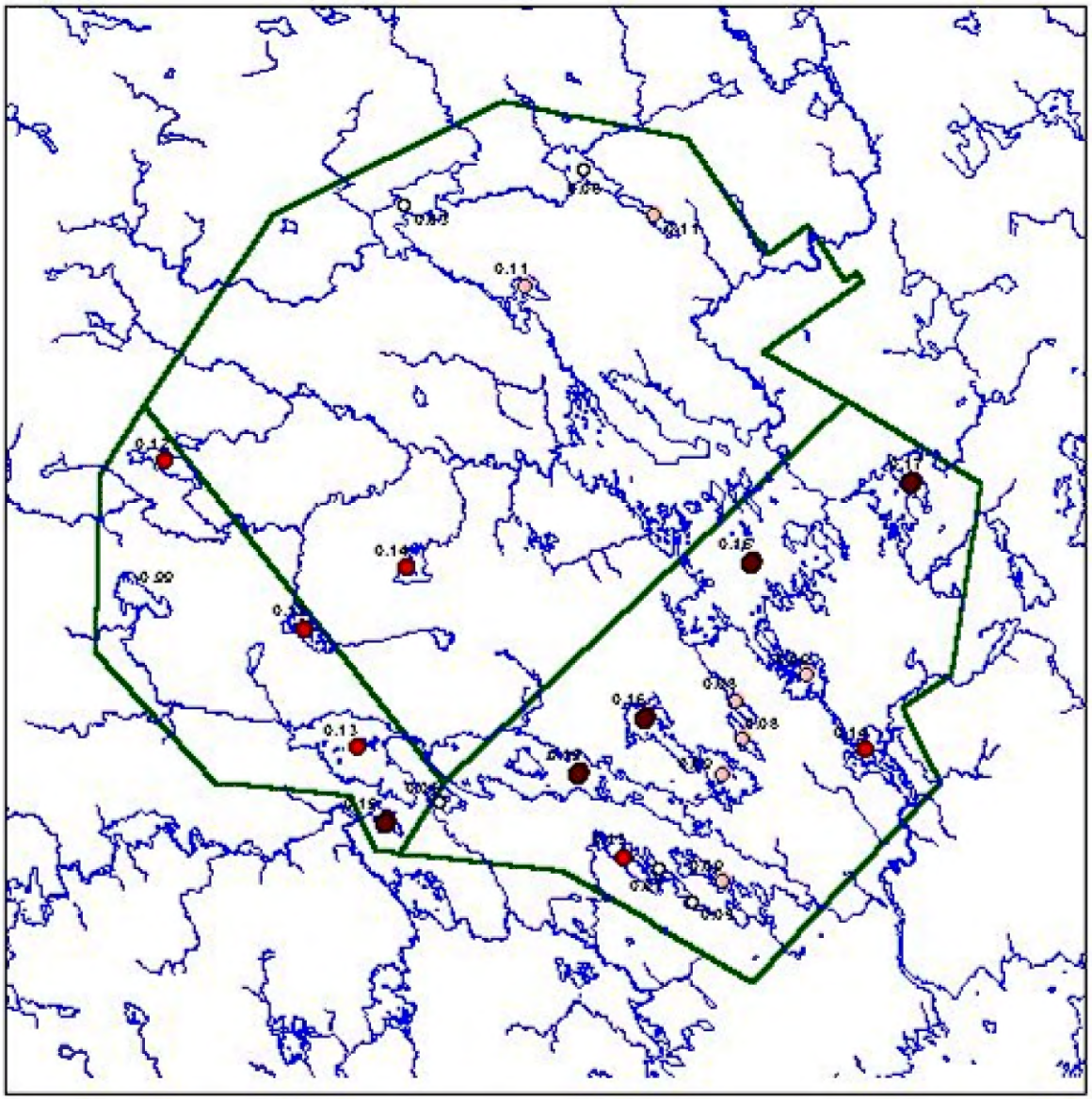
- 0.87 - 1.93 ng/L
- 1.93 - 3.18 ng/L
- 3.18 - 4.54 ng/L
- 4.54 - 7.40 ng/L

2 0 2 4

Kilometers

Figure 4.34.

Lake Sediment Hg (mg/kg)



CLASSIFICATION: Quantile Break

- 0.00 - 0.07 mg/kg
- 0.07 - 0.11 mg/kg
- 0.11 - 0.14 mg/kg
- 0.14 - 0.19 mg/kg

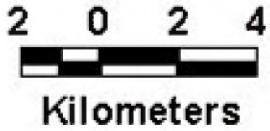
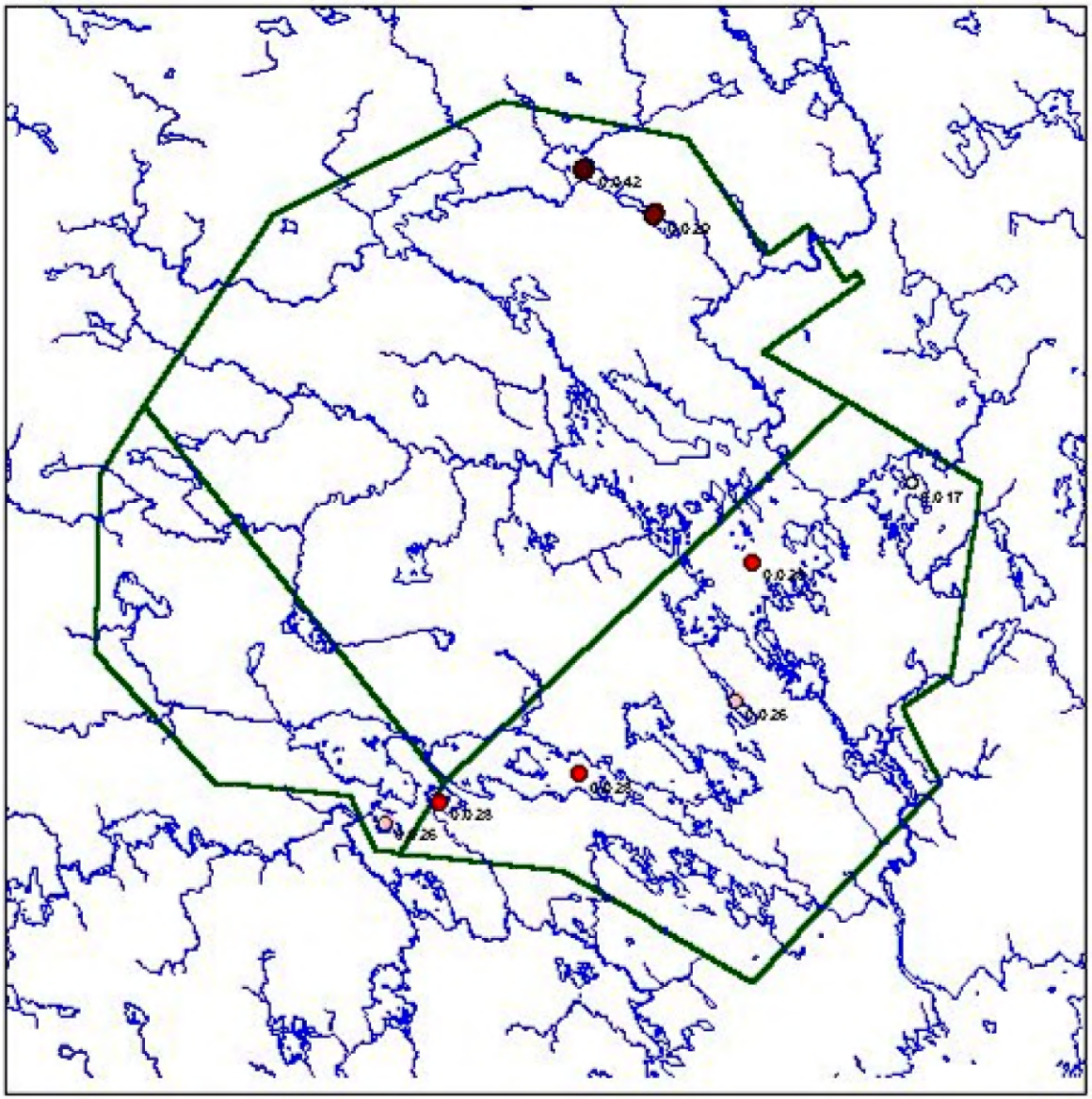


Figure 4.35.

Total Mercury in Dragonfly Larvae (ug/g)



N

CLASSIFICATION: Unique Value

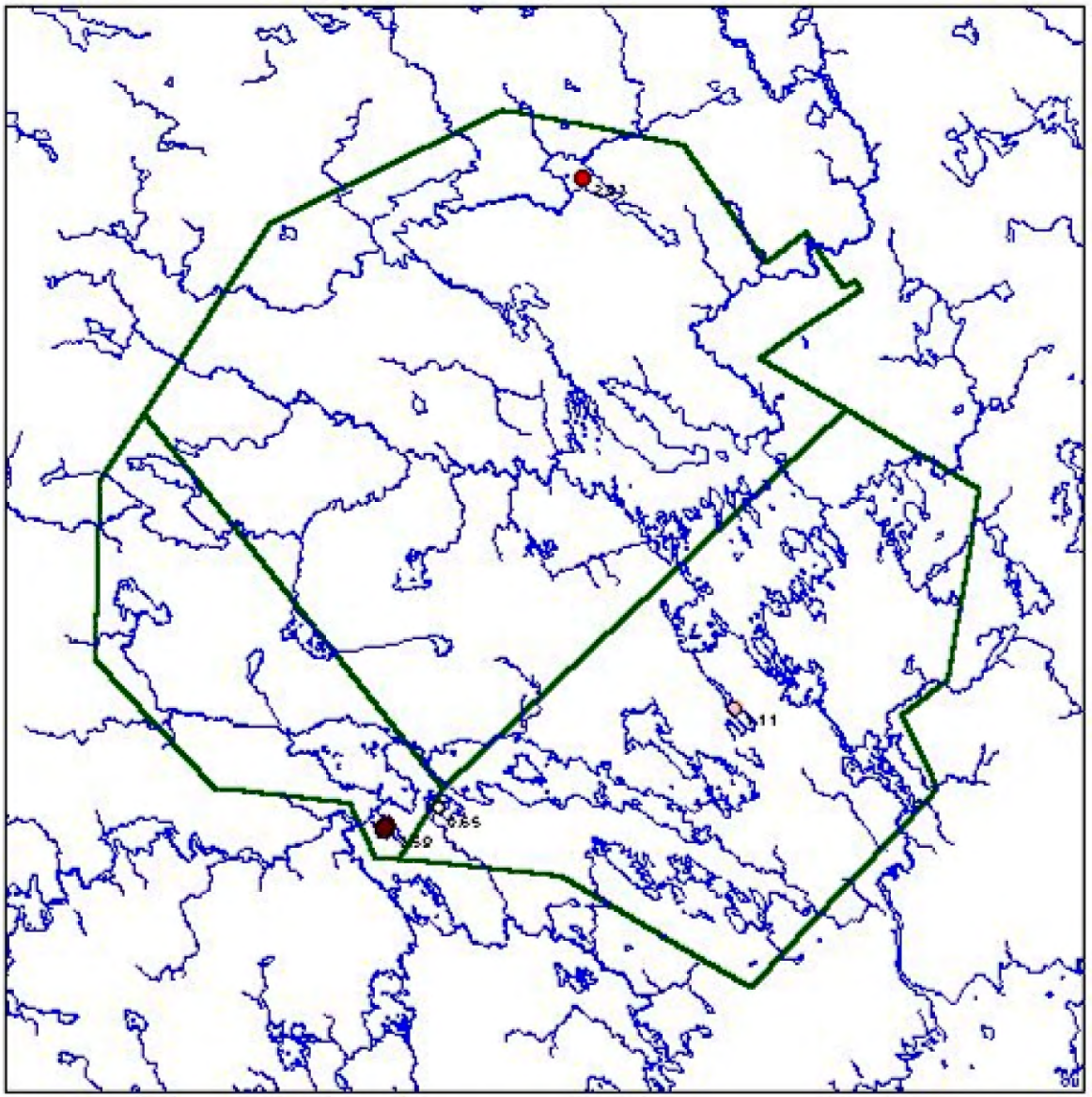
- 0.017 ug/g
- 0.026 ug/g
- 0.028 ug/g
- 0.029 ug/g
- 0.042 ug/g

2 0 2 4

Kilometers

Figure 4.36.

Total Mercury in Water - Unfiltered (ng/L)



N

CLASSIFICATION: Unique Value

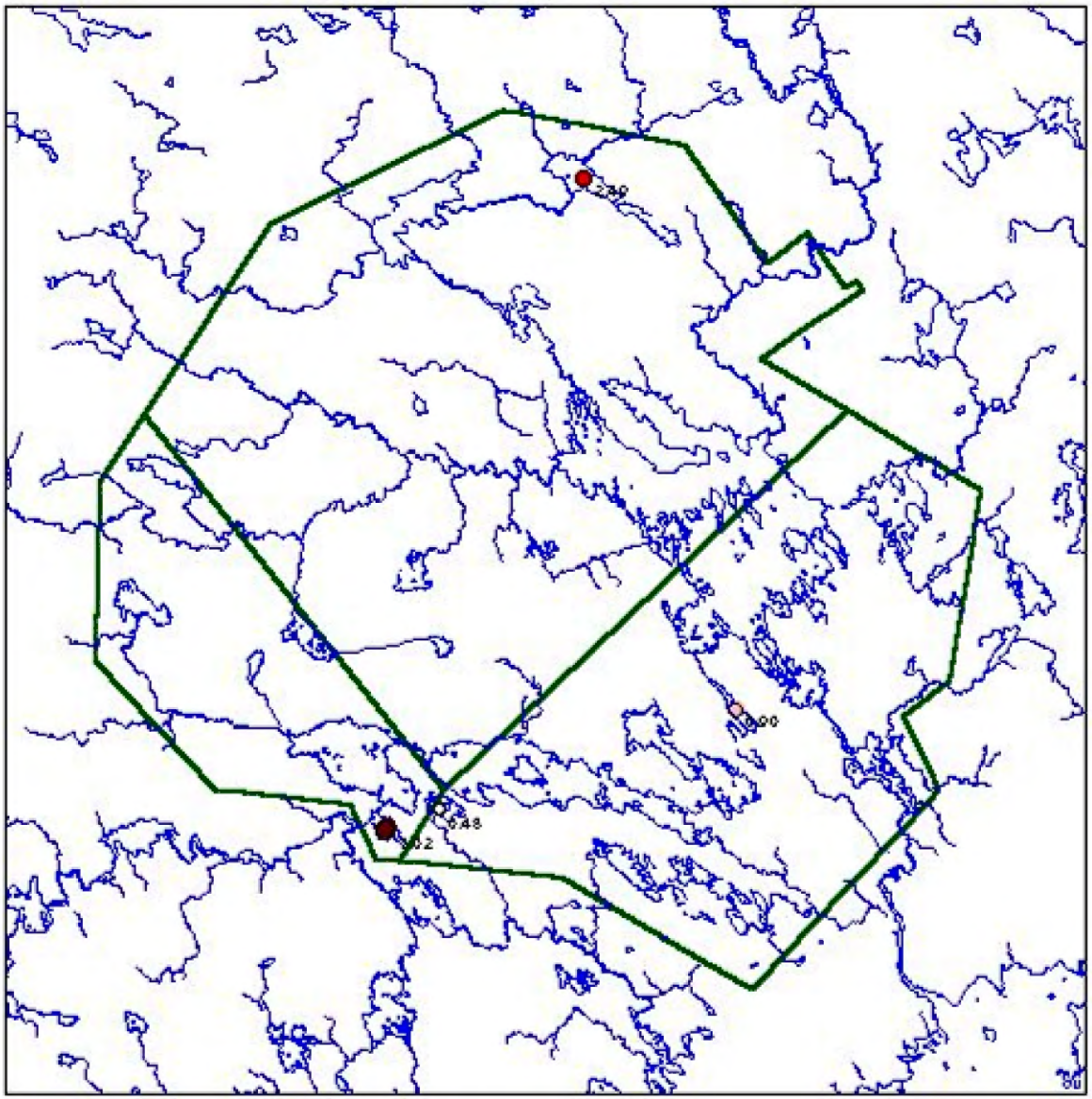
- 0.65 ng/L
- 1.11 ng/L
- 2.93 ng/L
- 3.59 ng/L

2 0 2 4

Kilometers

Figure 4.37.

Total Mercury in Water - Filtered (ng/L)



N

CLASSIFICATION: Unique Value

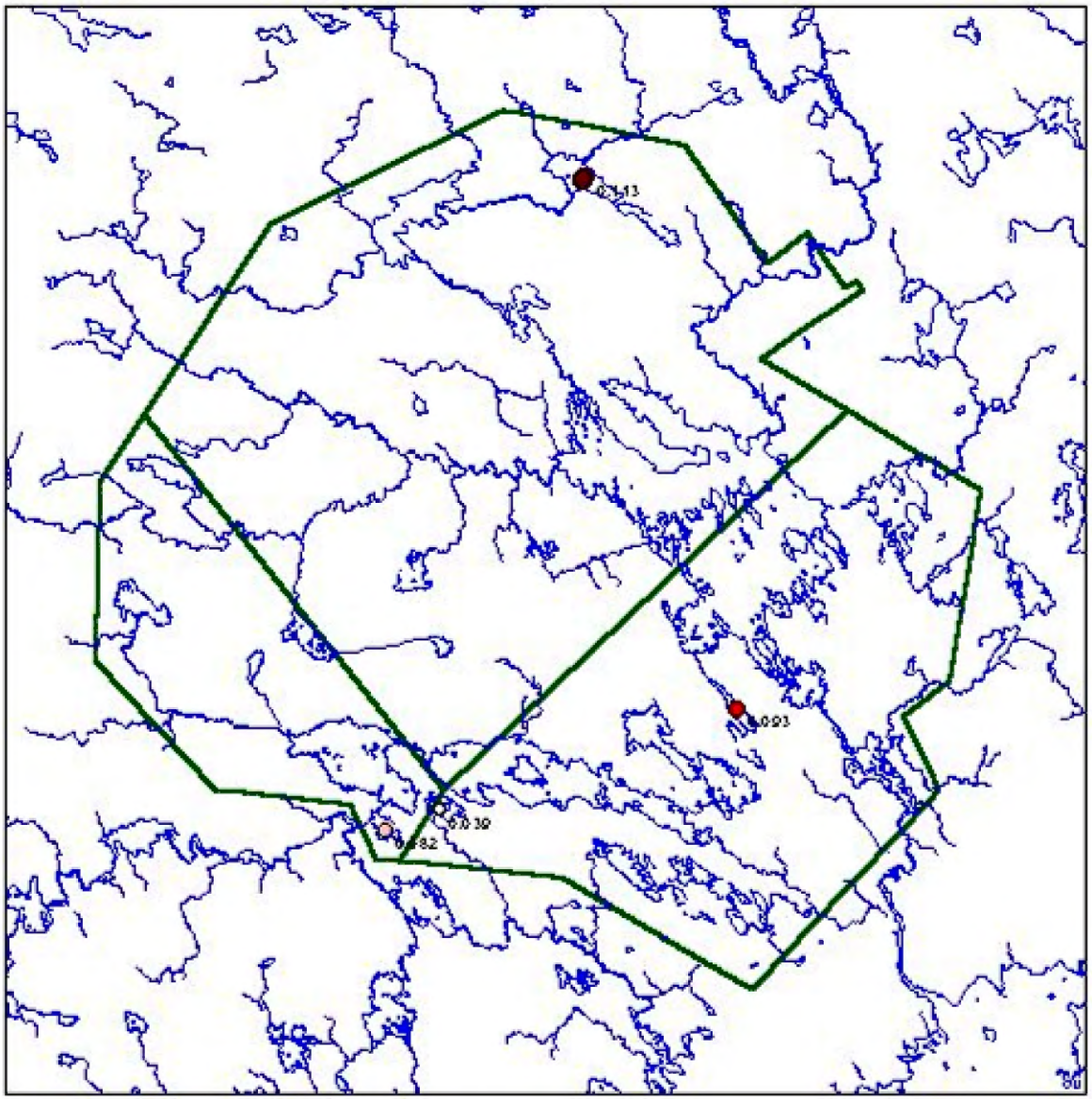
- 0.48 ng/L
- 0.90 ng/L
- 2.49 ng/L
- 3.02 ng/L

2 0 2 4

Kilometers

Figure 4.38.

Methylmercury in Water - Unfiltered (ng/L)



N

CLASSIFICATION: Unique Value

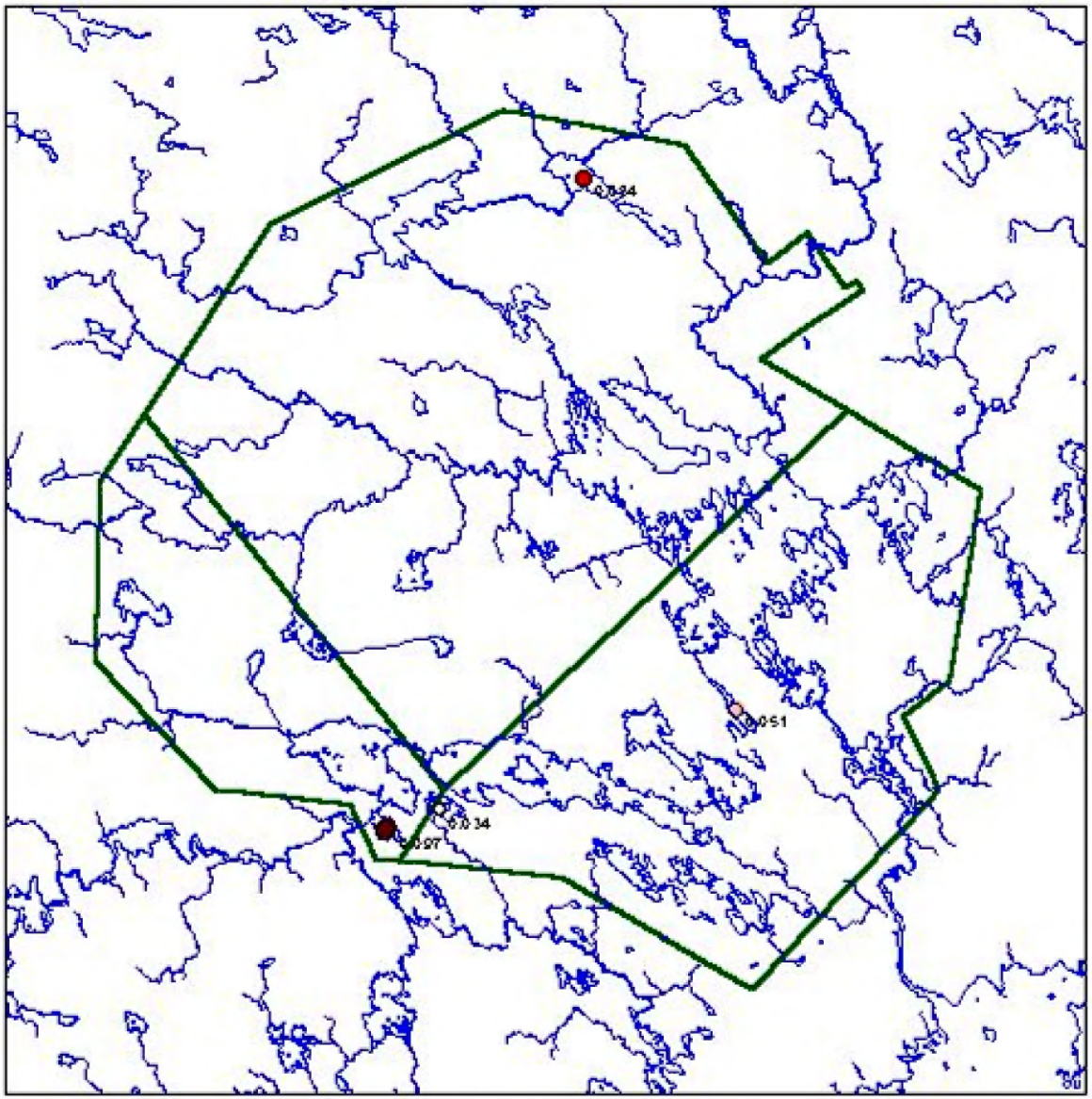
- 0.039 ng/L
- 0.082 ng/L
- 0.093 ng/L
- 0.113 ng/L

2 0 2 4

Kilometers

Figure 4.39.

Methylmercury in Water - Filtered (ng/L)



N

CLASSIFICATION: Unique Value

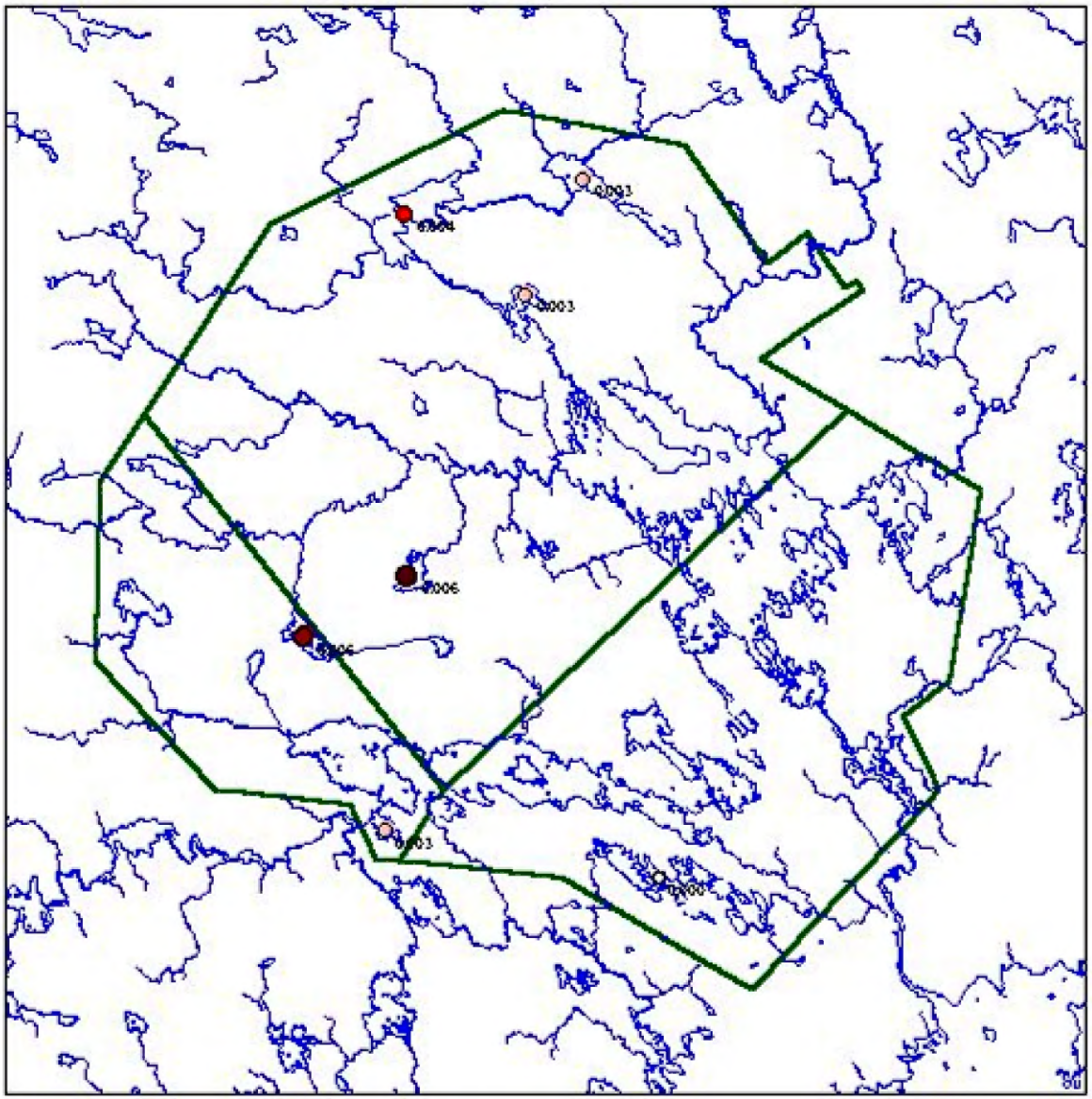
- 0.034 ng/L
- 0.051 ng/L
- 0.084 ng/L
- 0.097 ng/L

2 0 2 4

Kilometers

Figure 4.40.

Lake Water Data Collected by A. Rencz - Mercury (ppb)



N

CLASSIFICATION: Unique Value

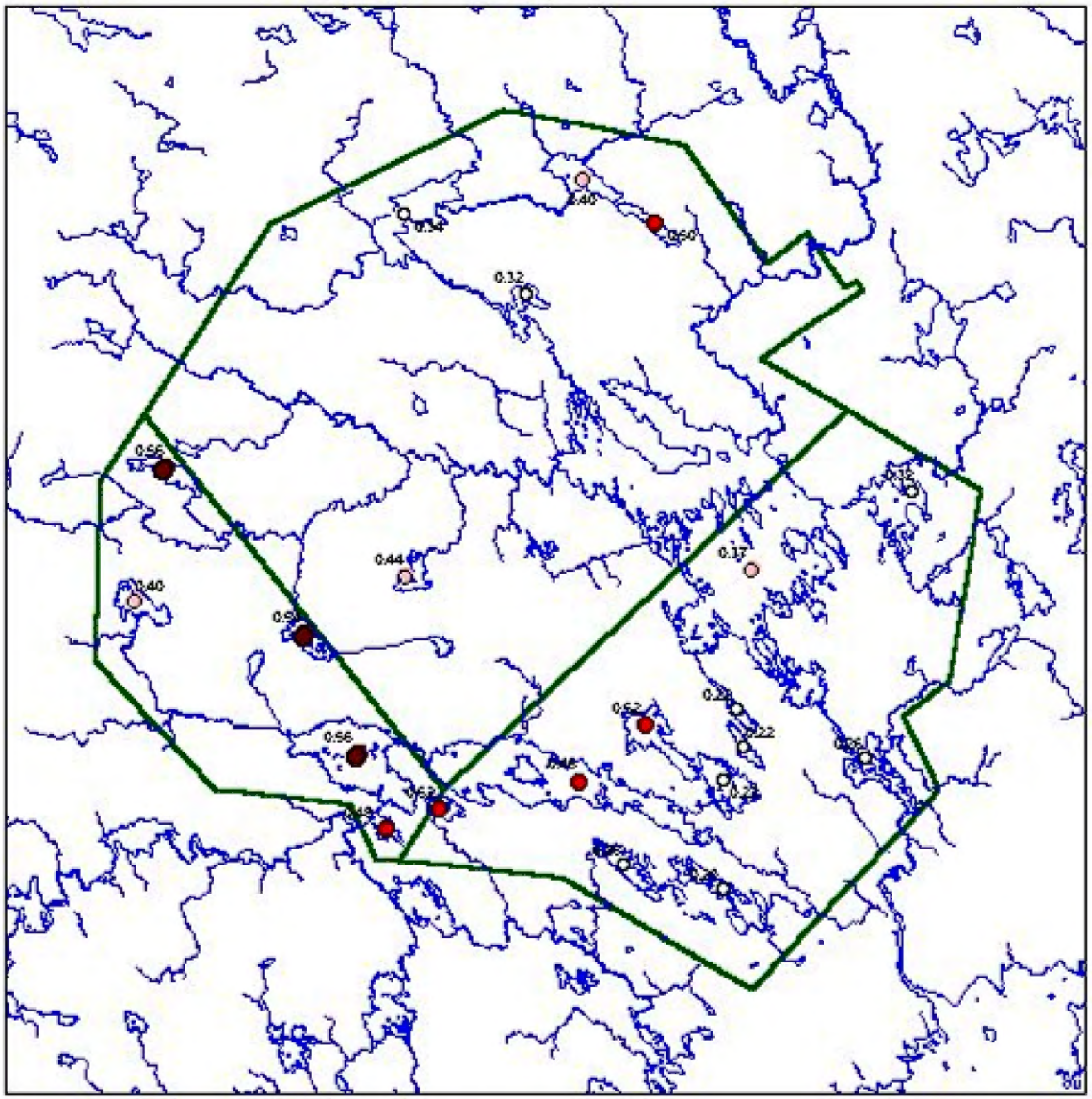
- 0.000 ppb
- 0.003 ppb
- 0.004 ppb
- 0.005 ppb
- 0.006 ppb

2 0 2 4

Kilometers

Figure 4.41.

Lake Sediment Data 1977 - Mercury (ppm)



N

CLASSIFICATION: Quantile Break

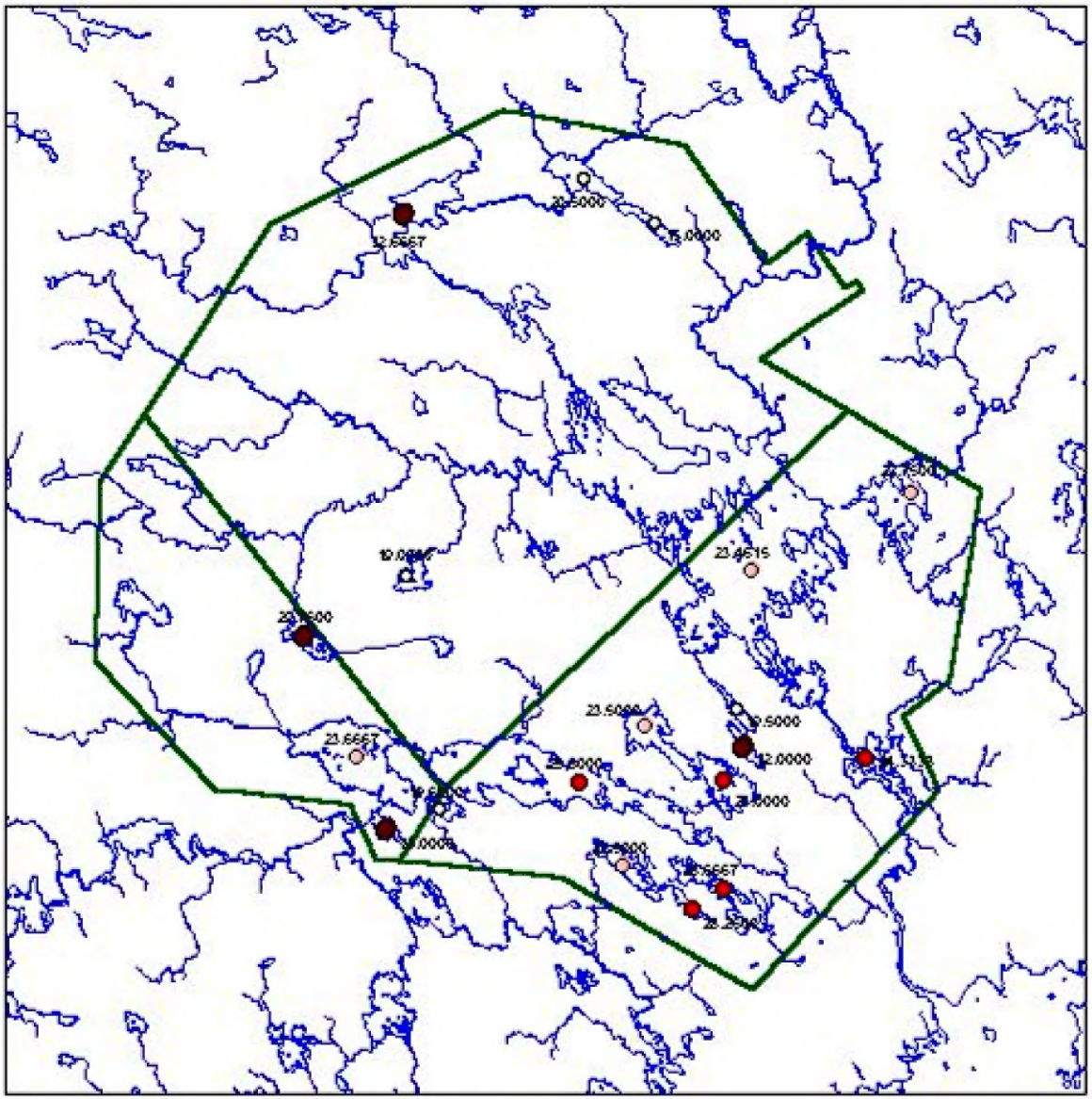
- 0.00 - 0.34 ppm
- 0.34 - 0.44 ppm
- 0.44 - 0.52 ppm
- 0.52 - 0.56 ppm

2 0 2 4

Kilometers

Figure 4.42.

Mercury in White Pine Leaf Tissue ppb - average watershed



CLASSIFICATION: Quantile Break

- 0.000 - 20.500 ppb
- 20.500 - 23.667 ppb
- 23.667 - 28.667 ppb
- 28.667 - 33.000 ppb

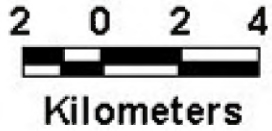
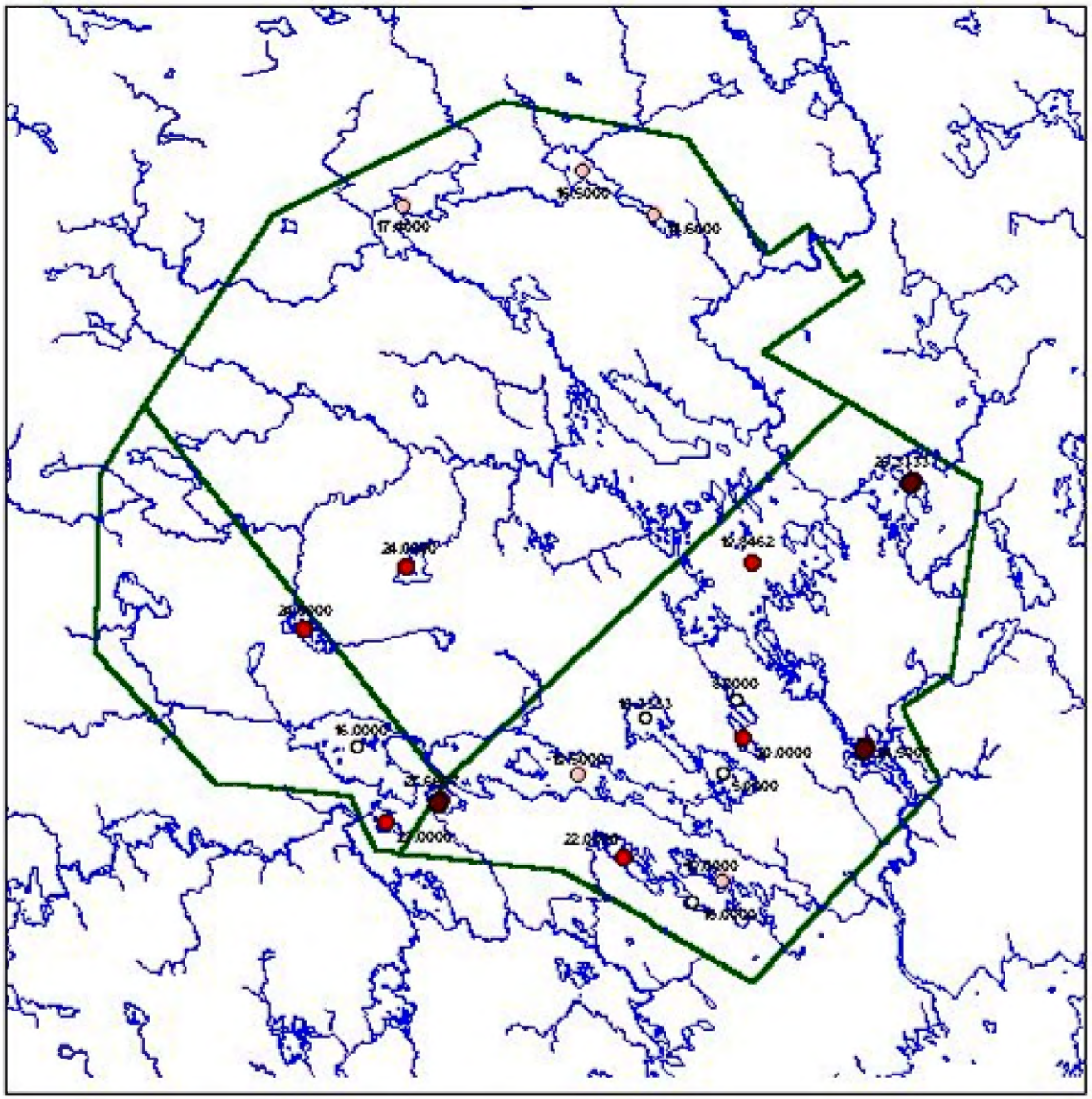


Figure 4.43.

Mercury in Red Maple Leaf Tissue ppb - average watershed



CLASSIFICATION: Quantile Break

- 0.000 - 16.000 ppb
- 16.000 - 19.500 ppb
- 19.500 - 24.000 ppb
- 24.000 - 27.667 ppb

2 0 2 4

Kilometers

Figure 4.44.

Table 4.4. Observations made for each of the Hg fields. * n = number of sample locations, r = correlation coefficient; significance of correlation values are discussed in section 4.2.2. ** Big Dam West and Big Dam East lakes are focused study lakes in the TSRI project. Big Dam West Lake is a dark coloured, high DOC, low pH lake and Big Dam East Lake is a clear, low DOC, higher pH lake. Their contrasting characteristics make them ideal lakes for concentrated studies. Characteristics of these lakes are further discussed in the text. See Appendix 4.2 for a description of each Hg field.

Hg Fields	Observations Made From The Maps
- ADULT LOON BLOOD (PPM) - JUVENILE LOON BLOOD (PPM) - ADULT LOON FEATHERS (PPM)	*Geographic Coverage* ♦ Hg in juvenile loon blood (n = 7) – no values in the west. ♦ Hg in adult loon blood (n = 9) – no values in the west. ♦ Hg in adult loon feathers (n = 9) – no values in the west. *Geographic Locations of High Hg Values* ♦ Hg levels high in adult/juvenile loon blood in Kejimkujik Lake. *General* ♦ Hg in adult loon blood does correlate with Hg in juvenile loon blood (r = 0.952, n = 4). * ♦ Hg in adult loon blood does not correlate with Hg in adult loon feathers (r = 0.286, n = 8). * ♦ Much higher Hg in the adult loons than in the juvenile loons.
- YPERCH AVG CONC/WT (%) - YPERCH AVG CONC/LGTH (%)	*Geographic Coverage* ♦ Complete geographic coverage (n = 24). *Geographic Locations of High Hg Values* ♦ Highest values are in the east (Poplar, Liberty, Big Red, and Luxton lakes) and in the west (Kejimkujik, North Cranberry, and Puzzle lakes). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has higher Hg values than Big Dam East Lake.
- PERCH TOT HG (10CM) - PERCH TOT HG (20CM)	*Geographic Coverage* ♦ Complete geographic coverage (n = 24). *Geographic Locations of High Hg Values* ♦ 10 cm perch – Highest values are in the east (Poplar, Liberty, Big Red, and Luxton lakes) and in the west (Kejimkujik and North Cranberry lakes). ♦ 20 cm perch – Highest values in the east (Big Red and Luxton lakes), in the west (George and North Cranberry lakes), and in the north (Big Dam West and Channel lakes). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has higher Hg values than Big Dam East Lake. *General* ♦ Some differences in perch that are 10 cm long versus perch that are 20 cm long.

Table 4.4. (Continued)

- WPERCH AVG CONC/WT (%) - WPERCH AVG CONC/LGTH (%)	*Geographic Coverage* ♦ Hg in white perch (n = 3).
- TROUT AVG CONC/WT (%) - TROUT AVG CONC/LGTH (%)	*Geographic Coverage* ♦ Hg in trout (n = 8) – no values in the west. *Geographic Locations of High Hg Values* ♦ Highest values in the east (Kejimkujik and Grafton lakes), next highest values to the north (Big Dam West and Frozen Ocean lakes).
- SW TOTAL HG – UNFILTERED (NG/L)	*Geographic Coverage* ♦ Complete geographic coverage (n = 24). *Geographic Locations of High Hg Values* ♦ Highest values in the east (Big Red and Poplar lakes) and in the north (Big Dam West, Frozen Ocean, and Channel lakes). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has higher Hg values than Big Dam East Lake.
- LAKE SEDIMENT HG (MG/KG)	*Geographic Coverage* ♦ Hg in lake sediment (n = 23). *Geographic Locations of High Hg Values* ♦Highest values in a series of NE trending lakes (Pebble, Peskowesk, Mountain, Kejimkujik, and Grafton). ♦ Values in the east are fairly high (Big Red, Luxton, and Liberty lakes). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has lower Hg values than Big Dam East Lake.
- TOT HG DRAGONFLY LARVAE (UG/G)	*Geographic Coverage* ♦ Hg in dragonfly larvae (n = 8) – no values in the west. *Geographic Locations of High Hg Values* ♦ Highest values in the north (Big Dam West Lake). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has higher Hg values than Big Dam East Lake.
- TOT HG UNFILTERED (NG/L) - TOT HG FILTERED (NG/L) - MEHG UNFILTERED (NG/L) - MEHG FILTERED (NG/L)	*Geographic Coverage* ♦ All four fields (n = 4). *General* ♦ There is an excellent correlation between filtered and unfiltered Hg. ♦ There is an excellent correlation between filtered Hg and filtered MeHg.

Table 4.4. (Continued)

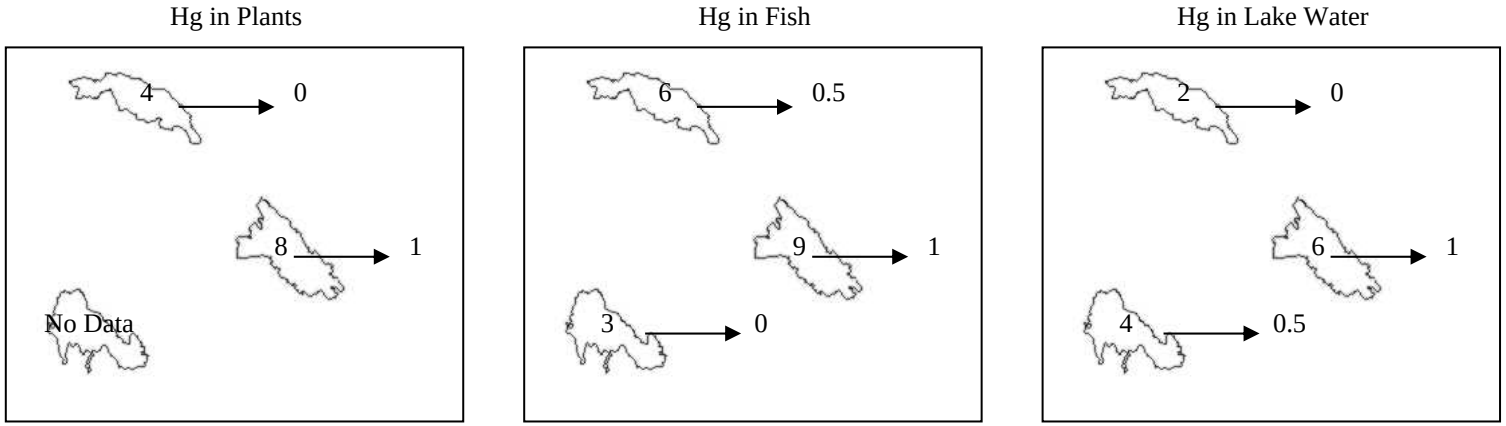
- AR H2O HG PPB	*Geographic Coverage* ♦ Complete geographic coverage (n = 24) – 18 are below detection limit and are recorded as zero. *Geographic Locations of High Hg Values* ♦ Highest values in the west (Luxton Lake). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has higher Hg values than Big Dam East Lake.
- LKS77 MERCURY	*Geographic Coverage* ♦ Hg in lake sediment (n = 21). *Geographic Locations of High Hg Values* ♦ Highest values in the west (Libery, Big Red, and Peskawa lakes). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has lower Hg values than Big Dam East Lake.
- WPINE HG PPB (AVG WSHED)	*Geographic Coverage* ♦ Hg in white pine (n = 19). This field is based on the watersheds. *Geographic Locations of High Hg Values* ♦ Highest values in the west (Big Red and Pebbleloggitch lakes), north (Frozen Ocean Lake), and south (Puzzle Lake). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has about the same Hg values as Big Dam East Lake.
- RMAPLE HG PPB (AVG WSHED)	*Geographic Coverage* ♦ Hg in red maple (n = 19). This field is based on the watersheds. *Geographic Locations of High Hg Values* ♦ Highest values in the east (Grafton and Loon lakes). ♦ Values in the east are fairly high (Beaverskin, Big Red, and Luxton lakes). *Big Dam East Lake vs. Big Dam West Lake* ** ♦ Big Dam West Lake has about the same Hg values as Big Dam East Lake.

derived from this table. (1) Only nine Hg fields (Table 4.3b) provide a good geographic coverage of the park and are useful for statistical analysis and relative comparisons of the park's lakes. (2) The highest Hg values are in the western part of the park (generally in Big Red and Luxton lakes; see Figure 4.1 for lake names). (3) The lowest Hg values are in the southern part of the park. (4) Big Dam West Lake generally has higher Hg values than Big Dam East Lake, however both lake sediment data sets (the TSRI data set and the NSDNR data set, Table 4.1) show the opposite relationship (i.e. Big Dam West Lake has lower Hg values in the lake sediment than Big Dam East Lake). Big Dam West and Big Dam East lakes are focused study lakes in the TSRI project. Big Dam West Lake is a dark colored, high dissolved organic content (DOC), low pH lake and Big Dam East Lake is a clear, low DOC, higher pH lake. Their contrasting characteristics, and close proximity (Figure 4.1), make them ideal lakes for concentrated studies. (5) High Hg values in the lake sediment and the vegetation data sets do not geographically correspond to high Hg values in the fish and lake water data sets.

4.3.1.2. Spatial Analysis of the Hg Fields

In order to obtain a better understanding of Hg levels in each of the 24 lakes and watersheds, the nine Hg fields that represent a good geographic coverage were used to perform a spatial analysis in the park (i.e. to see the coincidence of the nine layers). Figure 4.45 explains the concepts behind this analysis. Basically, the minimum and maximum value was extracted for each of the nine Hg data sets. For each of the data sets, a value of zero was assigned to the minimum value and a value of one was assigned to the maximum value. All values were then linearly stretched between the zero and one (a linear stretch is a uniform distribution of the values between a lower value, in this case zero, and an upper value, in this case one). All of these values, for each data set, were added together and then the data was normalized (i.e. each lake was divided by the number of data sets that had actual values). A rank was then assigned to each lake (1 – 24); with a rank of one representing the lake with the least amount of Hg based on the nine data sets and a rank of 24 representing the lake with the most Hg. The final output is one map that shows which lakes contain the highest and lowest levels of Hg based on all

STEP 1 – Linear stretch each data set, assigning 0 to the minimum value and 1 to the maximum value. Note: the original numbers in each lake represent the average value for the lake.



STEP 2 - Add all the new linear stretched values from each lake together.

STEP 3 - Normalize the data by dividing each lake by the number of data sets that have actual values.

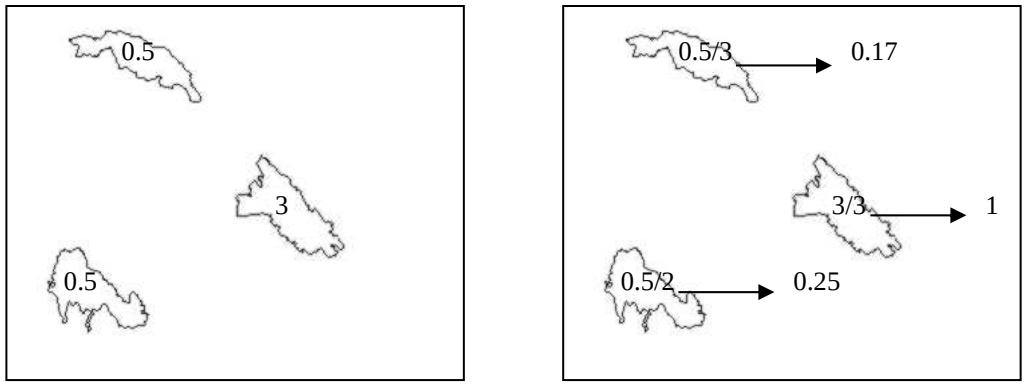


Figure 4.45. Simplified example showing the three steps required in order to perform a spatial analysis on the nine Hg data sets.

nine data sets. Two analyses were performed based on this principle. In the first analysis, equal weight was assigned to each of the nine data sets; this map is shown in Figure 4.46. In the second analysis, a weighting of one was assigned to each distinct category of data (i.e a weighting of 0.25 was assigned to each of the four fish data sets, a weighting of one was assigned to the surface water data set, a weighting of 0.5 was assigned to each of the two lake sediment data sets, and a weighting of 0.5 was assigned to each of the two plant data sets); this map is shown in Figure 4.47. All analyses were performed in IDRISI32® Version I32.11. Full documentation of both analyses is available in Appendix 4.7.

The rank distribution in Figures 4.46 and 4.47 agree with the visual examination performed above. (1) The highest rankings are in the western part of the park (generally in Big Red and Luxton lakes; see Figure 4.1 for lake names). (2) The lowest rankings are in the southern part of the park. (3) Big Dam West Lake has a higher ranking than Big Dam East (see Figure 4.1 for lake names).

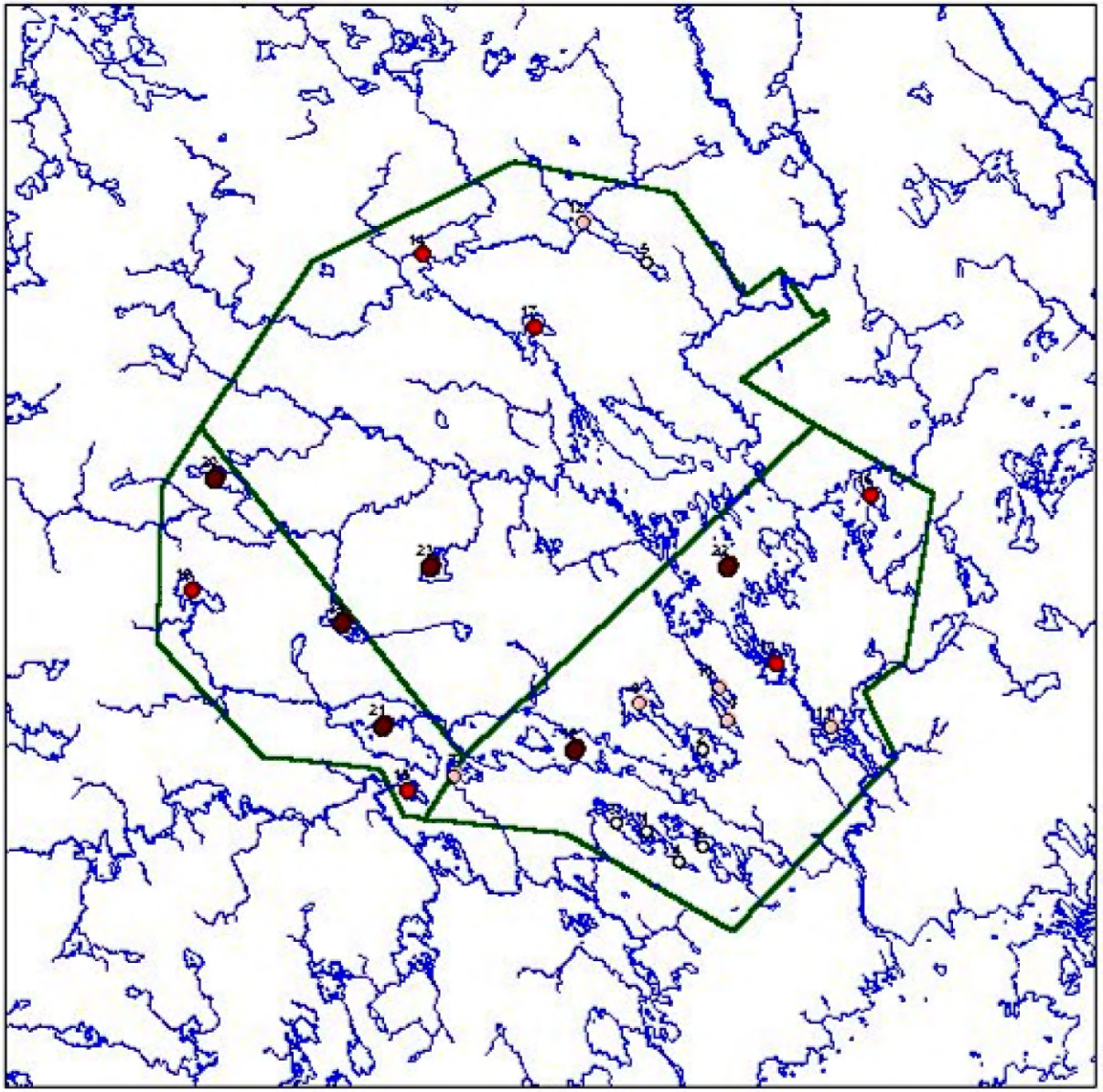
4.3.2. Correlations Between Hg Fields

In order to compare and interpret relationships between the data fields in the **KEJI DATASETS COMBINED** database, *correlation coefficients* are used. *Correlation* is a measure of strength of correlation between two variables; it is the degree to which two variables vary together (Wheater and Cook, 2000). C*orrelation coefficients* are measures of the strength of a relationship (Wheater and Cook, 2000). A correlation coefficient of +1 means a perfect positive relationship. A correlation coefficient of –1 means a perfect negative relationship. A correlation coefficient of 0 means there is no relationship. Values between –1 to 0 and 0 to +1 define intermediate relationships. All correlation coefficients in this thesis are calculated using Pearson's product moment correlation coefficient (*r*). The formula is as follows:

$$r = \frac{n\sum xy - \sum x\sum y}{([n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2])^{1/2}}$$

Where: r = correlation coefficient
n = number of data pairs
x = data point for one parameter
y = data point for the other parameter

Mercury in Kejimukjik Lakes (Non-weighted Ranking)



N

CLASSIFICATION: Quantile Break

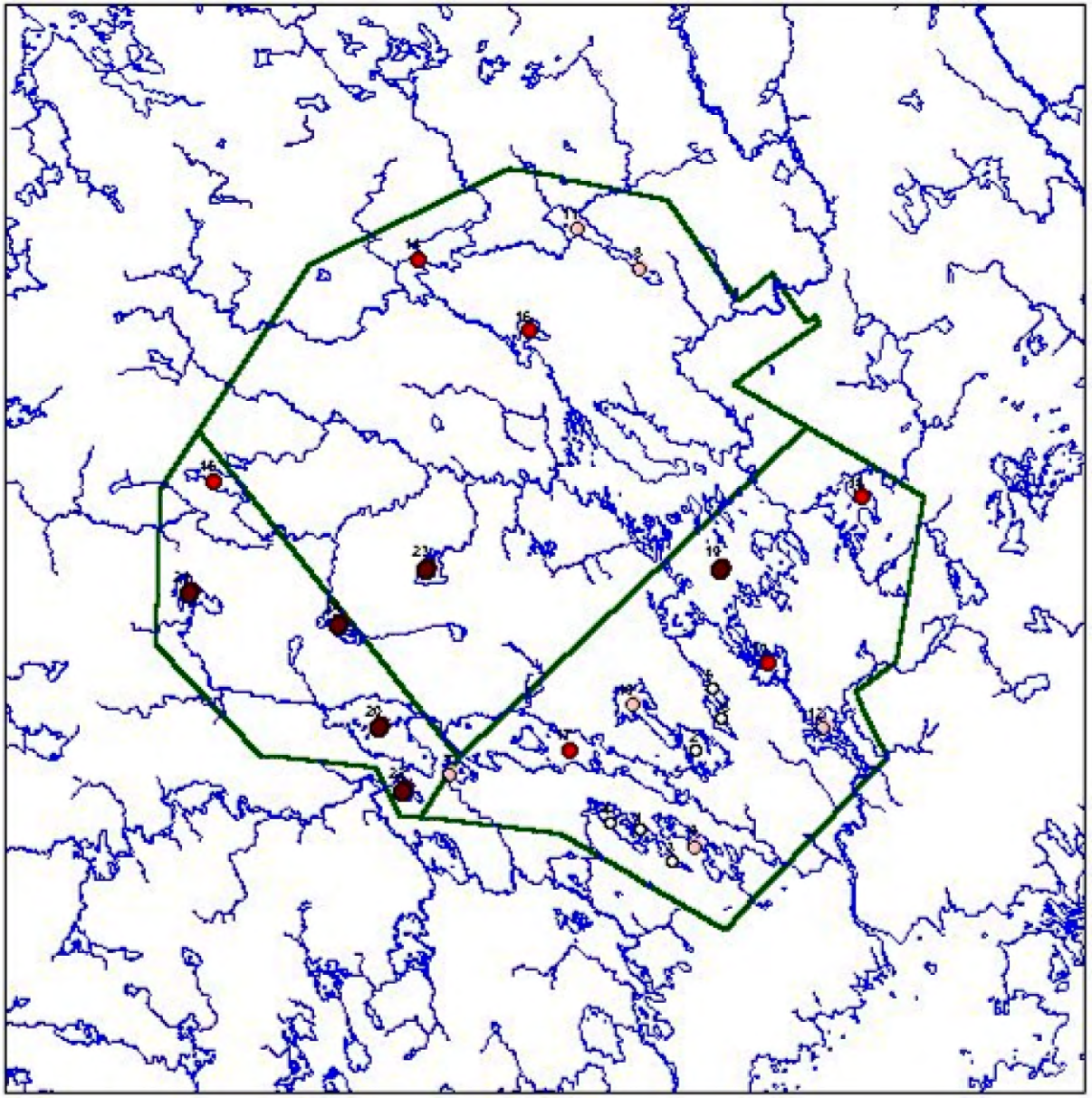
- 1 - 6
- 7 - 12
- 13 - 18
- 19 - 24

2 0 2 4

Kilometers

Figure 4.46.

Mercury in Kejimukjik Lakes (Weighted Ranking)



N

CLASSIFICATION: Quantile Break

- 1 - 6
- 7 - 12
- 13 - 18
- 19 - 24

2 0 2 4

Kilometers

Figure 4.47.

The Pearson's product moment correlation coefficient (*r*) can only be used when there is a linear relationship between the two parameters. Therefore, before the correlation coefficient is calculated, the two parameters have to be plotted on a scatterplot. Visual inspection of the scatterplot is enough to determine if the relationship is linear (Wheater and Cook, 2000). Unless otherwise noted, all *r*-values calculated in this thesis are from linear data. Correlation coefficients were calculated in Microsoft Excel (which uses Pearson's formula).

Once a correlation coefficient is calculated for two parameters, the significance of the correlation needs to be determined, i.e. what *r*-value yields a significant correlation? Wheater and Cook (2000) give an excellent overview on correlation and the significance of a calculated correlation coefficient. The significance depends on (1) the probability of obtaining the computed *r*-value by chance (P) and (2) the number of data pairs (n) (Wheater and Cook, 2000). When comparing fields in the **KEJI DATASETS COMBINED** database, the maximum number of data pairs is 24 (there are only 24 lakes). Therefore using an n-value of ≤ 24 and a 95% probability that the values are not obtained by chance (P = 0.05), Table 4.5 was created. The results are significant if the correlation coefficient calculated between the two parameters is higher than the value shown in Table 4.5.

A significant correlation does not necessarily mean there is a cause-effect relationship between the two parameters (Wheater and Cook, 2000). For example, a correlation between two parameters might mean that both parameters are influenced by a third parameter, and may have no direct relationship with each other. Correlation coefficients are generally used to take a preliminary look at the data and provide a source, or a focus for further investigation (Wheater and Cook, 2000).

From the *r*-values presented in Table 4.5, as the number of sample points (n) decrease, the *r*-value required for a significant correlation increases. For example, determining a correlation between parameters using less than 10 sample points would require a high *r*-value (≥ 0.666) in order for the correlation to be significant. As stated above (section 4.3.1.1), only nine Hg fields cover most of the study area (Table 4.3b), and are therefore suitable for correlation.

Table 4.5. Significant values for Pearson's product moment correlation coefficients (*r*) for a given number of data pairs and a 95% probability.

n	***r*-value for P = 0.05**
24	0.404
23	0.413
22	0.423
21	0.433
20	0.444
19	0.456
18	0.468
17	0.482
16	0.497
15	0.514
14	0.532
13	0.553
12	0.576
11	0.602
10	0.632
9	0.666
8	0.707
7	0.754
6	0.811
5	0.878
4	0.950
3	0.997

Comparing these nine fields to each other produces 36 correlation coefficients that are presented in Table 4.6. Using the data for the nine Hg fields, there are five key points that can be drawn out of this table: (1) there is a significant correlation between the fish fields, (2) there is a significant correlation between the fish fields and the surface water, (3) there is no significant correlation of the fish and surface water fields with the lake sediment and vegetation fields, (4) the two lake sediment fields do not correlate with each other, and (5) the two vegetation fields do not correlate with each other.

4.3.3. Correlations Between Hg Fields and Other Element Fields

Four of the original data sets have values for other elements in addition to Hg: (1) surface water, (2) lake sediment 1977, (3) white pine, and (4) red maple. Correlations within these data sets allow an examination of the potential relationship of Hg with other elements. Surface water correlations are in Table 4.7; lake sediment 1977 correlations are in Table 4.8, and white pine and red maple correlations are in Table 4.9. Determining correlation coefficients for the original data sets (i.e. before data values were averaged) would be a more accurate test of their relationship. However, for the purpose of this study, average values were used to facilitate the creation of an integrated lake/watershed database and examine the correlations related to this database.

The surface water data (Table 4.7) reveals a significant positive correlation between Hg and N_2 (r = 0.633), Na (r = 0.505), Al (r = 0.728), and Fe (r = 0.726). Using the 1977 lake sediment data (Table 4.8), Hg displays a significant positive correlation with Fe (r = 0.454) and U (r = 0.450) and a significant negative correlation with Co (r = -0.501) and Ca (r = -0.763). The vegetation data (Table 4.9) shows that there are no significant correlations between Hg in white pine and any other field, not even Hg in red maple. However, there are significant positive correlations of Hg in red maple with Mn in white pine (r = 0.470) and Mn in red maple (r = 0.589), and significant negative correlations of Hg in red maple with Mo in white pine (r = -0.546), Pb in white pine (r = -0.583), Ag in white pine (r = -0.464), Mo in red maple (r = -0.698), Pb in red maple (r = -0.565), and Fe in red maple (r = -0.716).

Table 4.6. Table showing the correlation coefficients (*r*) between nine of the Hg fields from the **KEJI DATASETS COMBINED** database. Numbers in brackets represent the number of data pairs in a correlation. Highlighted numbers are significant correlations based on the criteria of Wheater and Cook (2000). For n = 24, a significant correlation has to be $r \geq 0.404$ (Table 4.5).

	yperch length	yperch weight	perch 10cm	perch 20cm	surface water	lake sediment	lake sediment 77	white pine	red maple
yperch length	(24) 1.000								
yperch weight	(24) **0.826**	(24) 1.000							
perch 10cm	(24) **0.977**	(24) **0.862**	(24) 1.000						
perch 20cm	(24) **0.671**	(24) **0.476**	(24) **0.536**	(24) 1.000					
surface water	(24) **0.522**	(24) 0.340	(24) **0.487**	(24) **0.528**	(24) 1.000				
lake sediment	(23) 0.097	(23) 0.111	(23) 0.142	(23) -0.124	(23) 0.210	(23) 1.000			
lake sediment 77	(21) 0.188	(21) 0.339	(21) 0.257	(21) 0.020	(21) 0.240	(20) 0.265	(21) 1.000		
white pine	(19) 0.017	(19) 0.017	(19) 0.014	(19) -0.197	(19) 0.201	(19) 0.041	(18) -0.179	(19) 1.000	
red maple	(19) 0.049	(19) 0.183	(19) 0.066	(19) -0.048	(19) 0.335	(19) 0.077	(18) 0.251	(19) 0.048	(19) 1.000

Table 4.7. Table showing the correlation coefficients (*r*) in surface water between Cl, SO_4, N_2, K, Ca, Mg, Al, Fe, Mn, and Hg; data taken from the **KEJI DATASETS COMBINED** database. Numbers in brackets represent the number of data pairs in a correlation. Highlighted numbers are significant correlations based on the criteria of Wheater and Cook (2000). For n = 24, a significant correlation has to be $r \geq 0.404$ (Table 4.5). One data outlier was excluded from Mn (0.108) (Appendix 4.1).

	SW Cl	SW SO_4	SW N_2	SW Na	SW K	SW Ca	SW Mg	SW Al	SW Fe	SW Mn	SW Hg
SW Dissolved Cl (mg/L)	(24) 1.000										
SW Dissolved SO_4 (mg/L)	(24) 0.392	(24) 1.000									
SW Total N_2 (mg/L)	(24) 0.227	(24) -0.125	(24) 1.000								
SW Dissolved Na (mg/L)	(24) **0.976**	(24) 0.347	(24) 0.319	(24) 1.000							
SW Dissolved K (mg/L)	(24) 0.207	(24) -0.123	(24) 0.270	(24) 0.250	(24) 1.000						
SW Dissolved Ca (mg/L)	(24) **0.736**	(24) 0.296	(24) 0.162	(24) **0.690**	(24) 0.058	(24) 1.000					
SW Dissolved Mg (mg/L)	(24) **0.889**	(24) **0.434**	(24) 0.223	(24) **0.864**	(24) 0.028	(24) **0.896**	(24) 1.000				
SW Extractable Al (mg/L)	(24) 0.010	(24) 0.024	(24) **0.414**	(24) 0.166	(24) 0.288	(24) -0.397	(24) -0.217	(24) 1.000			
SW Extractable Fe (mg/L)	(24) **0.542**	(24) 0.326	(24) **0.596**	(24) **0.621**	(24) 0.230	(24) 0.181	(24) 0.401	(24) **0.701**	(24) 1.000		
SW Extractable Mn (mg/L)	(21) 0.235	(21) 0.010	(21) -0.234	(21) 0.039	(21) 0.022	(21) 0.340	(21) 0.191	(21) -0.327	(21) 0.000	(21) 1.000	
SW Total Hg - unfiltered (ng/L)	(24) 0.347	(24) 0.096	(24) **0.633**	(24) **0.505**	(24) 0.402	(24) 0.000	(24) 0.253	(24) **0.728**	(24) **0.726**	(21) -0.378	(24) 1.000

Table 4.8. Table showing the correlation coefficients (*r*) in lake sediment between Copper, Nickel, Lead, Zinc, Cobalt, Iron, Manganese, Calcium, Magnesium, Molybdenum, Mercury, Uranium, and Arsenic; data taken from the **KEJI DATASETS COMBINED** database. Numbers in brackets represent the number of data pairs in a correlation. Highlighted numbers are significant correlations based on the criteria of Wheater and Cook (2000). For n = 24, a significant correlation has to be $r \geq 0.404$ (Table 4.5). One data outlier was excluded from Nickel (42.80), Cobalt (78.00), Iron (5.40), Zinc (160.00), and Uranium (10.20). Two outliers were excluded from Arsenic (41.20 and 16.20) and Manganese (800.00 and 600.00). Most of these outliers were for George Lake (Nickel, Cobalt, Iron, Zinc, Arsenic, and Manganese). Most values in the Copper, Cobalt, Iron, and Molybdenum fields were below the detection limit (indicated by a high frequency of one value); therefore determining correlations with these fields might be inappropriate (Appendix 3.1).

	Cu	Ni	Pb	Zn	Co	Fe	Mn	Ca	Mg	Mo	Hg	U	As
Lks77 Copper	(21) 1.000												
Lks77 Nickel	(20) 0.209	(20) 1.000											
Lks77 Lead	(21) **0.539**	(20) 0.024	(21) 1.000										
Lks77 Zinc	(20) 0.403	(20) 0.283	(20) 0.411	(20) 1.000									
Lks77 Cobalt	(20) 0.242	(20) 0.193	(20) 0.359	(20) **0.700**	(20) 1.000								
Lks77 Iron	(20) 0.232	(20) 0.014	(20) **0.476**	(20) **0.813**	(20) **0.598**	(20) 1.000							
Lks77 Manganese	(19) -0.042	(19) **0.505**	(19) 0.000	(19) **0.745**	(19) 0.420	(19) **0.589**	(19) 1.000						
Lks77 Calcium	(21) 0.177	(20) 0.129	(21) 0.305	(20) **0.493**	(21) **0.715**	(20) **0.504**	(19) 0.373	(21) 1.000					
Lks77 Magnesium	(21) 0.010	(20) 0.283	(21) 0.339	(20) **0.468**	(21) 0.175	(20) **0.542**	(19) **0.804**	(21) 0.313	(21) 1.000				
Lks77 Molybdenum	(21) 0.311	(20) **-0.480**	(21) 0.422	(20) 0.291	(21) 0.220	(20) **0.447**	(19) -0.253	(21) 0.355	(21) 0.000	(21) 1.000			
Lks77 Mercury	(21) 0.024	(20) 0.000	(21) -0.172	(20) -0.371	(21) **-0.501**	(20) **0.454**	(19) -0.308	(21) **-0.763**	(21) -0.375	(21) -0.259	(21) 1.000		
Lks77 Uranium	(20) -0.287	(19) -0.172	(20) -0.310	(19) -0.279	(19) -0.207	(19) -0.205	(18) -0.261	(20) **-0.604**	(20) -0.309	(20) -0.183	(20) **0.450**	(20) 1.000	
Lks77 Arsenic	(19) 0.017	(19) 0.185	(19) 0.046	(19) 0.260	(19) 0.240	(19) -0.065	(18) 0.221	(19) 0.234	(19) -0.124	(19) -0.040	(19) 0.082	(18) 0.041	(19) 1.000

Table 4.9. Table showing the correlation coefficients (*r*) in plants between wpine Mo, wpine Cu, wpine Pb, wpine Zn, wpine Ag, wpine Mn, wpine Au, wpine Ca, wpine Hg, rmaple Mo, rmaple Cu, rmaple Pb, rmaple Zn, rmaple Ag, rmaple Mn, rmaple Fe, rmaple As, rmaple Au, rmaple Ca, rmaple Hg, and rmaple W; data taken from the **KEJI DATASETS COMBINED** database. Numbers in brackets represent the number of data pairs in a correlation. Highlighted numbers are significant correlations based on the criteria of Wheater and Cook (2000). For n = 24, a significant correlation has to be $r \geq 0.404$ (Table 4.5). Fields with only one or two values were deleted from this analysis (i.e. wpine Fe, wpine U, wpine Th, wpine W, wpine As, rmaple U, and rmaple Th) (Appendix 4.1).

	W Mo	W Cu	W Pb	W Zn	W Ag	W Mn	W Au	W Ca	W Hg	R Mo	R Cu
Wpine Mo (avg wshed)	(19) 1.000										
Wpine Cu (avg wshed)	(19) -0.246	(19) 1.000									
Wpine Pb (avg wshed)	(19) **0.944**	(19) -0.212	(19) 1.000								
Wpine Zn (avg wshed)	(19) 0.258	(19) -0.084	(19) 0.172	(19) 1.000							
Wpine Ag (avg wshed)	(19) **0.669**	(19) -0.157	(19) **0.825**	(19) -0.056	(19) 1.000						
Wpine Mn (avg wshed)	(19) -0.197	(19) **0.461**	(19) -0.340	(19) 0.074	(19) -0.291	(19) 1.000					
Wpine Au (avg wshed)	(19) 0.359	(19) -0.296	(19) **0.496**	(19) -0.228	(19) **0.588**	(19) -0.196	(19) 1.000				
Wpine Ca (avg wshed)	(19) 0.079	(19) 0.047	(19) 0.000	(19) 0.368	(19) 0.000	(19) **0.493**	(19) 0.308	(19) 1.000			
Wpine Hg (avg wshed)	(19) -0.182	(19) 0.033	(19) -0.274	(19) 0.074	(19) -0.206	(19) 0.288	(19) -0.164	(19) 0.332	(19) 1.000		
Rmaple Mo (avg wshed)	(19) **0.929**	(19) 0.222	(19) **0.928**	(19) 0.236	(19) **0.746**	(19) -0.323	(19) 0.353	(19) 0.036	(19) -0.120	(19) 1.000	
Rmaple Cu (avg wshed)	(19) 0.254	(19) 0.217	(19) 0.290	(19) 0.073	(19) 0.329	(19) 0.028	(19) 0.000	(19) -0.262	(19) -0.150	(19) 0.373	(19) 1.000
Rmaple Pb (avg wshed)	(19) **0.713**	(19) -0.293	(19) **0.799**	(19) 0.213	(19) **0.696**	(19) -0.345	(19) **0.518**	(19) 0.106	(19) -0.086	(19) **0.849**	(19) 0.134
Rmaple Zn (avg wshed)	(19) 0.097	(19) 0.073	(19) 0.042	(19) 0.060	(19) 0.000	(19) -0.116	(19) 0.231	(19) -0.081	(19) -0.302	(19) 0.000	(19) -0.172
Rmaple Ag (avg wshed)	(19) 0.406	(19) 0.000	(19) **0.571**	(19) 0.028	(19) **0.736**	(19) -0.303	(19) 0.261	(19) 0.072	(19) -0.064	(19) **0.557**	(19) 0.120
Rmaple Mn (avg wshed)	(19) -0.165	(19) 0.135	(19) -0.286	(19) -0.037	(19) -0.321	(19) **0.736**	(19) 0.078	(19) **0.540**	(19) -0.068	(19) -0.401	(19) -0.386
Rmaple Fe (avg wshed)	(19) **0.538**	(19) -0.103	(19) **0.632**	(19) 0.263	(19) **0.504**	(19) -0.330	(19) 0.392	(19) -0.085	(19) -0.108	(19) **0.702**	(19) 0.307
Rmaple As (avg wshed)	(13) -0.367	(13) -0.158	(13) -0.283	(13) 0.240	(13) -0.047	(13) -0.224	(13) 0.000	(13) 0.124	(13) 0.308	(13) 0.162	(13) -0.069
Rmaple Au (avg wshed)	(19) 0.302	(19) 0.185	(19) 0.418	(19) 0.226	(19) 0.354	(19) -0.341	(19) -0.151	(19) -0.213	(19) -0.220	(19) 0.341	(19) 0.289
Rmaple Ca (avg wshed)	(19) 0.105	(19) -0.439	(19) 0.095	(19) 0.020	(19) 0.040	(19) -0.137	(19) **0.485**	(19) 0.322	(19) 0.235	(19) 0.124	(19) **-0.595**
Rmaple Hg (avg wshed)	(19) **-0.546**	(19) 0.124	(19) **-0.583**	(19) 0.000	(19) **-0.464**	(19) **0.470**	(19) -0.253	(19) 0.428	(19) 0.048	(19) **-0.698**	(19) -0.391
Rmaple W (avg wshed)	(19) **0.807**	(19) -0.275	(19) **0.884**	(19) 0.180	(19) **0.809**	(19) -0.344	(19) **0.559**	(19) 0.081	(19) -0.140	(19) **0.922**	(19) 0.263

Table 4.9. (Continued)

	R Pb	R Zn	R Ag	R Mn	R Fe	R As	R Au	R Ca	R Hg	R W
Wpine Mo (avg wshed)										
Wpine Cu (avg wshed)										
Wpine Pb (avg wshed)										
Wpine Zn (avg wshed)										
Wpine Ag (avg wshed)										
Wpine Mn (avg wshed)										
Wpine Au (avg wshed)										
Wpine Ca (avg wshed)										
Wpine Hg (avg wshed)										
Rmaple Mo (avg wshed)										
Rmaple Cu (avg wshed)										
Rmaple Pb (avg wshed)	(19) 1.000									
Rmaple Zn (avg wshed)	(19) 0.022	(19) 1.000								
Rmaple Ag (avg wshed)	(19) **0.663**	(19) -0.052	(19) 1.000							
Rmaple Mn (avg wshed)	(19) -0.307	(19) 0.101	(19) -0.421	(19) 1.000						
Rmaple Fe (avg wshed)	(19) **0.821**	(19) 0.066	(19) 0.429	(19) -0.432	(19) 1.000					
Rmaple As (avg wshed)	(13) **0.609**	(13) -0.388	(13) 0.124	(13) -0.287	(13) 0.536	(13) 1.000				
Rmaple Au (avg wshed)	(19) 0.167	(19) -0.364	(19) 0.414	(19) **-0.591**	(19) 0.203	(13) -0.054	(19) 1.000			
Rmaple Ca (avg wshed)	(19) 0.414	(19) 0.319	(19) 0.098	(19) 0.205	(19) 0.271	(13) 0.371	(19) -0.439	(19) 1.000		
Rmaple Hg (avg wshed)	(19) **-0.565**	(19) -0.169	(19) -0.352	(19) **0.589**	(19) **-0.716**	(13) -0.194	(19) -0.252	(19) -0.087	(19) 1.000	
Rmaple W (avg wshed)	(19) **0.957**	(19) 0.026	(19) **0.665**	(19) -0.377	(19) **0.787**	(13) 0.428	(19) 0.231	(19) 0.278	(19) **-0.614**	(19) 1.000

The results from Tables 4.7 to 4.9 are summarized in Table 4.10. The only elements that show a significant positive correlation with Hg are **Fe** and **U** in 1977 lake sediment; **N_2**, **Na**, **Al**, and **Fe** in surface water; and **Mn** in red maple.

4.3.4. Correlations Between Hg Fields and Non-Element Fields

In addition to the fields already examined, there are non-element fields that are compared to the nine Hg fields listed in Table 4.3b (Table 4.11). The non-element fields were selected if they have sufficient variation in data values (for statistical analysis) and if they have some logical relationship with Hg variations. Correlation coefficients are shown in Table 4.12.

Since there are only five distinct lithologies in the park, the geology is examined through visual interpretation (see below) and no correlation coefficients are calculated between Hg and lithology.

Using the data for the nine Hg fields, the surface water, the lake physical characteristics, A. Rencz's water data, and the wetlands, there are four key points that can be drawn out of Table 4.12: (1) there are significant negative correlations of Hg in fish and Hg in surface water with lake alkalinity and pH, (2) there are significant positive correlations of Hg in fish and Hg in surface water with lake elevation, flushing rate, color, specific conductance, and total organic content, (3) there are few to no significant correlations of Hg in lake sediment and Hg in vegetation with all other parameters, and (4) there are few to no significant correlations of the Hg fields with lake surface area, catchment area, dissolved oxygen, and total wetlands.

4.3.5. Examination of the Wetlands and the Geology

Wetlands: In the previous section, correlation coefficients were calculated between the wetlands and the nine Hg fields (Table 4.12); however there are few statistically significant correlations. This is surprising, as wetlands are believed to be major contributors of Hg to downstream lakes. To further evaluate the relationship between Hg and the wetlands, the wetlands were mapped using two different watershed layers: (1) watersheds generated by A. Rencz and (2) watersheds generated by the Nova Scotia

Table 4.10. A summary of Tables 4.7 to 4.9.

	LKS77 MERCURY	SW TOTAL HG - UNFILTERED (NG/L)	WPINE HG (AVG WSHED)	RMAPLE HG (AVG WSHED)
Significant + correlation	**Fe, U**	**N_2, Na, Al, Fe**		**Mn**
No significant correlation	**U Cu, Ni, Pb, Mn, Mo, As**	**Cl, SO_4, K, Ca, Mg, Mn**	**Cu, Pb, Zn, Ag, Mn, Au, Ca**	**Cu, Zn, Ag, As, Au, Ca, W**
Significant – correlation	**Co, Ca**			**Mo, Pb, Fe**

Table 4.11. 17 fields in the **KEJI DATASETS COMBINED** database are compared to the nine Hg fields listed in Table 4.3b. Field descriptions are provided in Appendix 4.2; data sources are provided in Table 4.1.

Field
(1) SW ALKALINITY (MG/L)
(2) SW PH
(3) SW COLOR (HAZENS)
(4) SW SPECIFIC CONDUCTANCE
(5) SW TOTAL ORGANIC CARBON
(6) PC LAKE ELEVATION (M)
(7) PC SURFACE AREA (HECTARES)
(8) PC TOTAL CATCHMENT AREA (KM^2)
(9) PC FLUSHING RATE (TIMES/YR)
(10) AR H2O PH
(11) AR H2O DO
(12) AR H2O CONDUCTIVITY
(13) AR H2O ALKALINITY
(14) AR H2O DOC PPM
(15) BOG (% WSHD)
(16) FEN (% WSHD)
(17) TOTAL (% WSHD)

Table 4.12. Table showing the correlation coefficients (*r*) between the nine Hg fields and sw alkalinity, sw pH, sw color, sw conductance, sw TOC, PC elevation, PC surface area, PC catchment area, PC flushing rate, AR pH, AR DO, AR conductivity, AR alkalinity, AR DOC, Bog, Fen, and Total Wetland; data taken from the **KEJI DATASETS COMBINED** database. SW – surface water, PC – lake physical characteristic, AR – A. Rencz water data. Numbers in brackets represent the number of data pairs in a correlation. Highlighted numbers are significant correlations based on the criteria of Wheater and Cook (2000). For n = 24, a significant correlation has to be $r \geq 0.404$ (Table 4.5). One data outlier was excluded from PC surface area (Kejimkujik Lake), one from AR DOC (13.14), one from Bog (20.64), one from Fen (10.02), three from PC total catchment area (682.0, 687.0, and 726.0), and five from PC flushing rate (13.1, 23.2, 138.6, 319.0, and 418.0) (Appendix 4.1). * The data plotted on the scatterplot does not look linear.

	yperch lgth	yperch wt	perch 10cm	perch 20cm	surface water	lake sed	lake sed 77	white pine	red maple
SW alkalinity	(24) **-0.638**	(24) **-0.551**	(24) **-0.672**	(24) -0.275	(24) **-0.645**	(23) -0.254	(21) -0.411	(19) -0.343	(19) -0.167
SW pH	(24) **-0.577**	(24) **-0.493**	(24) **-0.573**	(24) -0.374	(24) **-0.684**	(23) -0.260	(21) -0.253	(19) -0.342	(19) -0.145
SW color	(24) **0.455**	(24) 0.345	(24) **0.438**	(24) **0.456**	(24) **0.908**	(23) 0.122	(21) 0.146	(19) 0.438	(19) 0.228
SW conductance	(24) **0.479**	(24) 0.324	(24) **0.439**	(24) **0.526**	(24) **0.940**	(23) 0.269	(21) 0.231	(19) 0.259	(19) 0.451
SW TOC	(24) **0.495**	(24) 0.377	(24) **0.455**	*(24) **0.533**	(24) **0.912**	(23) 0.112	(21) 0.199	(19) 0.398	(19) 0.271
PC lake elevation	(24) **0.508**	(24) **0.421**	(24) **0.572**	(24) 0.093	(24) 0.347	(23) 0.110	(21) **0.492**	(19) 0.014	(19) 0.051
PC surface area	(23) 0.040	(23) 0.024	(23) 0.000	(23) 0.129	(23) 0.060	(22) 0.420	(20) 0.177	(18) 0.058	(18) -0.036
PC catchment area	(21) 0.000	(21) 0.053	(21) -0.070	(21) **0.433**	*(21) 0.370	(20) 0.000	(19) -0.045	(17) 0.212	(17) 0.000
PC flushing rate	(17) **0.742**	(17) **0.558**	(17) **0.757**	(17) **0.597**	(17) **0.699**	(17) 0.215	(15) 0.048	(16) 0.107	(16) 0.032
AR pH	(24) **-0.565**	(24) **-0.502**	(24) **-0.590**	(24) -0.295	(24) **-0.599**	(23) -0.291	(21) -0.380	(19) -0.286	(19) 0.096
AR DO	(24) -0.177	(24) -0.209	(24) -0.180	(24) -0.152	(24) 0.010	(23) 0.146	(21) 0.014	(19) 0.000	(19) -0.122
AR conductivity	(24) **0.484**	(24) 0.308	(24) **0.458**	(24) **0.513**	(24) **0.878**	(23) 0.246	(21) 0.158	(19) 0.210	(19) 0.407
AR alkalinity	(24) **-0.603**	(24) **-0.506**	(24) **-0.574**	(24) **-0.556**	(24) **-0.535**	(23) -0.232	(21) -0.106	(19) -0.341	(19) 0.081
AR DOC	(23) 0.000	(23) 0.116	(23) 0.028	(23) 0.252	(23) **0.783**	(22) 0.167	(20) 0.022	(18) 0.424	(18) 0.290
Bog	(23) 0.102	(23) 0.026	(23) 0.080	(23) 0.157	(23) -0.098	(22) 0.026	(20) -0.395	(18) 0.191	(18) **-0.677**
Fen	(23) 0.026	(23) -0.074	(23) 0.017	(23) 0.399	(23) 0.342	(22) 0.000	(20) -0.302	(18) 0.036	(18) -0.028
Total Wetland	(24) -0.033	(24) -0.064	(24) -0.067	(24) 0.099	(24) -0.145	(23) 0.069	(21) **-0.447**	(19) **0.475**	(19) -0.232

Department of the Environment (NSDOE) (Figure 4.48 and 4.49 respectively). Selected items (e.g. coastline and primary, secondary, and tertiary watershed boundaries) were extracted from the original NSDOE watershed layer in order to obtain a watershed layer without lakes, streams, and county boundaries (see Appendix 4.8 for details).

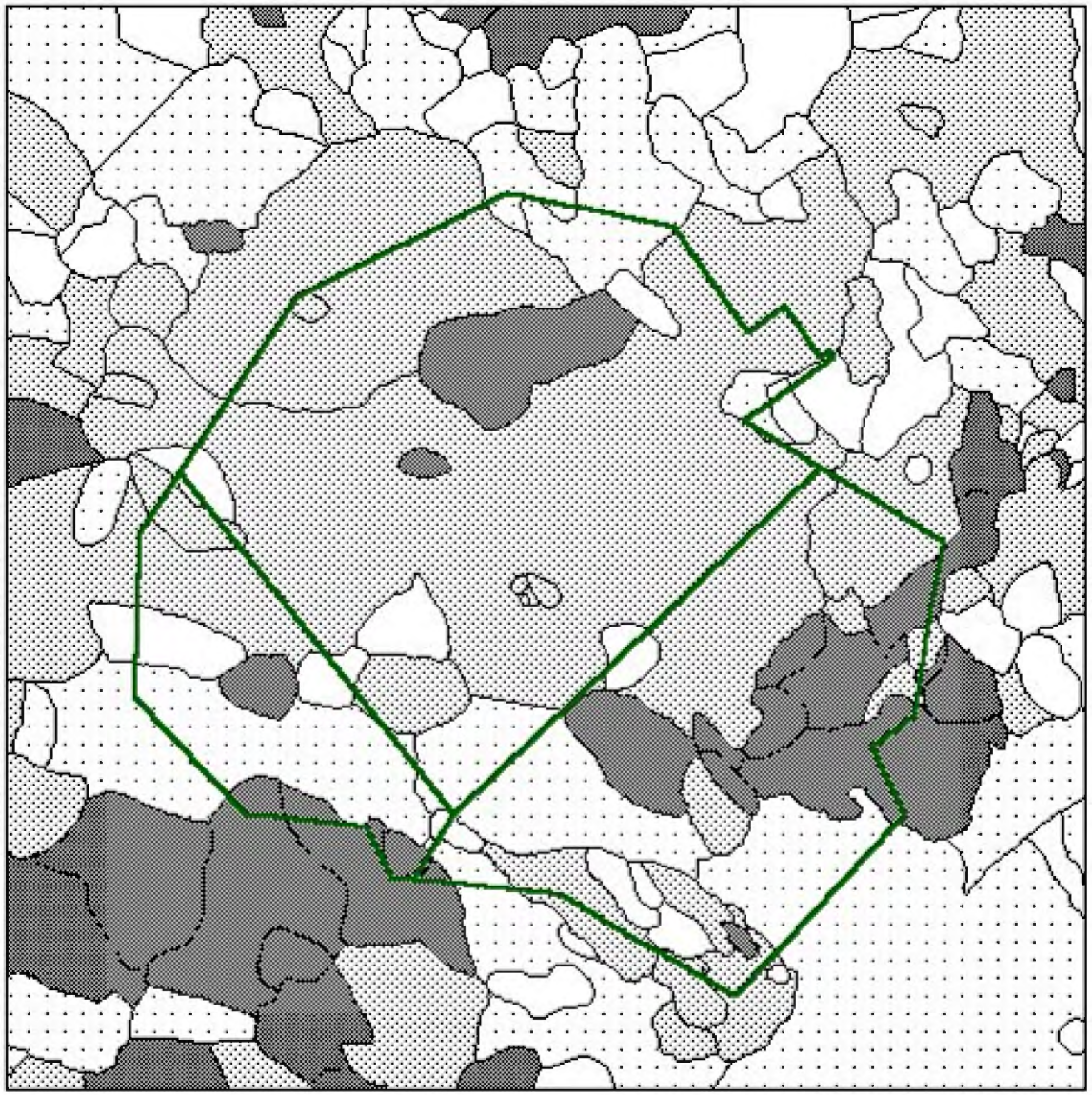
The NSDOE watersheds (Figure 4.49) clearly show that there are more wetlands (5.43-49.64% wetlands per watershed surface area) in the western and northern parts of the park than in the southern and eastern parts of the park (3.63-5.43% wetlands per watershed surface area). The watersheds defined by A. Rencz (Figure 4.48) also show this relationship, however in this scheme there are high percentages of wetlands in the southeast part of the park as well (9.46-47.49% wetlands per watershed surface area). This may be important because a number of lakes do show high Hg values in this area (i.e. terrestrial plants, yellow perch, and perch data).

Geology: Regional maps (scale 1:500,000) indicate that five lithologic units underlie KNP (Figure 2.5). According to the results presented above (section 4.3.1.2), the highest Hg values in the park are in the Big Red Lake area, which is underlain by muscovite biotite monzogranite. The rest of the park is underlain mainly by the Halifax and Goldenville groups.

To get a more regional perspective, an AML was written (Appendix 4.9) to calculate the average lake sediment (1977) Hg value for each geological unit in a subset area of southwest Nova Scotia; the subset area includes the park and areas that might be draining into the park. The lake sediment data were used because they are the only data set that covers all of southwest Nova Scotia. The results are presented in Table 4.13.

Using the 1977 lake sediment data and the 1:500,000 scale digital geology map, there are three key observations (Table 4.13): (1) the highest Hg in lake sediment values are obtained in an area underlain by biotite-rich granite (0.490 – 0.542 average Hg), (2) the intermediate Hg in lake sediment values are obtained in an area underlain by leucomonzogranite (0.420 – 0.462 average Hg), and (3) the lowest Hg in lake sediment values are obtained in an underlain by the Halifax and Goldenville groups (0.323 – 0.360 average Hg).

Percent Wetlands per Watershed (Based on A. Rencz Watershed Layer)



CLASSIFICATION: Quantile Break

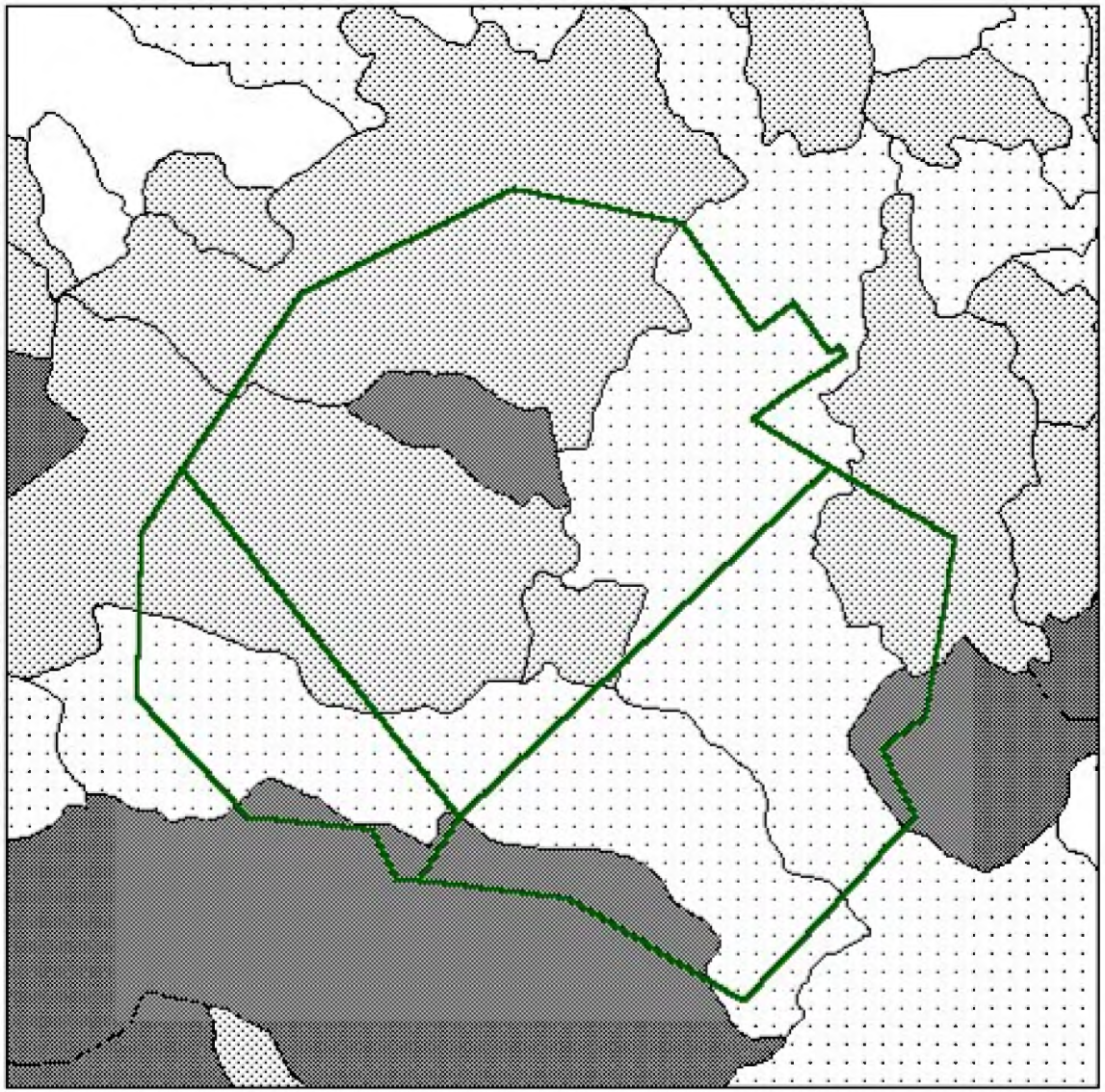
- 0.00 - 2.53 %
- 2.53 - 5.73 %
- 5.73 - 9.46 %
- 9.46 - 47.39 %

4 0 4 8

Kilometers

Figure 4.48. The wetlands are divided into four categories. The values in each category represent the percentage of wetlands that occupy a given watershed.

Percent Wetlands per Watershed (Based on NSDOE Watershed Layer)



CLASSIFICATION: Quantile Break

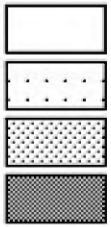


Figure 4.49. The wetlands are divided into four categories. The values in each category represent the percentage of wetlands that occupy a given watershed.

Table 4.13. Average lake sediment Hg values for lakes underlain by a given geological unit.

GEOLOGICAL UNIT	AVERAGE HG IN LKS77	NUMBER OF POINTS
Muscovite Biotite Monzogranite	0.541667	12
Biotite Monzogranite	0.519675	123
Granodiorite	0.490000	29
Leucomonzogranite	0.462250	40
Fine Grained Leucomonzogranite	0.420000	7
Goldenville Group	0.360667	30
Halifax Group	0.323220	59

4.4. DISCUSSION

Examining the results from the **KEJI DATASETS COMBINED** database produces four main topics for discussion: (1) the geographic locations of high Hg values, (2) Hg values in Big Dam West Lake versus Big Dam East Lake, (3) the correlation coefficients for the fish and surface water fields, and (4) the correlation coefficients for the lake sediment and terrestrial plant fields. The following section is divided up based on these four topics.

4.4.1. Geographic Locations of High Hg Values

The highest Hg values occur in the western part of the park (around Big Red, Luxton, Poplar, and Liberty lakes). Two possible explanations for this pattern are proposed in this thesis and may provide guidelines for further study: (1) high Hg values are related to the percentage of wetlands in each watershed and/or (2) high Hg values are a function of the underlying geology.

4.4.1.1. Wetlands

In KNP, there are extensive bogs and fens (Wood et al, 1991). Bogs and fens are distinguished from other wetlands by their enormous amounts of peat (NS Wet Places, 1998, http). Because of the mass accumulation of peat, bogs and fens are poorly drained areas where water is absorbed during wet periods and then later released during times of drought (Osmond, 1995, http). During the wet periods, bogs and fens are the largest areas of bound Hg (R. Milton, personal communications, April 4, 2000). Bogs, which have more peat than fens, tend to be fairly self-contained systems. Therefore, if there is no drainage leaving a bog, the bog is probably only contributing minor amounts of Hg to the surrounding watershed (R. Milton, personal communications, April 4, 2000). Fens, on the other hand, contain less peat than bogs. Therefore, water moves slowly through a fen all year long (NS Wet Places, 1998, http). As a result, fens might be contributing more Hg to the downstream lakes.

The role of wetland types and percentages (for any given watershed) in contributing to the anomalous Hg concentrations in the park is controversial. Some researchers propose that the wetlands may play an important role in the anomalous concentrations of

Hg in the park (T. Clair, personal communications, 2000, September 6), whereas others believe they may play a smaller role (A. Rencz, personal communications, 2000, August 15). The overall wetland pattern (as demonstrated in Figures 4.48 and 4.49) shows a moderate-high percentage of wetlands in areas where there are high Hg values. This in addition to the strong positive relationship between Hg and DOC levels in lakes (DOC generally comes from wetlands and carries bound Hg with it to a lake) suggests that Hg levels in lakes are very dependant on wetlands. However, the lack of correlation and negative correlation between Hg data sets and wetland percentages (Table 4.12) seem to indicate the opposite relationship. This lack of correlation, however, could be a result of delineation of watershed boundaries. The watersheds generated by A. Rencz and NSDOE have very different boundaries, which might affect the interpretation of correlations between Hg and wetland percentages. Whether wetlands play a major role in the origin of the Hg anomalies, or whether they are one of many contributing factors, is still unresolved.

4.4.1.2. Geology

Although the percentage of wetlands in a watershed shows some relationship with the Hg anomalies in the park, the underlying lithology may also be a contributing factor. As stated above, the highest values of Hg are in the western part of the park, which is underlain by the granite rocks of the SMB.

Recently rocks have been sampled in southwest Nova Scotia by A. Sangster (Geological Survey of Canada) and P. K. Smith (Nova Scotia Department of Natural Resources). A. Sangster's results show that the highest Hg values in bedrock are found in the organic slates of the Halifax Group (personal communication, May 2, 2001). P. K. Smith's results show that the highest Hg values in bedrock are found in mafic intrusions and biotite-rich granites (personal communication, May 2, 2001). To date, the highest Hg values (38.9 ppb) have been found in biotite separates taken from rocks of the SMB (Smith, 2000), an Fe-Al rich silicate mineral that is common in granite.

Smith (2000) suggests that the breakdown of biotite during alteration may release Hg into the environment. This hypothesis is supported by the results presented in Table 4.10;

in lake sediment, Hg displays a significant correlation with Fe (r = 0.454) and in surface water Hg displays a significant correlation with Fe (r = 0.726) and Al (r = 0.728). This suggests a connection between Hg and the weathering of Fe-Al rich minerals in underlying sediment or bedrock. The weathering of granites and its relationship to Hg abundance is being studied by A.-M. O'Beirne-Ryan as part of a Ph.D. study at Dalhousie University.

Smith's results are also supported by the results presented in Table 4.13; Hg levels are higher in lake sediments that are underlain by biotite rich granite. A preliminary study on the 1977 lake sediment data by Richardson and Bingley (1979) suggests that there is a close association between the trace elements of the lake sediment and the underlying lithology.

The association of high Hg levels with biotite rich rocks prompted the work for chapter 5.

4.4.2. Big Dam East versus Big Dam West

The TSRI project is conducting a detailed comparison on the behavior of Hg in Big Dam East Lake and Big Dam West Lake, two adjacent lakes in the northern part of the park (Figure 4.1). For most of the Hg fields in the **KEJI DATASETS COMBINED** database, Hg values are higher in Big Dam West Lake than in Big Dam East Lake (Table 4.4). There are a number of important chemical and physical differences between these two lakes that may account for the varying Hg behavior (Table 4.14). The higher Hg values in Big Dam West Lake may be attributed to lower alkalinity and pH levels, a darker colored lake, higher specific conductance, higher levels of DOC, and a higher flushing rate. As discussed in chapter 3, these characteristics tend to correlate with higher Hg values.

Big Dam West's watershed has a higher percentage of wetlands than Big Dam East's watershed (Table 4.14). Studies done by D. Lean (University of Ottawa) show that wetlands are one of the major sources of Hg to Big Dam West Lake and that the lake is a sink, not a source for Hg (A. Rencz, personal communications, 2000, November 27). Big Dam East's watershed has no wetlands.

Table 4.14. Data taken from the surface water, lake physical characteristics, total wetlands, and geology fields in the **KEJI DATASETS COMBINED** database. TOC – Total Organic Content.

	Big Dam East Lake	*Big Dam West Lake*
Alkalinity (mg/L)	0.92	0.07
pH	5.9	5.0
Color (Hazens)	21	94
Specific Conductance (uS/cm)	23.8	30.1
TOC (mg/L)	3.7	10.5
Flushing Rate (times/yr)	1.6	13.1
Wetlands (%)	0.00	5.04
Underlying Bedrock Geology (%)	~ 100 Halifax Group	~ 50 Goldenville Group, ~ 50 Biotite Monzogranite

Big Dam West's watershed is underlain by biotite monzogranite and the Goldenville Group, whereas Big Dam East's watershed in underlain by the Halifax Group (Table 4.14). As discussed above, areas underlain by biotite-rich granite (i.e. Big Dam West Lake) have higher Hg values.

4.4.3. Fish and Surface Water Fields

There is a positive relationship between the amount of total Hg in the lake water and the amount of Hg in the fish (Table 4.6). Fish incorporate Hg into their system through their gills and through their food (see Chapter 3, section 3.6.3), and since both of these processes are directly related to the amount of Hg in the water, a correlation between Hg levels in the water and in the fish is not surprising. However, fish only incorporate Hg into their systems in a methylated complex (MeHg; Mercury in the Environment, 2001, http), therefore it would be more appropriate to correlate levels of MeHg in water with levels of Hg in fish. However, no data for MeHg in water are currently available.

There is a direct positive relationship of Hg in the fish and surface water with all the other parameters that are typically associated with Hg (i.e. alkalinity, pH, lake color, specific conductance, and TOC; Table 4.12). Again, these characteristics tend to correlate with higher Hg values. For example, Hg tends to enter a lake bound to DOC (or TOC). Therefore, as the levels of DOC increase in a lake, the levels of Hg increase. An increase in DOC makes the lake darker in color and decreases the pH and alkalinity.

The fish and surface water fields show a significant positive correlation with elevation (Table 4.12). This is probably because the elevation is directly related to the underlying bedrock geology. The highest elevations in the park are around Big Red, Luxton, Poplar, and Liberty Lake, which is underlain by the SMB.

The fish and surface water fields show a significant positive correlation with the flushing rate of the lake (Table 4.12). Low flushing rates might enable Hg to settle out of the water and be buried in the lake sediment, preventing significant Hg uptake by the fish. Or, a high flushing might bring in a continual fresh supply of MeHg into the lake, which would then be directly available to the fish.

Using the data sets available for KNP, there is no apparent correlation between Hg in fish and surface water fields and lake catchment area (Table 4.12). Hultberg et al. (1994) suggest that the ratio of drainage area to lake area may be an important factor in determining the Hg contamination potential of a lake. Lakes with high drainage areas are susceptible to high runoff which may contain high levels of Hg. Lodenius (1994) believes that most of the Hg in aquatic environments comes from the terrestrial environment. The lack of correlation between these fields may be evidence that terrestrial runoff is not the major contributing source of Hg to the lakes.

4.4.4. Lake Sediment and Plant Fields

Given the data sets used in this project, there are very few significant correlations of Hg in the lake sediment and plant fields with all other fields. This suggests that the Hg behavior in these fields is substantially different from Hg behavior in the lake water and fish.

The lack of correlation in the lake sediment fields may be the result of hydrologic factors in the lake such as lake stratification, turbulence, and flushing rate. For example, if Hg binds to particles and sinks to the bottom of the lake, then these sediments become Hg sinks, and the Hg is not accessible to the biosphere. This would explain the lack of correlation of lake sediment fields with fish and surface water fields. However, a significant negative correlation between Hg in lake sediment and flushing rate is not apparent. Therefore, there is a possibility that the Hg in the lake sediment might be directly related to the underlying geology, and may have little to do with the chemical and physical properties of the lake.

In terms of Hg, the lake sediment fields (TSRI data and NSDNR data) do not correlate with each other. There are a number of reasons that could account for this: (1) sampling inaccuracies in one or both data sets, (2) different levels of Hg in different parts of the lake, and/or (3) the two data sets were created 20 years apart and Hg levels in lake sediment may vary over time. Although a detailed analysis of the two lake sediment data sets do not show any significant correlations with each other, on a reconnaissance scale, there is some correspondence between them. For, example, both lake sediment maps

(Figure 4.35 and 4.42) show higher Hg values in Big Dam East Lake than in Big Dam West Lake; both show moderate-high to high values in a northeast trend through Pebbleloggith-Peskowesk-Mountain lakes (see Figure 4.1 for lake names); and both have fairly low Hg values in the southern lakes.

There are three main reasons why the plant fields may not correlate with any of the other fields: (1) as stated in chapter 3 (section 3.5.2.4), Hg uptake by plants in the terrestrial environment is minimal, (2) Hg uptake may be independent of Hg levels in the aquatic environment and/or (3) linking terrestrial plant data to a lake via the watershed may be an inappropriate method.

Chapter 5 – Bedrock Study

5.1. INTRODUCTION

As part of the Toxic Substance Research Initiative (TSRI) Mercury Project, a number of researchers have collected and analyzed bedrock samples throughout southwest Nova Scotia. According to Smith (2000), the regional average value for Hg in various rock types sampled throughout the province is 3.3 ppb, and the highest values obtained in each lithology typically exceed this value. For example, Hg levels in slate reach 19.3 ppb, the granite 22.9 ppb, the mafic intrusions 24.7 ppb, and the sheared rocks adjacent to the Tobeatic Shear Zone have Hg values up to 30.4 ppb. Biotite separates from the granite reach 38.9 ppb. In this data set, the mafic intrusions (n=2; 22.8 and 24.7 ppb) and the biotite separates (n=6; 5.7, 5.9, 6.7, 8.4, 17.0, and 38.9 ppb) yield higher values than the regional average. Although the number of samples analyzed is limited, the potential association of high Hg levels with mafic rocks and mafic minerals and its possible significance to the understanding of Hg sources in KNP prompted the field work for this chapter.

As very few studies analyze the Hg content in bedrock, and Hg analyzing techniques are currently being refined, it is difficult to place Smith's (2000) results in a regional context. In order to test the above relationship, rock samples from the mafic intrusions and the most biotite-rich phases of the South Mountain Batholith (SMB) were collected and analyzed for Hg content. These results were compared to rocks that were collected and analyzed from the most muscovite-rich phases of the SMB. Bedrock sampling was limited to these three lithologies (biotite-rich granite, muscovite-rich granite, and mafic intrusions). Sampling of other lithologies in southwest Nova Scotia and in the park (e.g. the Meguma Supergroup) has/is being examined by other researchers (e.g. P. K. Smith, A. Sangster) and is not part of this study. The data presented in this chapter allow a comparison between Hg levels in mafic versus felsic rocks and an analysis of potential correlations between Hg and other trace elements in rocks.

5.2. METHODS

5.2.1. Sampling Methodology

One hundred and twenty bedrock samples from 40 different locations were collected throughout southwest Nova Scotia during the summer of 2000. Three rock samples were taken at each location; one sample was used for Hg and trace element analysis and the other two samples are stored at Dalhousie University in case further analyses need to be performed. An attempt was made in the field to sample only fresh rocks with no visible signs of weathering. Of the 120 samples, only 30 samples (the freshest from each of 30 separate sample locations) were analyzed for Hg and trace elements. Twelve samples are from mafic intrusions, nine biotite-rich samples are from the SMB, and nine muscovite-rich samples are from the SMB. Visibly weathered rocks, and the rocks that were intermediate in composition between biotite-rich and muscovite-rich granites, were not sampled. A field photo for each rock sample is available on the CD-ROM in the back cover. Locations were marked using 1:50,000 road maps and a GPS.

5.2.2. Analytical Methodology

All samples were crushed and pulverized (-200 mesh) at DalTech, Halifax, Nova Scotia. One vile was sent to Bondar Clegg Laboratories, Vancouver, British Columbia, for trace element analysis (Au-Ag-Cu-Pb-Zn-Mo-Ni-Co-Cd-Bi-As-Sb-Fe-Mn-Te-Ba-Cr-V-Sn-W-La-Al-Mg-Ca-Na-K-Sr-Y-Ga-Li-Nb-Sc-Ta-Ti-Zr-S) and another vile was sent to Acme Laboratories, Vancouver, British Columbia, for Hg analysis. For Au analysis, samples were weighted into a fire assay pot and were analyzed by Induced Coupled Plasma Atomic Emissions Spectrometry (ICP-AES). For the other trace elements (excluding Hg), samples were digested with a mixture of hydrochloric and nitric acids and analyzed using ICP-AES. For Hg analysis, the samples were digested in an aqua regia mixture of 1:1:1 H_2O-HCl-$HN0_3$ and analyzed using a Cetac Hg Analyzer. A complete description of each laboratory's analyzing techniques, including upper and lower detection limits, is available in Appendix 5.1.

5.2.3. Quality Assurance/Quality Control (QA/QC)

One standard and two duplicates were included with the 30 rock samples sent to Acme and Bondar Clegg laboratories. In addition to the standard and duplicates inserted with the rock samples, Acme Laboratories inserted an additional duplicate and two additional internal standards for the Hg analysis. For Hg analysis, Acme evaluates the quality at three separate levels based on results of reference materials, duplicates, and analytical blanks included in each batch. The lower detection limit for Hg is 0.1 ppb.

5.3. LITHOLOGICAL DESCRIPTION

MacDonald (2001) provides a detailed description of the lithologies of the SMB. In addition, over the last 10 years, geological maps, at the 1:50,000 scale, have been published for the entire batholith. The map sheets used for this thesis are from Ham (1991; 1994), Horne (1992), MacDonald and Ham (1992; 1994a, b), Corey and Horne (1994), Ham and MacDonald (1994), and Horne and Corey (1994). It is this report and these maps that were used for field work. MacDonald (2001) divides the SMB into six dominant rock units based on (1) modal proportions of quartz-alkali feldspar-plagioclase and mafic minerals (primarily biotite), (2) texture, and (3) grain size. From most felsic to mafic, these rock types include (1) leucogranite, (2) fine-grained leucomonzogranite, (3) coarse-grained leucomonzogranite, (4) muscovite-biotite monzogranite, (5) biotite monzogranite, and (6) biotite granodiorite. A general textural and petrographic description for each unit is available in Table 5.1. An additional unit, termed the “mafic porphyry” is not included in the six-unit scheme; however, MacDonald (2001) does make special mention of this unit in his report. The mafic porphyry is a granitoid rock that contains the highest percentages of biotite in the batholith, and is therefore an important rock unit for this study. Terminology used in this chapter is adopted from MacDonald (2001) and the series of 1:50,000 geological maps mentioned above.

Table 5.2 gives a summary of the lithology and location for each of the 30 rock samples sent in for analysis. This table includes the sample number, the rock type (based on the above scheme), the 1:50,000 NTS map sheet that the sample was taken from, and additional comments on the field site. The bedrock samples for this thesis have been divided into three general categories of rocks: (1) felsic phase, (2) mafic phase, and (3)

Table 5.1. An overview of the textural and petrographic characteristics of each of the six units. Table taken directly from MacDonald (2001).

ROCK TYPE	% of SMB	GRAIN SIZE	DOMINANT TEXTURES	BIOTITE %	MUSCOVITE %	MUSCOVITE Type	PLAGIOCLASE An	PLAGIOCLASE Zoning	K-SPAR EXSOL	CORD %	AND %	TOPAZ %	XENOLITHS
Leucogranite	0.7%	f-m(c)	porp, equi, pegm	0-2	3-28	euh > repl	<5	unzoned	non-exsolved	tr.	0-2	0-8	none
Fine-grained leucomonzogranite	6.8%	f-m(c)	porp, equi	2-7	3-13					tr.	0-tr	0	rare
Coarse-grained leucomonzogranite	21.8%	m-c(f)	mega, seri	2-7	4-8	repl > euh		zoned > unzoned	patch > rod & bead perthite	tr-5	0-tr	0	rare
Muscovite-biotite monzogranite	8.9%	m-c(f)	mega, seri, equi	7-12	1-3					tr-5	0	0	common
Biotite Monzogranite	52.2%	m-c(f)	mega, seri	10-17	tr-1					tr-1	0	0	common-abundant
Biotite granodiorite	9.6%	m-c(f)	mega, seri	15->25	tr	repl	<5-35	zoned	rod & bead perthite	tr.	0	0	abundant

EXPLANATION: GRAIN SIZE - f - fine (<0.1 cm), m - medium (0.1-0.5 cm), c - coarse (>0.5 cm) brackets denote minor occurrence
DOMINANT TEXTURE - equi - equigranular, porp. - porphyritic, pegm - pegmatitic, mega - megacrystic, seri - seriate, listed in descending order of importance
BIOTITE, MUSCOVITE, CORD (CORDIERITE), AND (ANDALUSITE), TOPAZ % - modal determinations from point counting (500-1000 points) of stained rock slabs and thin sections
MUSCOVITE TYPE - euh - euhedral (primary?), repl - replacement (secondary)
PLAGIOCLASE An - anorthite content (from microprobe analysis)
K-SPAR EXSOL - alkali feldspar exsolution textures
XENOLITHS - abundance of metasedimentary xenoliths: abundant - several in all outcrop; common - a few in most outcrop; rare - minor occurrence in some outcrop.

Table 5.2. Thirty samples were analyzed by the author for Hg and trace element levels. This table indicates if a rock sample was taken from an outcrop or a boulder, if the unit is actually mapped on the 1:50,000 series of geological maps, and if a rock sample has any visible weathering. Abbreviations (e.g ODM) taken from the 1:50,000 series of geological maps.

Sample Id	Rock Unit	Map Sheet	Comments
KP-R002	Mafic Porphyry (DCmp)	21A11	outcrop, identified on 50K map
KP-R003	Mafic Intrusion (ODM)	21A12	outcrop, identified on 50K map
KP-R004	Mafic Intrusion (ODM)	21A12	outcrop, identified on 50K map
KP-R005	Mafic Intrusion (ODM)	21A12	outcrop, identified on 50K map
KP-R007	Mafic Intrusion (ODM)	21A12	boulder, not identified on 50K map
KP-R009	Mafic Intrusion (ODM)	21A05	boulder, identified on 50K map, boundary assumed
KP-R010	Mafic Intrusion (ODM)	21A12	outcrop, identified on 50K map
KP-R011	Mafic Intrusion (ODM)	21A12	outcrop, not identified on 50K map
KP-R012	Mafic Intrusion (DM)	21A04	boulder, identified on 50K map
KP-R013	Davis Lake Leucomonzogranite (DClmDL)	21A04	boulder, near TSZ and EK tin deposit (greisen)
KP-R014	Davis Lake Leucomonzogranite (DClmDL)	21A04	boulder, near TSZ and EK tin deposit (greisen)
KP-R015	Davis Lake Leucomonzogranite (DClmDL)	21A04	boulder, near TSZ and EK tin deposit (greisen)
KP-R018	Lake Lewis Leucogranite (DClgLL)	21A16	outcrop, identified on 50K map
KP-R020	Lake Lewis Leucogranite (DClgLL) - Aplite	21A16	outcrop, identified on 50K map
KP-R023	Keddy-Reeves Leucogranite (DClgKR)	21A10	outcrop, identified on 50K map, moderately weathered
KP-R024	Mafic Porphyry (DCmp)	21A10	outcrop, identified on 50K map
KP-R025	Mafic Porphyry (DCmp)	21A10	outcrop, identified on 50K map
KP-R026	Murphy Lake Leucogranite (DClgML)	21A15	outcrop, identified on 50K map
KP-R029	Mafic Intrusion (DM)	21A14	outcrop, not identified on 50K map (might be White Rock Group)
KP-R030	Mafic Intrusion (DM)	21A14	boulder, not identified on 50K map (might be White Rock Group)
KP-R031	Mafic Intrusion (DM)	21A14	boulder, identified on 50K map
KP-R033	Undifferentiated Mafic Granitoid (u)	21A06	boulder, identified on 50K map
KP-R034	Murphy Lake Leucogranite (DClgML)	21A15	outcrop, identified on 50K map, moderately weathered
KP-R035	Murphy Lake Leucogranite (DClgML)	21A15	outcrop, identified on 50K map, moderately weathered
KP-R037	Mafic Porphyry (DCgdmp)	21A15	outcrop, identified on 50K map
KP-R038	Mafic Porphyry (DCgdmp)	21A15	outcrop, identified on 50K map
KP-R040	Mafic Porphyry (DCgdmp)	21A15	outcrop, identified on 50K map
KP-R041	Mafic Porphyry (DCgdmp)	21A15	outcrop, identified on 50K map
KP-R042	Mafic Intrusion (DM)	21A14	outcrop, identified on 50K map
KP-R043	Boot Lake Granodiorite (DCgdBL)	21A15	outcrop, identified on 50K map

mafic intrusions. Felsic phase rocks are muscovite-rich rocks from the SMB. Using MacDonald's (2001) scheme, they include rocks from the leucogranite and leucomonzogranite. Mafic phase rocks are biotite-rich rocks from the SMB. Using MacDonald's (2001) scheme, they include rocks from the biotite granodiorite and mafic porphyries. Mafic intrusion rocks are primarily gabbroic sills.

5.3.1. Felsic Phases

5.3.1.1. Leucogranite

The most felsic phase in the batholith is the leucogranite, and it underlies 0.7% of the region mapped as SMB (Table 5.1). Most of the leucogranite bodies in the SMB are buff, orange, pink, or whitish-grey; these colors generally reflect the variable extent of alteration (MacDonald, 2001). The leucogranite is mostly fine to medium-grained, equigranular, and is devoid of xenoliths. Mineralogically, these units contain 0-2% biotite, 3-28% muscovite, 0-8% topaz, 0-2% andalusite, and trace amounts of cordierite (MacDonald, 2001). Three leucogranite units were sampled: (1) the Lake Lewis Leucogranite (KP-R018, R020), (2) the Murphy Lake Leucogranite (KP-R026, R034, R035), and (3) the Keddy-Reeves Leucogranite (KP-R023).

The Lake Lewis Leucogranite (map sheet 21A16) is white to cream in color, fine to medium-grained, equigranular, with < 2% biotite, and 2-3% muscovite (Ham, 1991). This unit represents a typical leucogranite of the SMB (MacDonald, 2001), and is represented by sample KP-R018. Aplite dykes are common throughout the unit, and are represented by sample KP-R020.

The Murphy Lake Leucogranite (map sheet 21A15) shows a wide range of textures and mineralogy (MacDonald and Ham, 1992). Most of the rocks are leucogranite, however some are leucomonzogranite. They are light grey, buff, orange, pink or red in color. They vary considerably in texture, containing fine to medium-grained, equigranular, aplitic, porphyritic, and pegmatitic phases. These rocks are characterized by 0-5% biotite and 2-8% muscovite. Most of the biotite in this unit has been altered to hematite (MacDonald and Ham, 1992).

The Keddy-Reeves Leucogranite is located in a quarry on map sheet 21A10. The rocks from this unit are white to buff in color, fine to medium-grained, and equigranular to slightly megacrystic. These rocks have 0-2% biotite, 1-5% muscovite, and contain secondary hematite and clay minerals (Horne, 1992).

5.3.1.2. Leucomonzogranite

The only leucomonzogranite unit sampled in the batholith was from the Davis Lake Leucomonzogranite (map sheet 21A04). Ham and MacDonald (1994) describe the Davis Lake Leucomonzogranite as light grey to blue-white or buff in color, medium to coarse-grained, and megacrystic (5-15%). It contains 4-6% biotite, <1% muscovite, trace cordierite, trace fluorite, and trace quartz. The samples taken (KP-R013, R014, R015) are greisen rocks that were sampled near the Tobeatic Shear Zone and East Kemptville Tin Deposit.

5.3.2. Mafic Phases

There are three different rock types that fall under the broader category of "mafic phases", which refers to rocks with relatively high percentages of mafic minerals (mainly biotite) that are a part of the SMB. These rock types include the (1) mafic porphyry (KP-R002, R024, R025, R037, R038, R040, R041; Table 5.2), (2) Boot Lake Granodiorite (KP-R043; Table 5.2), and (3) undifferentiated mafic granitoid (KP-R033; Table 5.2). Generally, the mafic porphyries contain the largest percentages of biotite (~15-20%), however, the Boot Lake Granodiorite has the largest percentage of biotite in the entire SMB (up to 32%; MacDonald, 2001). For this reason, a sample was taken from this unit. In addition, a sample was taken from a mafic phase within KNP, which according to Horne and Corey (1994) is an undifferentiated mafic granitoid (map sheet 21A06).

5.3.2.1. Mafic Porphyry

The mafic porphyry units as described by MacDonald (2001), underly about 0.07% of the entire SMB. They are generally small bodies that range in diameter from <100 m^2 – 1 km^2 , and show a wide range of textures and mineralogy. They range in composition

from granodiorite to monzogranite, and are typically medium to dark grey to brownish-grey, fine to coarse-grained, and porphyritic with phenocrysts of quartz, plagioclase, and K-feldspar. They generally contain between 10 and 20% biotite (biotite contains inclusions of apatite, zircon, monazite, and ilmenite), trace amounts of muscovite, and less than 2% garnet. They have a high proportion of xenoliths of metasedimentary rocks, which are probably derived from the Meguma Supergroup.

The mafic porphyry samples are all granodiorite in composition, dark grey, and fine to medium-grained. All samples (excluding KP-R002, which has >20% biotite), have 15-20% biotite (MacDonald, 2001).

5.3.2.2. Boot Lake Granodiorite

The Boot Lake Grandiorite (map sheet 21A15) is medium to dark grey, fine to medium-grained, porphyritic (feldspar and quartz) to equigranular, rarely megacrystic, composed of granodiorite (with some tonalite), and contains up to 32% biotite (MacDonald and Ham, 1992). Sample KP-R043 was taken from this unit. These characteristics are different from typical granodiorite bodies in the SMB, which are light grey, medium to coarse-grained, megacrystic, have 15-25% biotite (with accessory apatite, zircon, monazite, xenotime, ilmenite), trace amounts of muscovite, cordierite, garnet, and have high proportions of xenoliths (MacDonald, 2001).

5.3.2.3. Undifferentiated Mafic Granitoid

The ‘u’ unit (map sheet 21A06), located in KNP, is described as a mafic granitoid (Horne and Corey, 1994). It is fine to medium-grained and has abundant xenoliths. Although the unit does not have surface outcrops, there are a number of boulders in the area that are believed to represent the unit (Horne and Corey, 1994). Sample KP-R033 was taken from one of these boulders.

5.3.3. Mafic Intrusions

The mafic intrusions are common along the northern part of southwest Nova Scotia (MacDonald, 1994). Most of the intrusions are gabbroic sills that cut the Early

Ordovician Halifax Group. Some of the sills cut the Late Ordovician White Rock Group, the Silurian Kentville Group, and the Devonian Torbrook Group. Based on these cross-cutting relationships, the mafic intrusions are interpreted as middle Devonian or younger in age (MacDonald, 1994). These intrusions are dark colored, fine to medium-grained, with some peridotite and quartz gabbro (Smitheringale, 1973). The rock samples taken for this study were from units that are mapped on NTS map sheets 21A04 (KP-R012), 21A05 (KP-R009), 21A12 (KP-R003, R004, R005, R007, R010, R011), and 21A14 (KP-R029, R030, R031, R042).

5.4. RESULTS

5.4.1. Data Quality

A table showing the Hg and trace element values for the 30 rock samples, the values for the standards and duplicates, the rock type that each sample belongs to, and the location (UTM, Nad83) is available in Appendix 5.2 (this appendix is also included as a table on the CD-ROM in the back cover). The standards and duplicates inserted with the Hg and trace element samples show that the data is of good quality. For Hg, the results of the duplicates are as follows: (1) 1.5 and 0.9 ppb, (2) 0.6 and below detection (<0.1 ppb), and (3) below detection and below detection (Appendix 5.2). For Hg, the results for the standards are as follows: (1) 78.1 (SO-2) and 82.0, (2) 79.3 (SO-2) and 82.0, and (3) 3.6 (CH-REF-1) and 4.1 (Appendix 5.2).

5.4.2. Hg Levels in Rocks

The minimum reported Hg value for the 30 samples is below the detection limit of 0.1 ppb and the maximum Hg value is 24.0 ppb ($n = 30$, $x = 3.65$, $sd = 5.59$). Apart from two highly anomalous values (19.9 and 24.0 ppb), all values range from below the detection limit to 9.6 ppb (Appendix 5.2).

The average value (using 0.05 for values below the detection limit) for the felsic phase is 1.50 ppb ($n = 9$, range = 0.6 – 2.6), the mafic phase is 2.44 ppb ($n = 9$, range = below detection limit – 9.6), and the mafic intrusion is 6.17 ppb ($n = 12$, range = below detection limit – 24.0).

Figure 5.1 shows the range in Hg values for each of the three rock categories (felsic phase, mafic phase, and mafic intrusion). Most of the values for each of the rock types are at or below the average value of 3.65 ppb Hg. All of the felsic phase samples are below this value, two of the mafic phase samples are above 3.65 ppb, and four of the mafic intrusion samples are above 3.65 ppb.

5.4.3. Correlation Matrix

A correlation matrix for all of the trace elements was generated for the 30 rock samples and is included in Table 5.3. Elements, where all 30 of the rocks were below the detection limit (Ag, Bi, Sb, Sn, W, and Ta), were deleted from the table before the matrix was created. All values below the detection limit were set to half of the detection limit (e.g. the lower detection limit for Hg is 0.1 ppb; these values were set to 0.05 ppb). The matrix was generated in WordPerfect® Office 2000 Quattro Pro 9 using the correlation analysis function (located under Tools/ Numeric Tools/ Analysis/ Correlation). All correlation coefficients are calculated using Pearson's product moment correlation coefficient (see Chapter 4, section 4.3.2). In order for a correlation (r) to be significant (at P = 0.05) for 30 samples, r must be ≥ 0.361 (Wheater and Cook, 2000). All values ≥ 0.361 are highlighted in bold. Mercury has a significant positive correlation with **Ca** (0.643), **Co** (0.452), **Fe** (0.487), **Ga** (0.388), **Mg** (0.453), **Mn** (0.584), **Mo** (0.532), **S** (0.569), **Sr** (0.649), **Te** (0.875), and **V** (0.371). By comparison, Smith (2000) showed that there are significant correlations between Hg and Ca, Cd, Co, Cr, Fe, Mg, Ni, Sb, Sr, and V.

5.5. DISCUSSION

Most of the rocks have Hg levels that are below the average value of 3.65 ppb (Figure 5.1). However, on average the more mafic rocks contain higher Hg levels.

The highest Hg value, for the mafic phase rocks, comes from the Boot Lake Granodiorite (KP-R043, 9.6 ppb Hg). This is the unit with the highest modal percentage of biotite (up to 32%). This association, in addition to consistently low levels of Hg in the

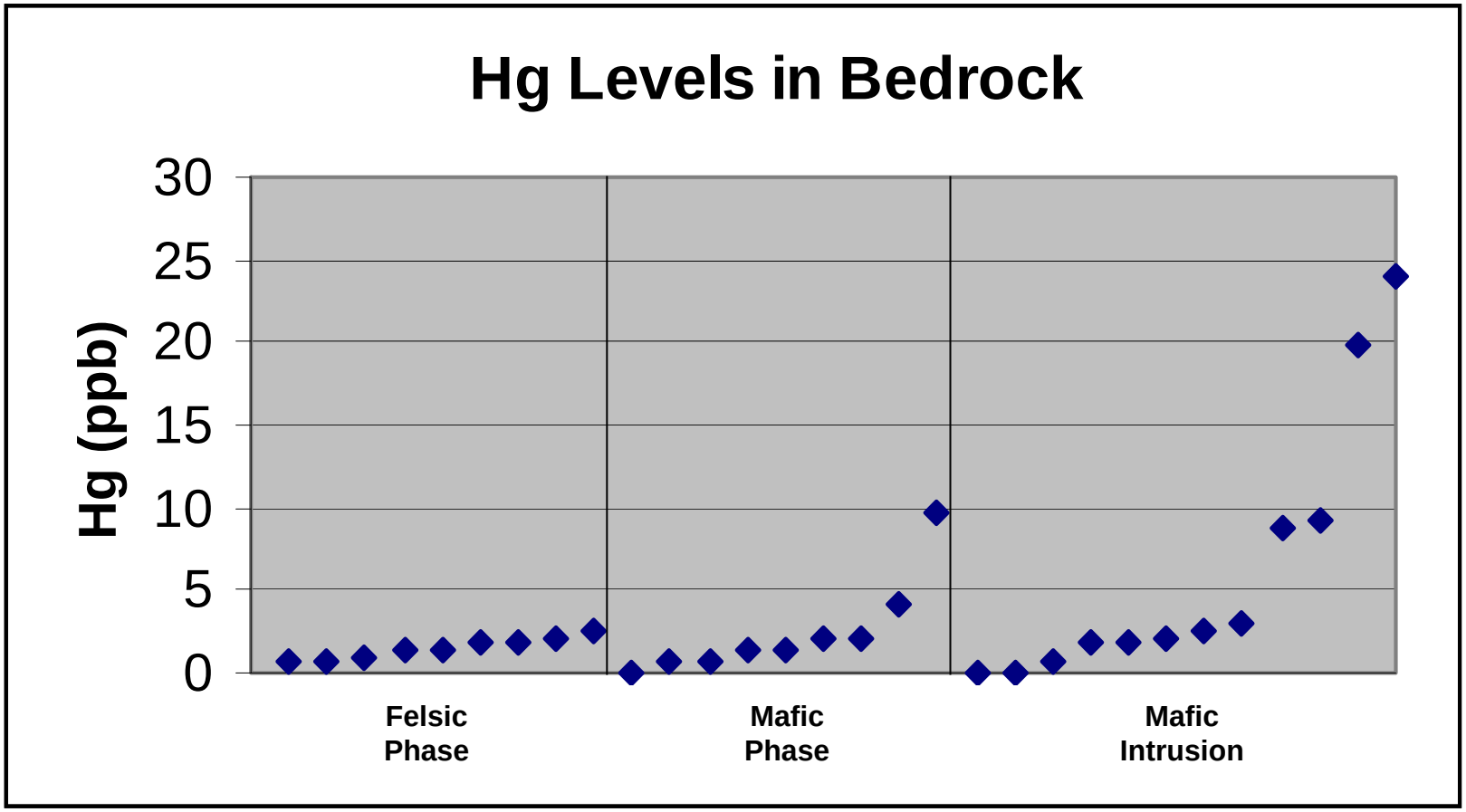


Figure 5.1. Hg values for each of the three lithological categories (felsic phase, mafic phase, and mafic intrusion). Average Hg value for 30 samples is 3.65 ppb. The felsic phase consists of rocks from the leucogranite, leucomonzogranite, and aplite dykes. The mafic phase consists of rocks from the mafic porphyry and the granodiorite. The mafic intrusions are primarily gabbroic sills.

Table 5.3. Table showing the correlation coefficients (*r*) between Hg and trace elements for rocks. Highlighted numbers are significant correlations based on the criteria of Wheater and Cook (2000); for n = 30, a significant correlation has to be $r \geq 0.361$.

	Hg	Au	Cu	Pb	Zn	Mo	Ni	Co	Cd	As	Fe	Mn	Te	Ba	Cr	V
Hg	1.000															
Au	0.017	1.000														
Cu	0.106	0.211	1.000													
Pb	-0.099	0.094	-0.048	1.000												
Zn	0.246	-0.001	0.065	**0.751**	1.000											
Mo	**0.532**	0.074	**0.372**	**0.520**	**0.663**	1.000										
Ni	0.221	0.238	**0.758**	-0.068	0.113	0.331	1.000									
Co	**0.452**	0.112	**0.707**	0.026	**0.434**	**0.654**	**0.797**	1.000								
Cd	0.002	0.064	0.225	**0.815**	**0.725**	**0.660**	0.091	0.258	1.000							
As	-0.122	-0.060	-0.178	0.103	0.214	-0.083	-0.137	-0.100	0.102	1.000						
Fe	**0.487**	0.008	**0.436**	0.177	**0.686**	**0.693**	**0.512**	**0.896**	0.337	0.049	1.000					
Mn	**0.584**	-0.181	0.150	0.224	**0.722**	**0.581**	0.226	**0.656**	0.305	0.044	**0.880**	1.000				
Te	**0.875**	-0.055	0.179	-0.140	0.198	**0.513**	**0.375**	**0.538**	0.005	-0.131	**0.512**	**0.530**	1.000			
Ba	0.323	-0.160	-0.132	0.243	**0.587**	0.258	0.022	0.151	0.157	0.194	**0.380**	**0.554**	0.218	1.000		
Cr	0.259	0.228	**0.418**	0.047	0.317	**0.444**	**0.618**	**0.605**	0.070	-0.016	**0.559**	**0.390**	0.167	**0.389**	1.000	
V	**0.371**	0.011	**0.501**	0.125	**0.589**	**0.680**	**0.398**	**0.841**	0.302	-0.004	**0.929**	**0.758**	0.356	0.249	**0.526**	1.000
La	**0.492**	-0.096	-0.096	0.294	**0.715**	**0.567**	0.012	**0.401**	0.265	0.258	**0.679**	**0.739**	**0.459**	**0.681**	**0.366**	**0.565**
Al	0.350	0.059	**0.733**	0.091	**0.504**	**0.550**	**0.755**	**0.911**	0.258	0.036	**0.872**	**0.691**	**0.410**	0.296	**0.629**	**0.795**
Mg	**0.453**	0.144	**0.646**	0.010	**0.437**	**0.643**	**0.819**	**0.974**	0.228	-0.081	**0.883**	**0.633**	**0.549**	0.219	**0.684**	**0.801**
Ca	**0.643**	0.054	**0.433**	-0.123	0.244	**0.649**	0.345	**0.739**	0.077	-0.215	**0.744**	**0.624**	**0.670**	0.009	**0.364**	**0.766**
Na	-0.034	0.165	**0.901**	-0.155	-0.128	0.167	**0.563**	**0.466**	-0.002	-0.195	0.225	-0.019	0.025	-0.183	**0.368**	0.355
K	0.072	-0.203	**-0.364**	**0.445**	**0.606**	0.046	-0.167	-0.136	0.268	**0.461**	0.149	**0.366**	-0.028	**0.766**	0.165	-0.020
Sr	**0.649**	0.175	**0.511**	-0.161	0.214	**0.603**	**0.622**	**0.814**	-0.002	-0.229	**0.738**	**0.566**	**0.725**	0.116	**0.604**	**0.678**
Y	0.136	-0.202	-0.167	**0.447**	**0.671**	0.320	-0.064	0.207	0.302	0.135	**0.480**	**0.641**	0.145	**0.601**	0.123	0.324
Ga	**0.388**	0.019	0.249	0.208	**0.741**	**0.582**	0.329	**0.731**	0.324	0.131	**0.925**	**0.844**	0.362	**0.536**	**0.523**	**0.857**
Li	-0.064	**-0.406**	**-0.364**	0.164	0.243	-0.075	-0.147	-0.105	0.122	0.265	0.049	0.197	-0.036	0.210	-0.164	-0.089
Nb	0.305	0.026	**0.373**	0.083	**0.519**	**0.641**	0.284	**0.749**	0.247	-0.072	**0.854**	**0.668**	0.279	0.168	**0.460**	**0.954**
Sc	0.176	-0.101	-0.053	**0.371**	**0.741**	**0.394**	0.076	**0.427**	0.274	0.277	**0.717**	**0.764**	0.078	**0.542**	**0.404**	**0.625**
Ti	0.175	-0.098	0.180	0.341	**0.747**	**0.414**	0.160	**0.413**	0.342	0.257	**0.649**	**0.658**	0.110	**0.760**	**0.449**	**0.600**
Zr	-0.075	0.124	-0.081	-0.128	-0.021	-0.068	-0.154	-0.013	-0.177	-0.240	0.071	0.066	-0.061	-0.151	-0.014	0.127
S	**0.569**	0.032	0.198	0.240	**0.590**	**0.714**	0.308	**0.680**	0.291	-0.080	**0.813**	**0.791**	**0.475**	**0.224**	**0.514**	**0.767**

Table 5.3. (Continued)

	La	Al	Mg	Ca	Na	K	Sr	Y	Ga	Li	Nb	Sc	Ti	Zr	S
Hg															
Au															
Cu															
Pb															
Zn															
Mo															
Ni															
Co															
Cd															
As															
Fe															
Mn															
Te															
Ba															
Cr															
V															
La	1.000														
Al	**0.427**	1.000													
Mg	**0.428**	**0.908**	1.000												
Ca	**0.453**	**0.603**	**0.685**	1.000											
Na	-0.191	**0.560**	**0.411**	0.360	1.000										
K	**0.524**	0.085	-0.066	-0.353	**-0.427**	1.000									
Sr	**0.432**	**0.715**	**0.827**	**0.896**	**0.415**	-0.261	1.000								
Y	**0.752**	0.290	0.198	0.139	-0.208	**0.507**	0.081	1.000							
Ga	**0.759**	**0.753**	**0.754**	**0.575**	0.056	0.330	**0.581**	**0.540**	1.000						
Li	0.147	-0.023	-0.072	-0.197	**-0.446**	**0.424**	-0.197	0.270	0.093	1.000					
Nb	**0.500**	**0.669**	**0.730**	**0.729**	0.230	-0.099	**0.625**	0.253	**0.825**	-0.079	1.000				
Sc	**0.618**	**0.555**	**0.456**	0.280	-0.168	**0.562**	0.244	**0.584**	**0.780**	0.331	**0.606**	1.000			
Ti	**0.675**	**0.626**	**0.472**	0.156	0.079	**0.670**	0.209	**0.535**	**0.785**	0.172	**0.541**	**0.768**	1.000		
Zr	0.036	-0.004	0.030	0.217	0.026	-0.318	0.180	0.121	0.158	-0.125	0.272	0.057	-0.049	1.000	
S	**0.504**	**0.647**	**0.705**	**0.678**	0.022	0.091	**0.656**	0.291	**0.717**	0.093	**0.783**	**0.696**	**0.483**	0.198	1.000

felsic phase granite, suggests a relationship between anomalous Hg levels and the abundance of biotite.

The correlation matrix (Table 5.3) shows a positive correlation of Hg with Fe and Mg. Smith's (2000) results also show these correlations. As biotite is the predominant Fe-Mg bearing mineral in these rocks, these positive correlations provide further evidence of a relationship between Hg and the abundance of modal biotite.

There is little data available in the literature about the location of Hg within the biotite crystal structure. However, the size (0.110 nm) of Hg^{2+} inhibits it from fitting in the tetrahedral or octahedral sites of the mineral. Cations must be between 0.034 - 0.056 nm (tetrahedral) or 0.056- 0.99 nm (octahedral) to fit inside these structures (Harter, 1998, http). This suggests that Hg is likely to be preferentially located between the silicate sheets, either in the sites that normally contain potassium (the potassium sites generally accept cations between 0.75 – 0.145 nm (Harter, 1998, http)), or in relatively high energy sites, such as along the cleavage planes or in crystal defects. In any of these locations, the Hg is readily available for transportation by secondary processes such as weathering. If so, then the weathering of biotite could quite readily release Hg to the environment. Work is taking place by the TSRI team to determine if Hg in bedrock is accessible to the environment. A.-M. O'Beirne-Ryan (Dalhousie University) is studying Hg levels in fresh versus weathered granites and preliminary results suggest that Hg is slightly depleted in weathered samples, indicating a potential release of Hg with weathering (A.-M. O'Beirne-Ryan, Ph.D. thesis in progress, Dalhousie University).

The two highest Hg values (19.9 and 24.0 ppb) come from a mafic intrusion that is located in Digby (KP-R003, R004). This is consistent with Smith's (2000) results from the same unit (22.8 and 24.7 ppb). The reason for the high Hg levels in this unit is unclear. Detailed work needs to be done in order to access the origin of this anomaly.

Chapter 6 – Shear Zone Study

6.1. INTRODUCTION

Two shear zones displaying intense brittle-ductile deformation are inferred to transect Kejimkujik National Park (KNP). These zones, referred to as the East Kemptville Shear Zone (EKSZ; O'Reilly, 1988) and the Tobeatic Shear Zone (TSZ; Corey, 1994), have been mapped on a regional scale and are most clearly defined to the southwest of KNP (e.g. Little Tobeatic Lake (Corey and Horne, 1988), Rushmore Lake (Smith, 1985), and Fanning Lake (O'Reilly and Smith, 1989)), where there is more bedrock exposure. However, owing to lack of exposure, their precise location within the park is not clearly delineated.

Southwest of KNP, the EKSZ defines the northern contact of the Davis Lake Pluton (DLP), and the TSZ defines the southern contact of the DLP (Figure 6.1). Both shear zones cut the Meguma Supergroup and the South Mountain Batholith (SMB) and extend to the northeast where they become part of a system of regional northeast trending shear zones that typify the Meguma terrane (Corey, 1994). The shear zones are believed to be pre- or syn-intrusion features (Horne et al., 1992; Keppie and Dallmeyer, 1995) that were sites of extensive post-emplacement tectono-thermal activity (Corey, 1994). $^{40}Ar/^{39}Ar$ dating of sheared granites in the East Kemptville deposit indicate a thermal event at ~ 300 Ma (Zentilli and Reynolds, 1985). Rb-Sr and $^{40}Ar/^{39}Ar$ dating by Kontak and Cormier (1991) have detected thermal events at 344, 330, and 254 Ma. Therefore, these ages suggest that episodic thermal events and possible circulation of hot fluids took place between the Devonian and Permian.

Anomalous concentrations of precious and base metals as well as industrial minerals occur in both of these shear zones. Mineralization, including Au-As-Sn-W-Mo-Cu-Ag-Pb-Zn-Ba, and variably altered (chloritized, silicified, kaolinized, hematized) rocks exhibit a strong spatial relationship with the two shear zones (Horne and Corey, 1994; Corey, 1994). The types and styles of mineralization observed in boulders and diamond drill core from the TSZ are typical of epithermal deposits (Corey, 1994), which typically contain cinnabar (HgS) and Au-Cu-Ag-Pb-Zn-Sb-Se-Bi-U mineralization (Evans, 1993).

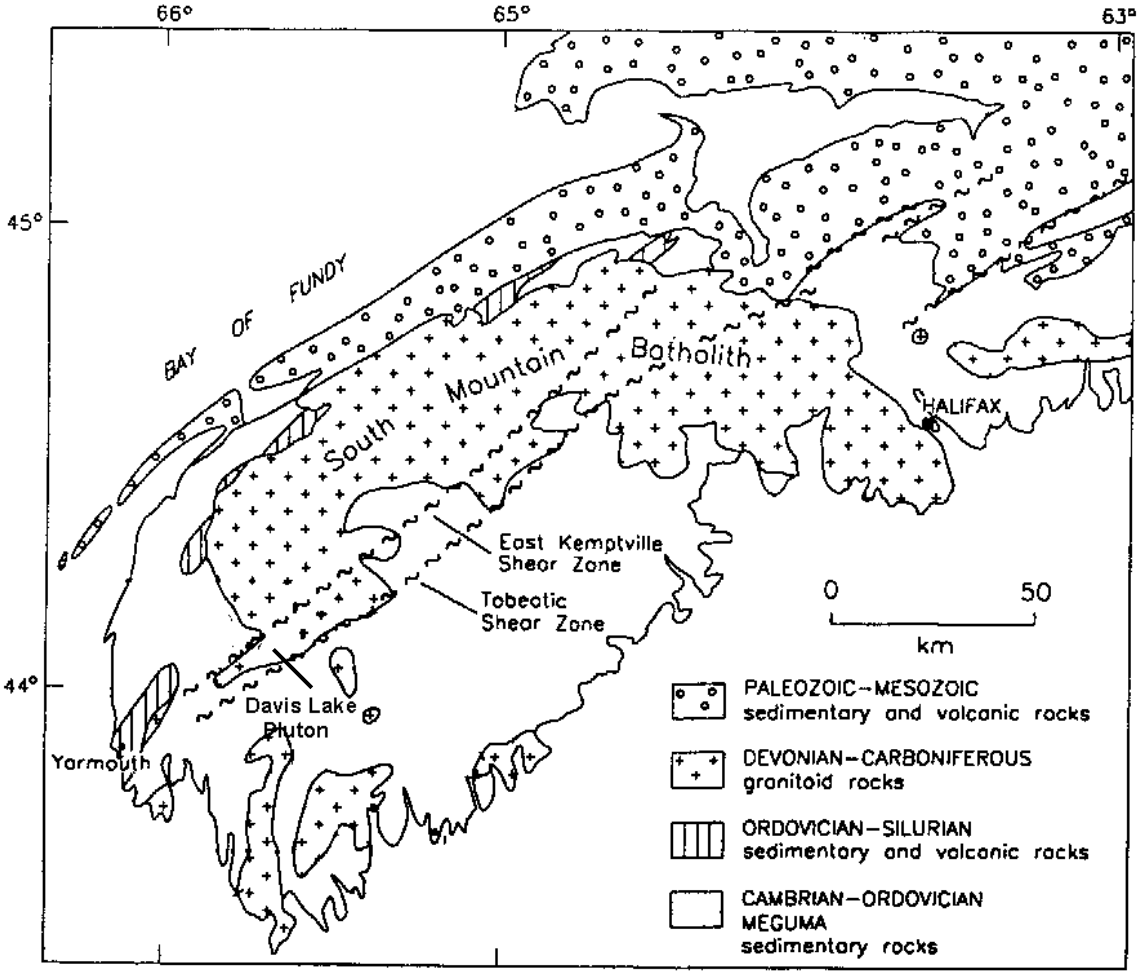


Figure 6.1. Map showing the simplified geographical relationship between the SMB, the Tobeatic Shear Zone, and the East Kemptville Shear Zone. Figure modified from Corey, 1994.

Cinnabar has not yet been found in either of the shear zones, although a possible greywacke hosted cinnabar zone has been located about 15 km east of KNP (P. K. Smith, personal communication, June 20, 2001).

In order to determine if the shear zones are a source of Hg to the surrounding watershed through the weathering of minerals, the location of the shear zones in the park must be determined and these shear zones must be tested for Hg. This chapter is divided into two sections: (1) identification of shear zone traces in KNP and (2) testing the shear zones for Hg.

6.2. GENERATION OF SHADED RELIEF MAP

6.2.1. Definition

In order to identify shear zone traces throughout the park, a high-resolution shaded relief map for most of southwest Nova Scotia was created (Appendix 6.1). A shaded relief map shows the shape of the land by intensity of the sun's shadow (i.e. the user defines an artificial angle and azimuth for the sun). Because shaded relief maps show features on the surface, such as structural zones, drainage patterns, mountains, and valleys, they are extremely useful for structural, tectonic, and geomorphological interpretations (Moore and Simpson, 1982; Moore and Mark, 1986; Pike and Thelin, 1989; Pike, 1991).

6.2.2. Generation

Shaded relief maps are generated using a computer software package (in this case, PCI Version 6.3^{TM}) and a Digital Elevation Model (DEM). The DEM used to construct the shaded relief map in Appendix 6.1 was created by the Nova Scotia Geomatics Centre (NSGC); all DEM specifications are available on the NSGC website (Nova Scotia Topographic Database, 2001, http). The DEM is a mass point file containing x, y, and z coordinate data (a mass point is an individual elevation point on a DEM). The DEM was created using stereographic pairs of 1:40,000 scale aerial photos, where a point was collected systematically every 2 mm (equal to about 80 meters on the ground). Aerotriangulation, the process of densification and extension of field control through the

use of aerial photography (Aerial Survey Data Base, 1999, http), was also performed. In ARC/INFO®, a surface was interpolated using TOPOGRID and then was resampled to a 20 m resolution. Most shaded relief maps are generated with a 30 m or coarser resolution (Klinkenberg, 1997, http). Using a 20 m resolution greatly facilitates the ability to locate and distinguish between features on the ground. The original mass points used by the NSGC to produce the 20 m DEM have a horizontal accuracy of 2.5-3.5 meters and a vertical accuracy of 2.5 meters (Nova Scotia Topographic Database, 2001, http).

Using a DEM and the image processing software, the user can construct a virtual 3D landscape (Birrell, 1995, http). A simulation of what the landscape would look like when illuminated from an artificial azimuth and angle can then be constructed. The shaded relief map in Appendix 6.1 has a vertical exaggeration of five, an azimuth of 135^{o} (chosen to highlight suspected northeast trending features in the area), and an illumination angle of 45^{o}. Therefore, southeast-facing slopes are illuminated relative to northeast-facing slopes, which would be shaded. The resulting light-dark contrast pattern causes the 3D illusion (Birrell, 1995, http). Different colors can then be used to show variations in elevation. For the shaded relief generated in this thesis, the colors used (from lowest elevation to highest elevation) are dark blue (ocean), light blue (coastline), dark green, green, yellow, orange, and red.

6.2.3. Locating Shear Zone Traces

Figure 6.2 shows a number of inferred shear zone traces in KNP that were identified by myself, in collaboration with P. K. Smith (Nova Scotia Department of Natural Resources, NSDNR), and T. Goodwin (NSDNR). These features are more clearly delineated on the image in Appendix 6.1. These traces are interpreted to reflect the locations of the EKSZ and TSZ because of (1) their prominence as northeast trending features on the shaded relief map and (2) their location is along strike from known shear zone exposures to the southwest of the park (Corey, 1994). In addition, this interpretation is supported by field work carried out to ground-truth these images. The shear zone traces identified in Figure 6.2 were used to determine sample locations.

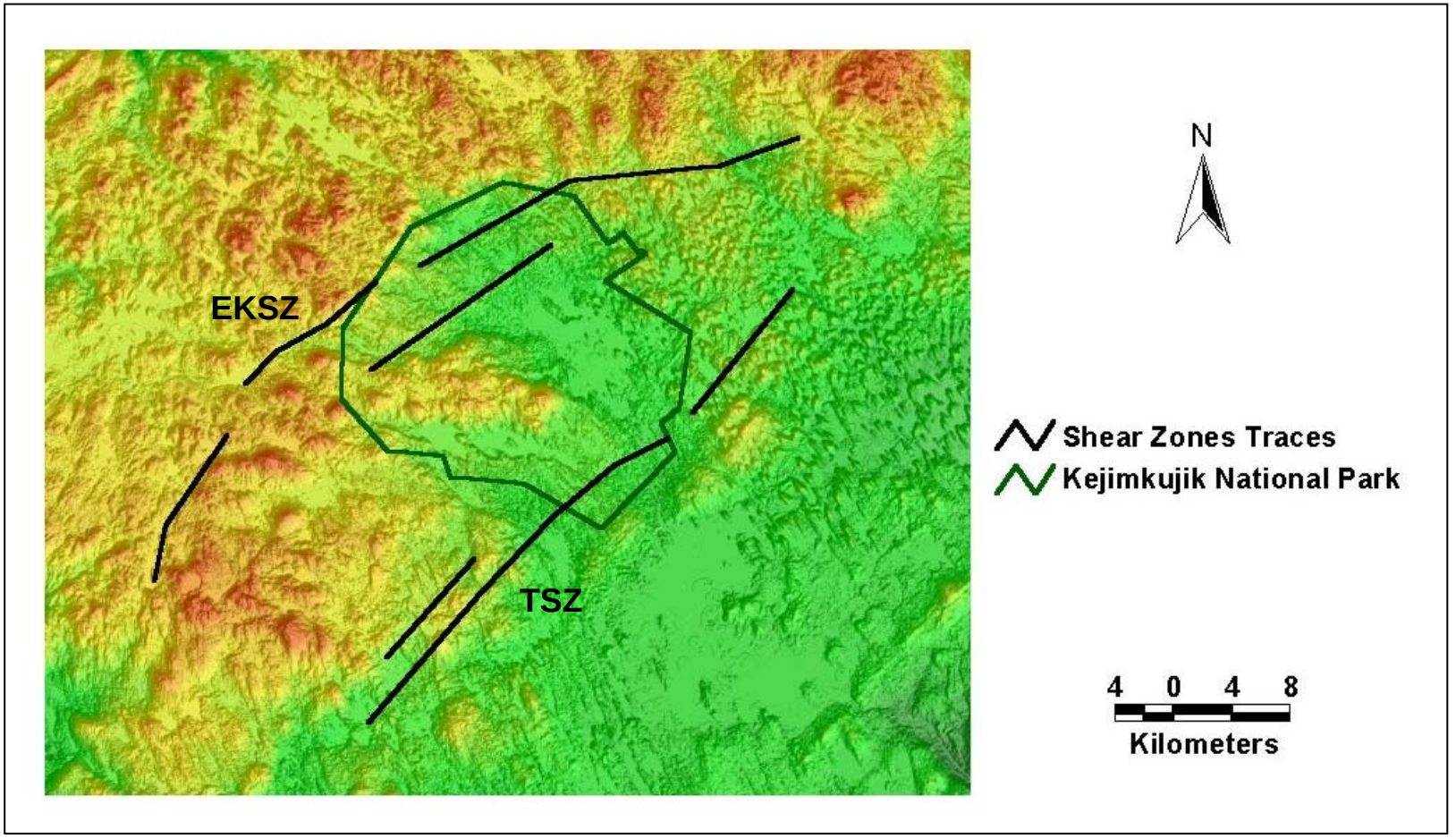


Figure 6.2. Shear zone traces identified in the park. The East Kemptville Shear Zone (EKSZ) transects the northern part of the park and the Tobeatic Shear Zone (TSZ) transects the southern part of the park.

6.3. TESTING THE SHEAR ZONES FOR HG

In September 2000, a total of 94 Quicksilver Hg vapor units (including 12 duplicates) were placed along four north-south trending lines around KNP (Figure 6.3, 6.4). The Quicksilver system works by amalgamating Hg vapor from soil gas onto a silver strip. Although various techniques using silver and gold collectors to sample Hg vapor in the field have been employed since the 1960's, the Quicksilver Hg vapor units are a new system that allows a large volume of soil gas to be sampled, in contrast to other designs which rely on the diffusion of Hg vapor into a small static air space (Rehn and Rehn, 1996). This is the first study using Quicksilver Hg vapor units in Nova Scotia. In fact, only one other known study exists; this study took place in Nevada over a known gold ore body (Rehn and Rehn, 1996). Therefore, this study not only tests the shear zones for Hg, but also tests a fairly new analytical technique. The sampling and analytical methods are described below.

Lines 1-3 (Figure 6.4) were designed to cross the TSZ and Line 4 (Figure 6.4) was designed to cross the EKSZ. Lines 1, 2, and 4 were also designed to cross the Goldenville-Halifax geological contact. Mercury vapor units placed along Lines 1, 3, and 4 correlate with till samples collected from the same sample site by T. Goodwin.

Line 1 is ~ 3 km long, Line 2 is ~ 5.5 km, Line 3 is ~ 9 km and Line 4 is ~ 5 km. On Line 1, Hg vapor units were placed along a secondary dirt road at a sample spacing of 500 m. Lines 2 and 3 were placed along logging roads at variable sample spacings of 100, 200, and 500 m. Line 4 was placed along Highway 8 at a sample spacing of 500-700 m.

6.3.1. Methods

6.3.1.1. Sampling Methodology

At each sample site, a 30 cm deep hole was dug with a tree planter-style shovel. The Hg vapor units were assembled at each site and placed at the bottom of the hole. A silver strip collector was removed from an airtight glass tube and inserted into a plastic mesh holder (Figure 6.3). A 20 x 20 cm piece of permeable fiberglass cloth (provided by Quicksilver Systems) was placed over the cup. The cloth created an air pocket below the

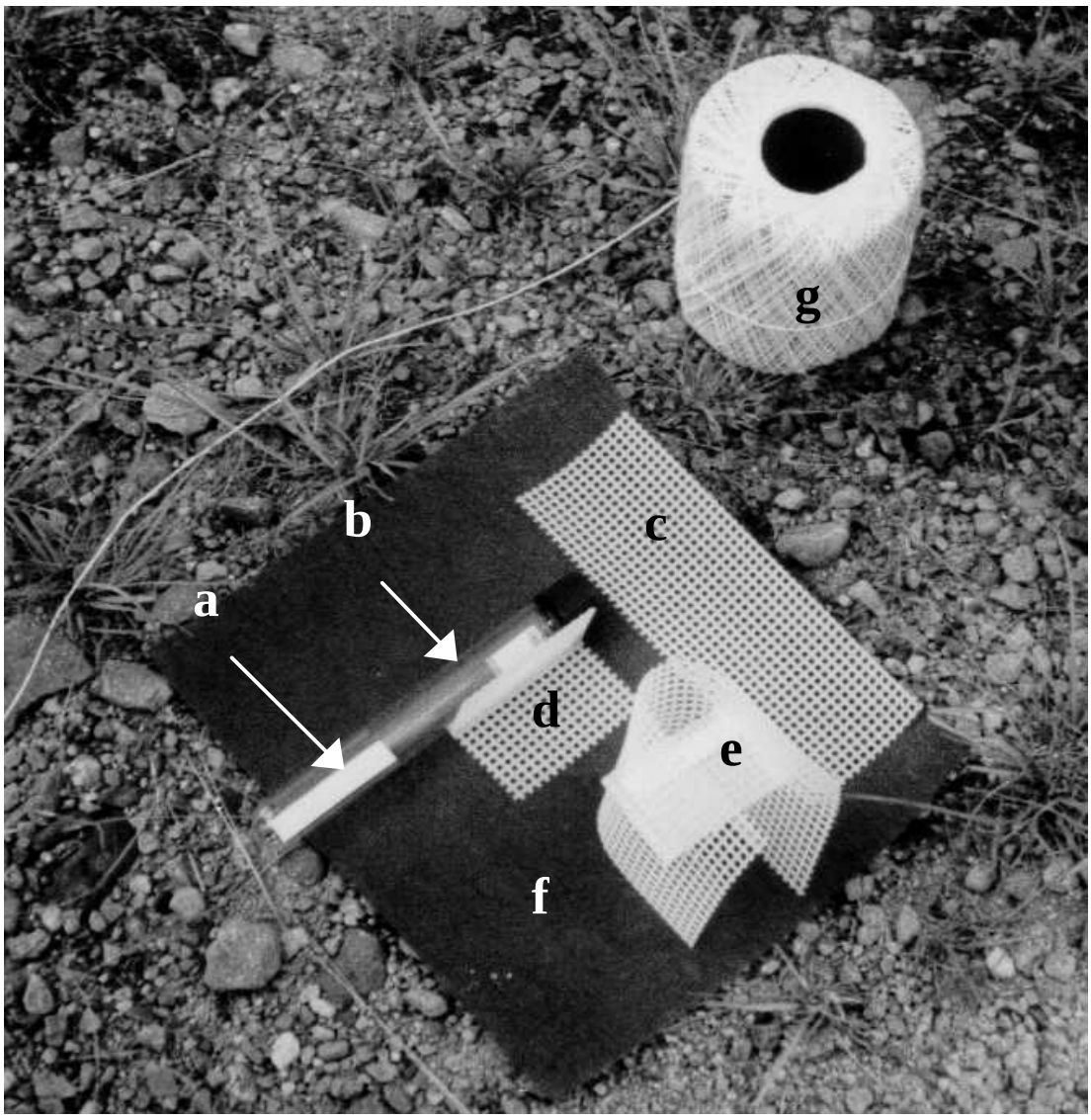


Figure 6.3. Elements of a Hg vapor unit: (a) silver strip collector (b) tube to store the silver strip (c) part 1 of the unit (d) part 2 of the unit (e) assembled unit (combination of parts a, c, d) (f) sheet that covers the unit in the dug hole (g) string that attaches to the unit and runs to the surface for re-location.

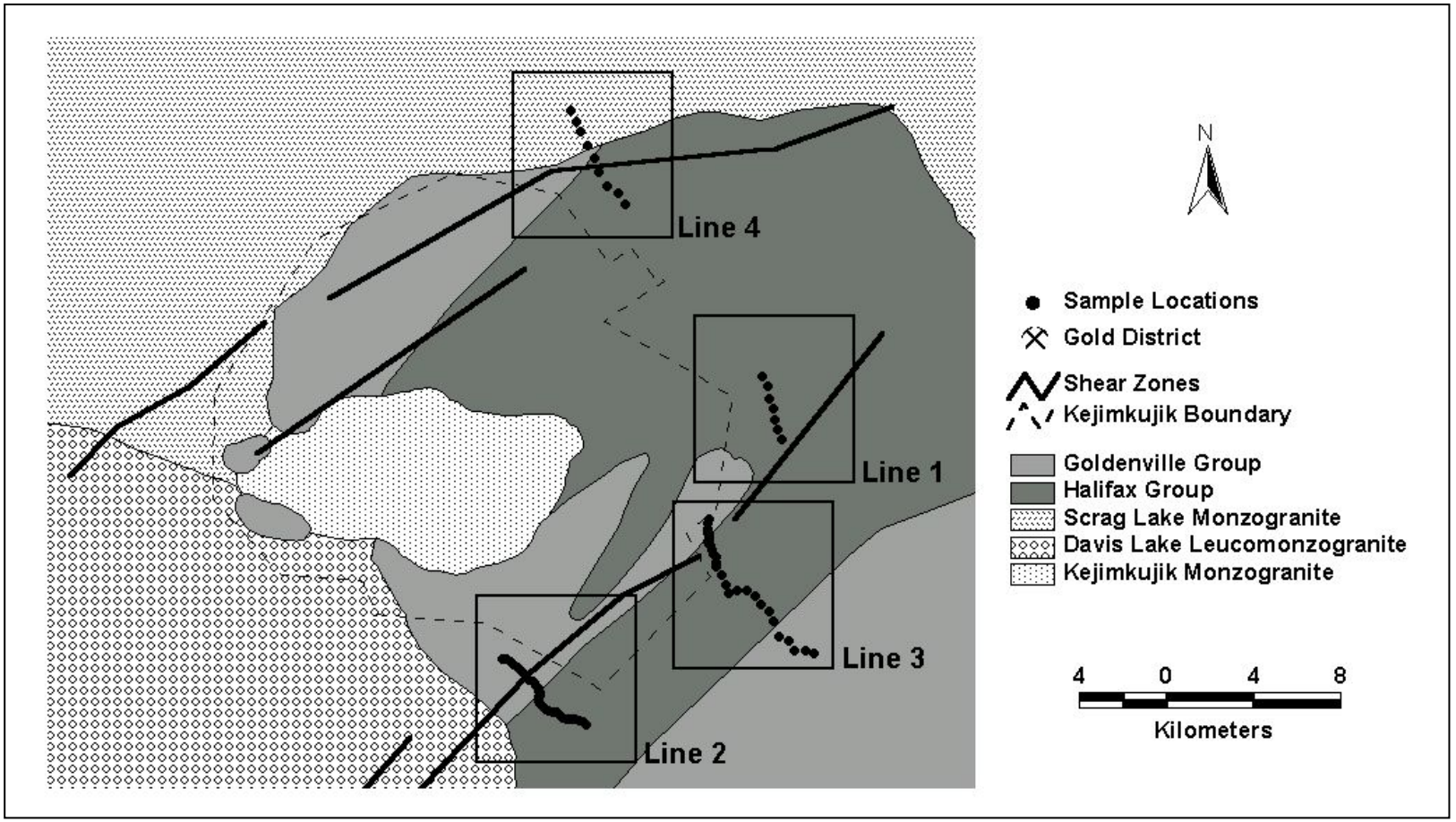


Figure 6.4. Sample locations of the 94 Hg vapor units.

unit and provided protection for the unit from contact with the overlying soil. The units were left buried and undisturbed for 30 days. Each site was marked with a picket and the sample location was recorded by GPS (Garmin 12).

After 30 days, the Hg collectors were carefully retrieved by digging up each unit. The silver strip collector was replaced into the airtight glass tube. The airtight tubes were sent via courier to Quicksilver Systems in Bend, Oregon for Hg analysis.

6.3.1.2. Analytical Methodology

At the laboratory, each silver strip was removed from the airtight glass tube and sprayed with distilled water in order to rinse off any soil or organic particulate. The strips were dried with lintless paper and placed in a clean glass tube for analysis.

The strips were heated to 700°C in a Thermolyne tube furnace, which forces Hg vapor into a stream of air. Mercury is then amalgamated onto a gold foil in a Jerome Gold Film Mercury Vapor Analyzer (Rehn and Rehn, 1996). Changes in the resistance of the gold foil compared to a reference gold foil represent the concentration of Hg (measured in nanograms per strip). The lower and upper detection limits for the Jerome Vapor Analyzer are 2 nanograms and 100 nanograms per strip, respectively.

6.3.1.3. Quality Assurance/Quality Control (QA/QC)

Certified reference standards are normally inserted with geochemical samples submitted for analysis in order to assess a laboratory's precision and accuracy. Four randomly inserted "blank" Hg detection strips (i.e. strips that were never buried) were used for analytical control. There are no known standards (apart from the previously mentioned reference gold foil) for the Quicksilver Hg vapor units, and this might affect the accuracy of the analyses, especially for those that are anomalous. However, this disadvantage does not significantly affect the main results of this study because absolute values obtained from the analyses are rarely used.

Twelve field duplicates, placed within 1-3 m of the original unit, were used to determine site variance.

6.3.2. Results

6.3.2.1. Determining Anomalous Hg Levels

The results of the Hg vapor units are available in Appendix 6.2 (this appendix is included as a table on the CD-ROM in the back cover). The minimum reported Hg in soil gas value for field samples is below the detection limit of 2 ng Hg/strip and the maximum value is 78 ng Hg/strip (n = 94, x = 4.7, sd = 9.3). Based on a review of the data set using (1) a cumulative frequency plot, (2) rank and percentile, and (3) published results by Rehn and Rehn (1996) it was determined that the background values for this study range from 0-6 ng Hg/strip and values ≥7 ng Hg/strip are considered anomalous (Figure 6.5). Apart from two highly anomalous values (46 and 78 ng Hg/strip) all values range between 0-15 ng Hg/strip (14 values are ≥ 7 ng).

6.3.2.2. Data Quality

The four blanks reported 0 ng Hg/strip and the results for the 12 field duplicates are shown in Table 6.1. Most of the field duplicates (67%) only vary within background levels (between 0-6 ng). This indicates the samples are representative of the area where they were collected from. Four of the field duplicates have one value that is background (between 0-6 ng) and one value that is anomalous (≥ 7 ng). Each of the field duplicates were placed anywhere from 1-10 m apart, therefore the difference in Hg values may indicate either local heterogeneity in Hg levels or differences in the dug holes (e.g. one hole may have heavy mineralized rocks located under it, whereas the other may not). Based on the limited QC data (the four blanks and twelve field duplicates), the data appear to be of acceptable quality.

6.3.2.3. Geographic Distribution of Hg

Line 1: The highest Hg in soil gas values reported for this study (46 and 78 ng Hg/strip) occur in two adjacent sites at the southern end of Line 1 (Figure 6.6a). These two sites are 500 m apart and are located along the inferred north edge of the TSZ (as indicated by the shaded relief image) and approximately 4 km northeast of known Au mineralization associated with the former West Caledonia Gold District. This district is

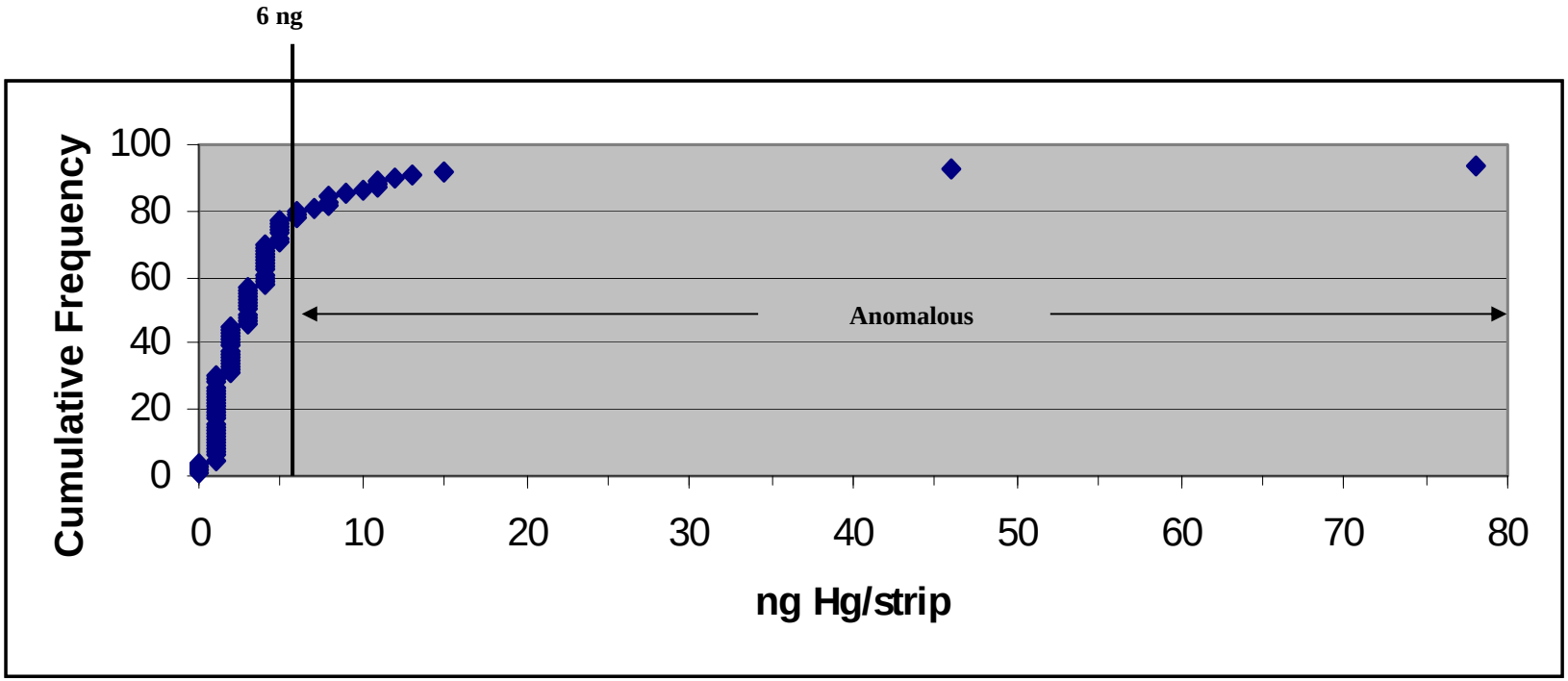


Figure 6.5. Cumulative frequency plot showing Hg vapor data. The background value (≤ 6 ng) was determined based on a change in slope in the cumulative frequency plot.

Table 6.1. Results of the 12 field duplicates. 67% (8 of 12) of the field duplicates only vary within background levels (0-6 ng). The other 33% (4 of 12 – shown in bold) have one value that is background and one value that is anomalous.

ID#s	Value	Value
KP-001, 002	3	5
KP-010, 011	**2**	**10**
KP-029, 030	**9**	**3**
KP-039, 040	1	4
KP-041, 042	**1**	**7**
KP-048, 049	1	4
KP-055, 056	2	6
KP-059, 060	3	2
KP-061, 062	3	1
KP-071, 072	1	0
KP-081, 082	**8**	**5**
KP-091, 092	2	3

characterized by a pair of doubly plunging, northeast trending anticlines (Horne and Corey, 1994) and epithermal type mineralization (P. K. Smith, personal communication, August 9, 2000).

Line 2: Line 2 (Figure 6.6b) contains seven anomalous sites (8-15 ng Hg/strip) that are each separated by at least two background values. The seven anomalous sites are spatially associated with the TSZ and the inferred structural contact between the Goldenville and Halifax groups. In the gold districts of Northern Nevada, a similar pattern of anomalies was identified by Rehn and Rehn (1996) across a drill inferred, deeply buried (up to 160 m of unconsolidated Quaternary overburden), gold ore body.

Line 3: Two anomalies (7 and 11 ng Hg/strip) were reported along Line 3 (Figure 6.6c), both at the southern end of the line. These sites are spatially associated with the Goldenville-Halifax Transition Zone.

Line 4: There are no anomalous Hg in soil gas values reported along Line 4 (Figure 6.6d).

6.3.3. Proximity Analysis

In order to determine if there is any direct spatial relationship between the Hg vapor unit values and the distance from shear zones traces, a proximity analysis was performed. Proximity is the measure of the distance between features. In order to perform proximity calculations, four parameters must be specified: (1) the target location, (2) the unit of measurement, (3) a function to calculate proximity, and (4) the area to be analyzed (Aronoff, 1995). In this case, the proximity of a Hg vapor unit from any shear zone trace was calculated in meters using Euclidean distance. The proximity of each Hg vapor unit to a shear zone is then plotted against the Hg values of the vapor units.

The proximity analysis was performed using IDRISI32® Version I32.11 and ArcView GIS® v.3.2. The complete procedure is shown in Appendix 6.3. The two files used for this analysis were (1) the shear zones traces and (2) the Hg vapor units (using an average of each pair of field duplicates). Results are shown in Figure 6.7a-b. Figure 6.7a shows the Hg vapor unit concentrations plotted against the distance in meters from a shear zone trace; Figure 6.7b excludes the two outliers (46 and 78 ng Hg/strip). The R^2

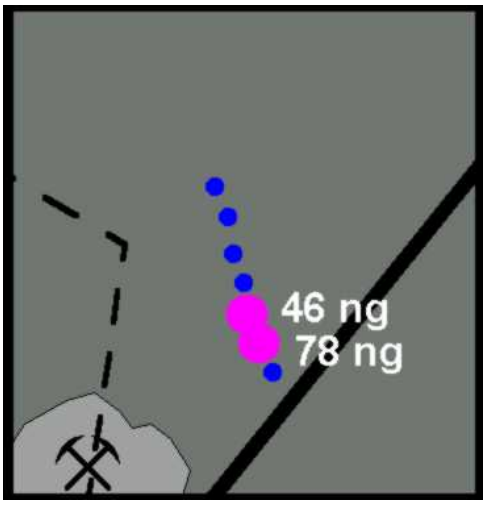


Figure 6.6a. Line 1

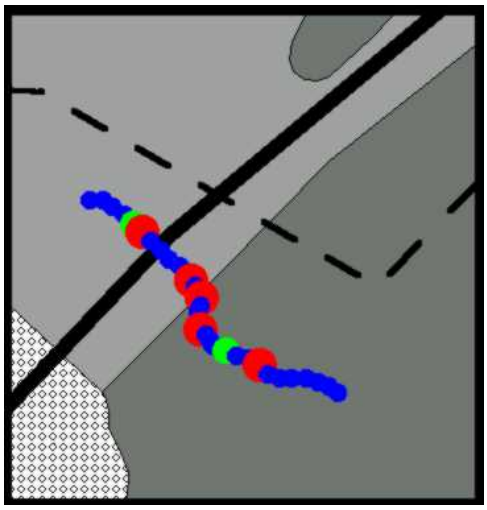


Figure 6.6b. Line 2

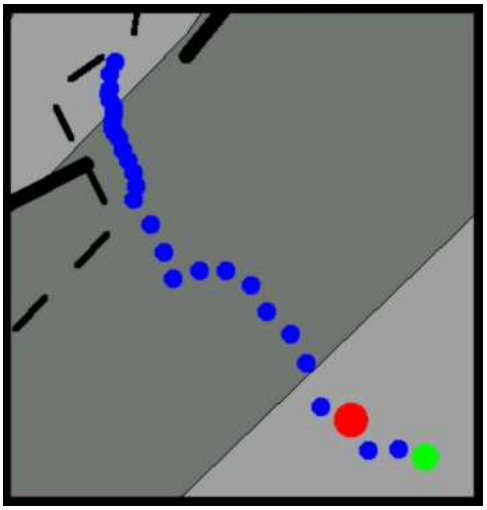


Figure 6.6c. Line 3

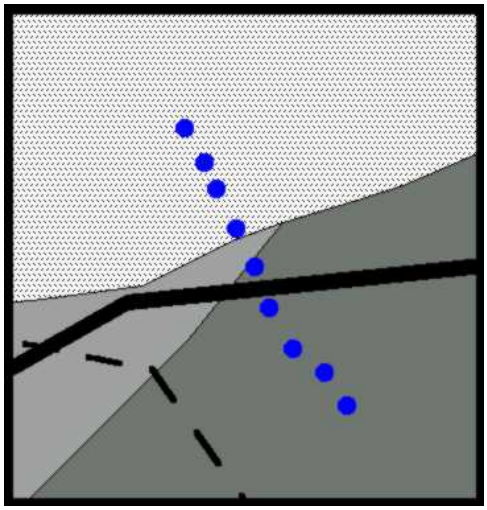


Figure 6.6d. Line 4

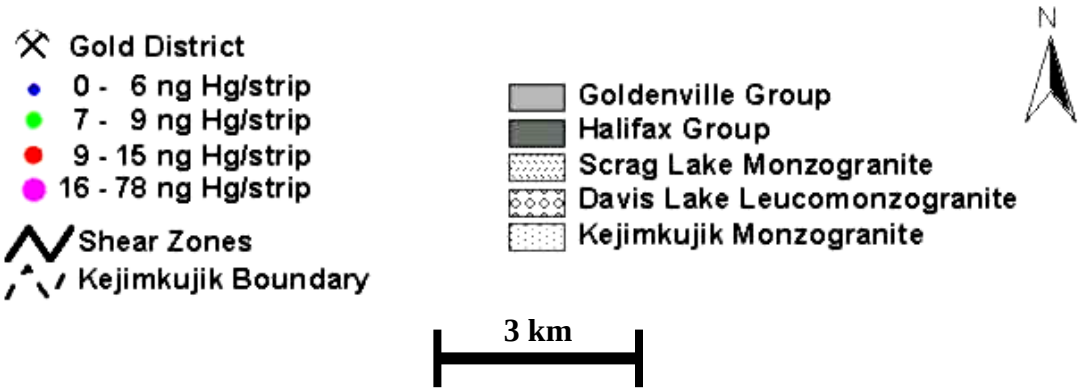


Figure 6.6. Hg values for the vapor units; plotted using four natural break categories.

values are included on both graphs; they are 0.0029 and 0.0040 respectively. There is no direct correlation between the distance from a shear zone trace and the value of a Hg vapor unit. This result is not surprising as shear zones don't necessarily emit gas along their trace, but may have a main shear zone at depth, which gives way to distributed shear zones near the surface (e.g. Figure 6.8). Fluid flow from the main shear would be dispersed above it, as appears to be the pattern along Line 2 (Figure 6.6b). Upon further examination of the shaded relief map (Appendix 6.1), parallel lineaments were identified in close proximity to some of the regional shear zone traces. This identification provides the context for future, more detailed studies.

6.4. DISCUSSION

The data indicate there is a strong spatial relationship between inferred structures, namely the TSZ, and anomalous Hg in the overlying soil gas. Rehn and Rehn (1996) also noted a positive relationship between vertical structures and anomalous Hg in soil gas. The inferred trace of the EKSZ returned no anomalous Hg values in the soil gas. Although the lack of response may reflect the absence of Hg source minerals in the shear zone, it could equally well be a function of sample distribution. These results indicate the importance of detailed petrographic and microprobe analyses of shear zone samples to further assess their importance to the Hg budget in KNP.

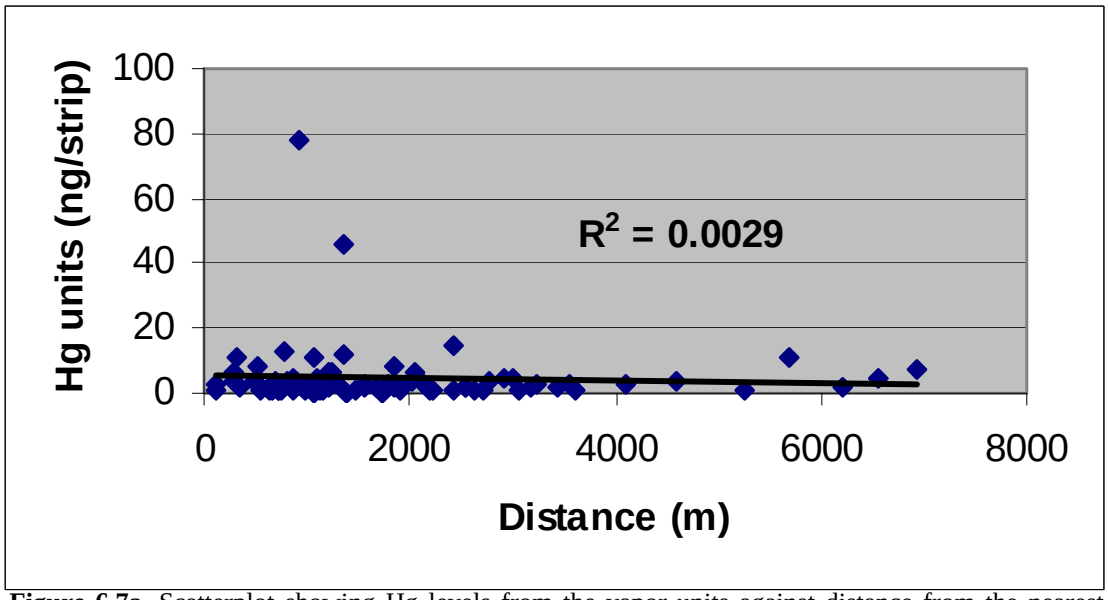


Figure 6.7a. Scatterplot showing Hg levels from the vapor units against distance from the nearest shear zone trace. $R^2 = 0.0029$, n = 82.

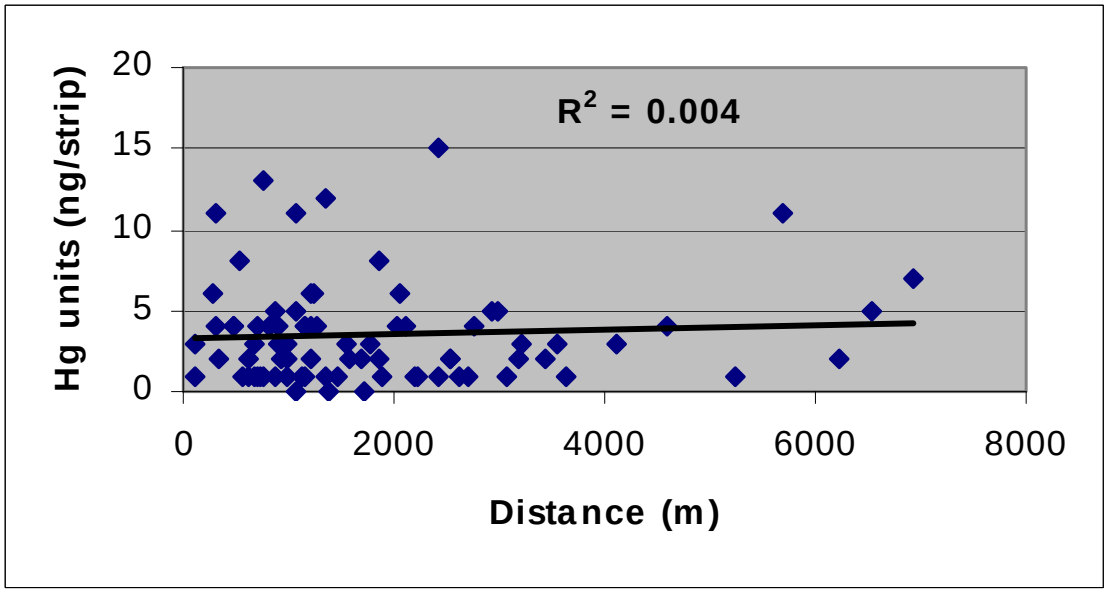


Figure 6.7b. Scatterplot showing Hg levels from the vapor units against distance from the nearest shear zone trace; the two highest Hg values are excluded (46, 78). $R^2 = 0.0040$, n = 80.

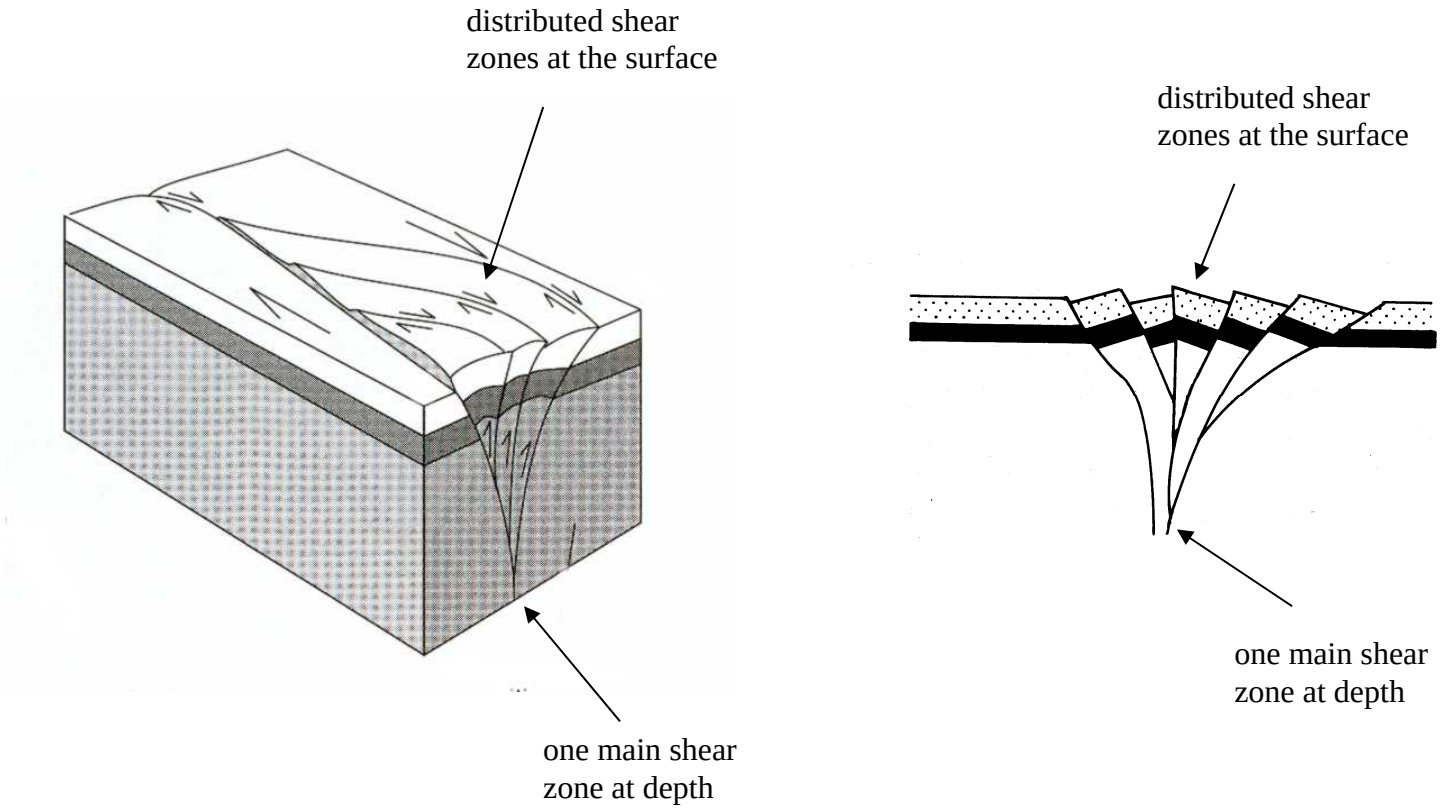


Figure 6.8. Typically shear zones have one main shear zone at depth, and then disperse into a number of shear zones at the surface. Figures taken from Twiss and Moores (1992) and Park (1997) respectively.

Chapter 7 – Summary and Synthesis

7.1. SUMMARY

7.1.1. Overview

The high levels of mercury (Hg) found in the fish and loons in Kejimkujik National Park (KNP) have prompted a number of studies on the distribution and migration of Hg in the park over the last 5-10 years. Typically, Hg contamination in remote locations such as KNP is attributed to atmospheric deposition. However, the levels of Hg in the atmosphere are only in the low to moderate range, indicating that atmospheric Hg levels might not be high enough to explain the anomalous levels found in the biota (Beauchamp et al., 1998a, b).

This study is three-fold: (1) Various combinations of published Hg data sets from within the park are integrated into a common GIS format in order to investigate the significance of geochemical trends and correlations. (2) Bedrock samples, in particular the biotite-rich rocks (which are thought to contain more Hg than the muscovite-rich rocks), were collected and analyzed for Hg. (3) Shear zones located in and around the park, in particular the East Kemptville and Tobeatic shear zones, were identified using a DEM model. These shear zones were then tested for Hg by placing Hg vapor units perpendicular to the strike of the shear zones.

7.1.2. Overview of Methods

7.1.2.1. GIS Study

In order to examine and interpret correlations and relationships between various mercury (Hg) data sets that have been gathered in the park, the data sets were collected from the various authors, incorporated into a common GIS format, and correlation coefficients for various combinations were calculated and interpreted.

Collecting the Data: In July, 2000, the Toxic Substance Research Initiative (TSRI) team released a CD-ROM containing a number of Hg data sets for the park (Rencz, 2000, CD-ROM). These data, along with various data sets from the Centre of Geographical Sciences (COGS), Nova Scotia Department of Natural Resources (NSDNR), and Nova

Scotia Department of the Environment (NSDOE), have been made available for this study.

Incorporating the Data into a GIS: Sixteen data sets were incorporated into one database using the watersheds as a common field. One value was assigned to each watershed in the park for each parameter (e.g. each watershed has one value for Hg in yellow perch, one value for Hg in loons, one value for Hg in red maples, one value for Fe in red maples, etc). A total of 125 attributes were extracted from the 16 data sets for each watershed in the park. The data sets were integrated using SPANS®, ARC/INFO® v.7.2.1, ArcView GIS® v.3.2, and Microsoft Excel® 97 (all software was made available by COGS).

Calculating Correlation Coefficients: Once the GIS database was created, correlations were calculated between: (1) Hg fields, (2) Hg fields and other element fields (e.g. Al, Fe, Au, etc.), and (3) Hg fields and non-element fields (e.g. pH, alkalinity, water color, etc). All correlation coefficients were calculated in Microsoft Excel® 97 using Pearson's product moment correlation coefficient (*r*; Wheater and Cook, 2000). The significance of the correlation was investigated using statistical methods described in Wheater and Cook (2000).

7.1.2.2. Bedrock Study

Thirty fresh bedrock samples were gathered throughout southwest Nova Scotia from different sampling locations and analyzed for Hg, as well as major and selected trace elements. Nine of these samples were taken from biotite-rich granite, nine from muscovite-rich granite, and eleven from mafic (gabbroic) intrusions.

7.1.2.3. Shear Zone Study

KNP has little bedrock exposure and very limited road access. Shear zone traces were identified using a high-resolution (20-meter) shaded relief map that was constructed using DEM data from the Nova Scotia Geomatics Centre (NSGC). The shaded relief map was constructed using PCI (image-processing software), available at COGS.

Once the location of the shear zone traces were interpreted, 94 Hg vapor units were placed across four chosen northwest-southeast trending lines (covering ~ 22.5 km). Mercury vapor units are characterized by a silver strip collector, which amalgamates Hg onto its surface. These units have been used in previous studies to investigate correlations between vertical structures and anomalous Hg levels in soil gas in Nevada (Rehn and Rehn, 1996).

7.1.3. Results

7.1.3.1. GIS Study

(1) The highest Hg values in the park are found in lakes that are underlain by biotite-bearing granite *and* have moderate-high percentages of wetlands.

(2) There are significant negative correlations of Hg in fish and Hg in surface water with lake alkalinity and pH, and significant positive correlations with lake color and dissolved organic content (DOC).

(3) There are significant positive correlations of Hg with Fe (lake sediment) and Hg with Al and Fe (surface water).

(4) The lake sediment data set shows that the highest Hg in lake sediment values are obtained in an area underlain by biotite-rich granite; intermediate values are underlain by muscovite-rich granite; and the lowest values are underlain by the Halifax and Goldenville groups.

7.1.3.2. Bedrock Study

(1) The biotite-rich granites have higher Hg levels than the muscovite-rich granites.

(2) The granite sample that yielded the highest Hg value was from the Boot Lake Granodiorite, which has the highest modal percentage of biotite (up to 32%) in the entire batholith.

(3) Mercury shows a significant positive correlation with Ca, Co, Fe, Ga, Mg, Mn, Mo, S, Sr, Te, and V. By comparison, Smith (2000) showed that there are significant correlations between Hg and Ca, Cd, Co, Cr, Fe, Mg, Ni, Sb, Sr, and V. Some of these elements (e.g. Ca, Cr, Fe, Mg, Ni, Sr, and V) typically have

high concentrations in mafic rocks, suggesting a possible relationship between diabase dykes and Hg content.

7.1.3.3. Structural Controls

(1) There is a positive association of Hg vapor with the inferred trace of the Tobeatic Shear Zone (TSZ) and with the Goldenville-Halifax Transition Zone (GHT).

7.2. SYNTHESIS

The data from this thesis indicates that: (1) Hg is associated with biotite, (2) the breakdown of biotite releases Hg to the environment, (3) wetlands provide an extra source of Hg to lakes via DOC, and (4) Hg vapor is being released from structural features in the park (i.e. the TSZ and GHT). These ideas have implications for the budget, release, and distribution of Hg in the park.

7.2.1. Hg and Biotite

The evidence presented in this thesis supports the idea that Hg is associated with biotite:

(1) Results from this thesis show that Hg levels are higher in biotite-rich granites than muscovite-rich granites.

(2) Of all the granite samples analyzed for Hg, the Boot Lake Granodiorite yielded the highest Hg levels. The Boot Lake Granodiorite has the highest modal percentage of biotite in the entire batholith.

(3) In whole rock analyses, there is a positive relationship of Hg with Fe and Mg. Smith's (2000) results show a similar pattern.

These basic results are in broad agreement with those of Smith (2000), which show that the biotite separates taken from the granite have Hg levels that are consistently above the average Hg value for southwest Nova Scotia.

7.2.2. Hg and the Breakdown of Biotite

The evidence presented in this thesis indicates that Hg is released by the breakdown of biotite:

(1) The highest Hg values in lake sediment are in lakes that are underlain by biotite-rich granite. Lake sediment chemistry is generally related to the underlying geology.

(2) There are four lakes in KNP that consistently yield high Hg levels. All of these lakes are underlain by muscovite-biotite monzogranite.

(3) There is a positive correlation of Hg with Fe and Al in surface water.

(4) Divalent Hg (Hg^{2+}) probably resides in relatively high energy sites within the biotite structure (i.e. in interlayer sites or in crystal defects). Thus Hg is probably very mobile, especially if the biotite structure breaks down during weathering.

These results are in basic agreement with the preliminary results of A.-M. O'Beirne-Ryan (Ph.D. thesis in progress, Dalhousie University) which suggest that Hg is slightly depleted in weathered granites.

7.2.3. Hg and Wetlands

The evidence presented in this thesis supports the idea that wetlands provide an extra source of Hg to lakes via DOC:

(1) There is a positive correlation between Hg and DOC in lakes (e.g. Meili, 1994), and this relationship is also found in the Kejimkujik lakes. Mercury commonly travels into a lake with DOC (various authors in Johansson and Iverfelt, 1994), and large amounts of DOC enter a lake from upstream wetlands. Therefore, as DOC levels increase in a lake, so will Hg levels.

An excellent example of the positive relationship between Hg in lakes, wetlands and underlying granite occurs in Big Dam West Lake. Big Dam West and Big Dam East are lakes that are adjacent to one another in the northern part of the park. Big Dam West Lake is half underlain by biotite monzogranite, has a higher percentage of wetlands, and has higher levels of DOC. Big Dam East Lake is underlain completely by metasedimentary rocks, has a lower percentage of wetlands, and has lower levels of

DOC. In general, mercury levels in Big Dam West Lake are significantly higher than Hg levels in Big Dam East Lake.

7.2.4. Hg Vapor and Structural Features

The positive association of Hg vapor with the TSZ and the GHT provides evidence that structural features may influence the Hg budget in the park.

7.2.5. The Implications of Geological Sources of Hg in KNP

The data presented in this thesis indicate the importance of geological contributions of Hg to the Kejimkujik system.

7.2.5.1. Granites

Although granites contain relatively low levels of Hg (when compared to the organic slates and mafic intrusions), these data suggest that they release more Hg than the metasedimentary rocks in the park. However the Hg contamination from granites may not be limited to watersheds underlain by biotite-bearing granite. The park is bordered to the north and west by the topographically elevated biotite monzogranite (see shaded relief map in Appendix 6.1). As weathering of this granite releases Hg^{2+} (which is soluble in water), drainage from this elevated area transports the Hg into the park, and some of this Hg inevitably ends up in the Kejimkujik lakes.

Even though there might be extra Hg in the KNP system, it doesn't mean that Hg will enter the food chain. In order for Hg to enter the food chain, it must be methylated. For methylation to occur, organic rich, oxygen depleted conditions are required. KNP has abundant wetlands, which are large sources of organics. The wetlands provide significant amounts of organics (i.e. DOC), Hg, and MeHg to downstream lakes. For example, Hg in a wetland binds to DOC and travels with the DOC to lakes (Johansson and Iverfeldt, 1994). Wetlands convert large amounts of Hg^{2+} to MeHg, and runoff from wetlands moves this MeHg to downstream lakes (Branfireun et al., 1999)). Therefore wetlands can either provide MeHg directly to lakes, or they can provide the lakes with the high organic content and Hg^{2+} they require to produce their own MeHg.

7.2.5.2. Structural Controls

The association of Hg vapor with the TSZ and the GHT provides a further geological source of Hg. In order for the Hg vapor units to pick up Hg, the Hg must be volatile (i.e. implying that it is being released from the TSZ and GHT).

TSZ: The TSZ is associated with epithermal type mineralization (Corey, 1994). Mercury-bearing minerals and sulphides are commonly associated with epithermal type settings (Krupp, 1988). If groundwater and surface water percolates through the shear zones, then weathering in the shear zones could be releasing Hg. In addition, these structural zones may be areas of enhanced biotite weathering.

GHT: The GHT is associated with large amounts of sulphides and Hg enrichment is present in some sulphide-rich layers of the GHT (P. K. Smith, personal communication, May 2, 2001). A study in Finland suggests that sulphide oxidation from black shale formations might be the cause of Hg contamination in fish (Loukola-Ruskeeniemi, 1992 in Fox, 1999). Previous studies show that the sulphides are oxidizing (i.e. acid rock drainage; Fox, 1999), and if Hg is associated with the sulphides it is probably being released to the environment.

The TSZ transects the southern part of the park, and the GHT is located to the south of the park where Hg data have not been collected. Mercury values tend to be relatively low in the southern watersheds and in the biota. The TSZ may be releasing significant amounts of Hg to the environment, however unless there is a trapping mechanism close by (e.g. wetlands), the Hg is probably escaping, either through volatilization or through drainage.

7.2.5.3. Summary

The data indicate that rocks and shear zones release Hg^0 and Hg^{2+} to the environment through natural processes such as weathering and degassing. However, for Hg to be absorbed by biota, it needs to be in a methylated form.

In order for Hg to build up in a watershed and in the biota, there needs to be (1) a source of Hg (e.g. granites or shear zones), (2) a trapping mechanism that will keep the

Hg in the watershed (e.g. wetlands), and (3) conditions that favor the formation of MeHg (e.g. high DOC). In KNP, several watersheds that meet all of these conditions tend to have higher levels of Hg and MeHg in their lakes and biota.

7.3. FUTURE WORK

Few studies involving Hg contamination consider the geological inputs of Hg to the environment. As a result, there is very little data on typical Hg levels in rocks, minerals, and structural features, and few measurements on the release of Hg from them. Therefore, future work should include the following:

(1) Determine which rock-forming minerals contain Hg and how Hg partitions into those minerals.

(2) Determine how much Hg is being released to the environment from geological sources (rocks, shear zones etc), and at what rate. An attempt is currently being made by the TSRI team to establish a method to measure the amount of Hg that is released from different rock types in the park.

(3) Further studies using Hg vapor units should be done to further test the ability of these units to determine Hg release into the environment. In addition, units should be placed over the granite to see if this rock unit is releasing Hg vapor. T. Goodwin and P. K. Smith (NSDNR) are currently placing more Hg units throughout the park.

(4) Further studies, including bedrock sampling, till sampling, and soil sampling should be conducted over the shear zones.

(5) Studies should include areas outside the park to determine the extent of Hg contamination. In particular, loons and fish that are found in watersheds that are underlain by biotite-rich granite and have large percentages of wetlands should be tested for Hg.

(6) Studies should be conducted on the GHT to see if Hg is associated with the sulphide minerals.

(7) As further data sets are gathered in the park, they should be combined into a common database so relationships can be established.

APPENDIX 4.1

Lake Name	Easting Nad83	Northing Nad83	Adult Loon Blood (ug/g)	Juvenile Loon Blood (ug/g)	Adult Loon Feathers (ug/g)
Frozen Ocean	313020	4924541	5.74	0.55	18.55
Pebbleloggitch	312490	4908016	9999.00	9999.00	9999.00
Big Red	310328	4913191	9999.00	9999.00	9999.00
Poplar	305778	4914145	9999.00	9999.00	9999.00
Big Dam East	319758	4924306	9999.00	9999.00	9999.00
Peskawa	311723	4910022	6.56	9999.00	16.95
Big Dam West	317825	4925517	4.56	9999.00	9.25
Channel	316276	4922422	9999.00	9999.00	9999.00
Hilchemakaar	321555	4906425	4.71	9999.00	21.87
Cobrielle	321587	4909312	5.66	0.58	14.60
Mountain	319476	4910804	9999.00	9999.00	9999.00
Loon	325398	4909950	9999.00	9999.00	9999.00
Kejimkujik	322340	4914994	7.17	0.59	15.67
Peskowesk	317698	4909292	9999.00	9999.00	9999.00
Luxton	313075	4914832	9999.00	1.29	9999.00
North Cranberry	321919	4911257	9999.00	9999.00	9999.00
Beaverskin	313931	4908537	9999.00	0.51	9999.00
Back	318892	4907065	2.88	0.38	8.64
Puzzle	322146	4910233	9999.00	9999.00	9999.00
Grafton	326667	4917092	9999.00	9999.00	9999.00
Liberty	306532	4917711	9999.00	9999.00	9999.00
Lower Silver	319869	4906725	9999.00	9999.00	9999.00
George	323852	4911959	4.31	9999.00	22.50
Upper Silver	320729	4905859	9999.00	9999.00	9999.00

* 9999 indicates no data

Lake Name	Wperch Avg Conc/Wt (%)	Wperch Avg Conc/Lgth (%)	Yperch Avg Conc/Wt (%)	Yperch Avg Conc/Lgth (%)	Trout Avg Conc/Wt (%)
Frozen Ocean	9999.000	9999.000	1.358	1.983	0.135
Pebbleloggitch	9999.000	9999.000	1.176	1.315	9999.000
Big Red	9999.000	9999.000	2.719	3.840	9999.000
Poplar	9999.000	9999.000	1.684	2.569	9999.000
Big Dam East	9999.000	9999.000	1.169	1.514	9999.000
Peskawa	9999.000	9999.000	1.938	2.083	0.087
Big Dam West	9999.000	9999.000	1.467	1.886	0.121
Channel	9999.000	9999.000	1.864	1.905	9999.000
Hilchemakaar	0.198	2.624	1.225	1.875	0.079
Cobrielle	9999.000	9999.000	0.756	1.746	9999.000
Mountain	9999.000	9999.000	1.307	1.701	9999.000
Loon	9999.000	9999.000	1.126	1.975	9999.000
Kejimkujik	0.314	3.848	2.061	2.452	0.205
Peskowesk	9999.000	9999.000	1.744	2.174	0.081
Luxton	9999.000	9999.000	2.697	3.053	9999.000
North Cranberry	9999.000	9999.000	2.007	2.861	9999.000
Beaverskin	9999.000	9999.000	1.298	1.626	9999.000
Back	9999.000	9999.000	0.845	1.047	9999.000
Puzzle	9999.000	9999.000	1.865	1.937	9999.000
Grafton	0.274	4.097	1.293	1.802	0.205
Liberty	9999.000	9999.000	1.915	2.343	9999.000
Lower Silver	9999.000	9999.000	1.833	1.602	9999.000
George	9999.000	9999.000	1.336	2.159	0.107
Upper Silver	9999.000	9999.000	1.278	1.280	9999.000

Lake Name	Trout Avg Conc/Lgth (%)	Perch Tot Hg (10cm)	Perch Tot Hg (20cm)	SW Alkalinity (mg/L)	SW pH	SW Color (Hazens)
Frozen Ocean	1.486	0.1570301	0.6843575	-0.27	4.8	97
Pebbleloggitch	9999.000	0.1328324	0.2205281	-1.27	4.5	101
Big Red	9999.000	0.3748806	0.7708910	-2.54	4.3	155
Poplar	9999.000	0.2401397	0.5751406	-0.52	4.8	51
Big Dam East	9999.000	0.1345188	0.5119211	0.92	5.9	21
Peskawa	1.089	0.1893991	0.6403656	-0.77	4.7	61
Big Dam West	1.023	0.1687917	0.7178786	0.07	5.0	94
Channel	9999.000	0.1741510	0.7230794	-0.53	4.7	107
Hilchemakaar	1.134	0.1445377	0.5909368	0.70	5.4	53
Cobrielle	9999.000	0.1570565	0.4306020	0.08	5.3	36
Mountain	9999.000	0.1480683	0.4893189	0.18	5.4	25
Loon	9999.000	0.1793449	0.5060681	-0.02	5.1	63
Kejimkujik	1.867	0.2262252	0.6622638	-0.03	5.0	72
Peskowesk	0.784	0.1982741	0.5007097	-0.60	4.8	39
Luxton	9999.000	0.2840586	0.6884747	-0.69	4.7	51
North Cranberry	9999.000	0.2638214	0.7435326	-0.12	5.1	29
Beaverskin	9999.000	0.1434667	0.4785761	-0.06	5.3	12
Back	9999.000	0.0941146	0.2498371	0.24	5.3	28
Puzzle	9999.000	0.1788154	0.5031703	0.09	5.3	20
Grafton	2.016	0.1494270	0.6666364	1.12	5.8	47
Liberty	9999.000	0.2370653	0.4616449	0.02	5.3	31
Lower Silver	9999.000	0.1652787	0.2132441	0.74	5.7	25
George	0.900	0.1654013	0.7568834	-0.21	5.0	63
Upper Silver	9999.000	0.1147453	0.4119410	0.85	5.9	21

Lake Name	SW Specific Conductance (uS/cm)	SW Total Organic Carbon (mg/L)	SW Dissolved Cl (mg/L)	SW Dissolved SO_4 (mg/L)
Frozen Ocean	29.0	10.7	4.26	1.68
Pebbleloggitch	30.1	11.2	3.46	1.87
Big Red	38.5	17.0	3.61	1.77
Poplar	26.5	6.8	3.79	2.07
Big Dam East	23.8	3.7	4.06	1.80
Peskawa	26.9	7.4	3.62	1.93
Big Dam West	30.1	10.5	4.84	1.69
Channel	29.0	12.2	3.85	1.53
Hilchemakaar	25.5	5.7	3.67	2.07
Cobrielle	21.8	3.9	3.61	1.78
Mountain	21.5	3.7	3.51	1.73
Loon	27.9	6.9	4.60	2.05
Kejimkujik	28.1	7.9	4.45	1.93
Peskowesk	24.7	5.5	3.65	1.97
Luxton	26.5	7.5	3.57	2.03
North Cranberry	21.1	4.5	3.27	1.74
Beaverskin	21.8	2.6	3.75	1.91
Back	21.7	4.1	3.56	1.86
Puzzle	20.6	3.6	3.41	1.69
Grafton	32.0	6.1	5.62	2.26
Liberty	22.9	4.5	3.88	1.81
Lower Silver	20.9	3.3	3.61	1.72
George	27.9	11.7	4.45	2.00
Upper Silver	21.7	3.3	3.62	1.92

Lake Name	SW Total N_2 (mg/L)	SW Dissolved Na (mg/L)	SW Dissolved K (mg/L)	SW Dissolved Ca (mg/L)	SW Dissolved Mg (mg/L)
Frozen Ocean	0.111	3.15	0.291	0.543	0.347
Pebbleloggitch	0.118	2.54	0.218	0.300	0.295
Big Red	0.127	2.72	0.324	0.255	0.304
Poplar	0.079	2.75	0.250	0.331	0.314
Big Dam East	0.071	2.93	0.210	0.606	0.381
Peskawa	0.099	2.67	0.259	0.274	0.276
Big Dam West	0.111	3.52	0.307	0.641	0.364
Channel	0.113	2.90	0.268	0.520	0.338
Hilchemakaar	0.100	2.69	0.223	0.768	0.375
Cobrielle	0.078	2.55	0.201	0.354	0.300
Mountain	0.071	2.49	0.207	0.416	0.288
Loon	0.083	3.19	0.277	0.623	0.376
Kejimkujik	0.090	3.14	0.303	0.616	0.370
Peskowesk	0.095	2.60	0.246	0.305	0.281
Luxton	0.088	2.67	0.274	0.260	0.290
North Cranberry	0.102	2.34	0.176	0.422	0.292
Beaverskin	0.063	2.63	0.223	0.302	0.309
Back	0.081	2.46	0.277	0.447	0.311
Puzzle	0.093	2.26	0.238	0.383	0.290
Grafton	0.120	3.89	0.224	0.953	0.489
Liberty	0.077	2.75	0.247	0.344	0.309
Lower Silver	0.098	2.50	0.328	0.515	0.303
George	0.083	3.14	0.263	0.585	0.359
Upper Silver	0.073	2.57	0.289	0.607	0.315

Lake Name	SW Extractable Al (mg/L)	SW Extractable Fe (mg/L)	SW Extractable Mn (mg/L)	SW Total Hg - unfiltered (ng/L)
Frozen Ocean	0.195	0.178	0.015	4.80
Pebbleloggitch	0.213	0.163	99999.000	4.75
Big Red	0.211	0.165	0.010	7.40
Poplar	0.202	0.165	0.010	4.75
Big Dam East	0.072	0.036	0.013	2.78
Peskawa	0.237	0.178	0.014	3.80
Big Dam West	0.198	0.165	0.015	5.01
Channel	0.200	0.194	0.018	5.03
Hilchemakaar	0.094	0.124	0.018	3.18
Cobrielle	0.099	0.076	0.024	2.60
Mountain	0.117	0.079	0.027	1.78
Loon	0.145	0.173	0.029	3.87
Kejimkujik	0.158	0.197	0.031	3.54
Peskowesk	0.224	0.134	0.019	2.74
Luxton	0.270	0.215	0.010	4.54
North Cranberry	0.081	0.070	0.010	1.93
Beaverskin	0.039	0.015	0.013	1.54
Back	0.079	0.057	0.020	2.44
Puzzle	0.061	0.105	0.035	0.87
Grafton	0.080	0.260	0.108	4.28
Liberty	0.155	0.142	0.017	2.85
Lower Silver	0.047	0.040	0.020	1.53
George	0.132	0.160	0.030	4.19
Upper Silver	0.056	0.022	99999.000	1.83

Lake Name	Lake Sediment Hg (mg/kg)	PC Lake Elevation (m)	PC Surface Area (hectares)	PC Total Catchment Area (km^2)	PC Volume (m^3)
Frozen Ocean	0.03	105	228.0	116.0	4241000
Pebbleloggitch	0.19	120	33.4	1.6	474000
Big Red	0.12	160	70.5	8.0	704000
Poplar	9999.00	170	82.5	5.6	-9999
Big Dam East	0.11	120	45.5	2.0	1055000
Peskawa	0.13	120	388.0	66.0	12249000
Big Dam West	0.06	120	105.0	40.0	2593000
Channel	0.11	100	68.4	128.0	779760
Hilchemakaar	0.09	105	95.4	3.8	1924000
Cobrielle	0.09	120	132.0	11.5	2595000
Mountain	0.16	120	136.0	8.2	5790000
Loon	0.14	85	73.8	726.0	1471000
Kejimkujik	0.16	90	2435.0	682.0	106017000
Peskowesk	0.19	105	685.0	85.0	26356000
Luxton	0.14	135	47.1	4.7	1420000
North Cranberry	0.08	105	34.3	3.6	498000
Beaverskin	0.05	120	39.5	1.0	864000
Back	0.13	100	78.4	4.1	1706000
Puzzle	0.08	120	33.7	2.1	911000
Grafton	0.17	100	270.0	53.0	7440000
Liberty	0.12	135	73.3	2.0	-9999
Lower Silver	0.07	105	24.7	1.6	451000
George	0.09	90	77.8	687.0	1825000
Upper Silver	0.05	90	24.3	0.9	566000

Lake Name	PC Mean Depth (m)	PC Max Depth (m)	PC Shoreline Length (km)	PC Flushing Rate (times/yr)	Tot Hg dragonfly larvae (ug/g)
Frozen Ocean	1.9	7.6	12.7	23.2	9999.000
Pebbleloggitch	1.4	2.5	4.4	2.9	0.026
Big Red	1.0	2.2	9.1	9.6	9999.000
Poplar	9999.0	9999.0	7.5	9999.0	9999.000
Big Dam East	2.3	4.2	5.0	1.6	0.029
Peskawa	3.2	9.0	18.2	4.6	9999.000
Big Dam West	2.5	9.5	6.1	13.1	0.042
Channel	1.1	1.8	6.1	138.6	9999.000
Hilchemakaar	2.0	7.3	12.4	1.7	9999.000
Cobrielle	2.0	6.3	12.7	3.8	9999.000
Mountain	4.3	14.3	13.7	1.2	9999.000
Loon	2.0	8.5	9.6	418.0	9999.000
Kejimkujik	4.4	19.2	95.4	5.5	0.028
Peskowesk	3.8	13.0	29.1	2.7	0.028
Luxton	3.0	8.5	6.1	2.8	9999.000
North Cranberry	1.4	5.0	4.9	6.1	0.026
Beaverskin	2.2	6.3	5.4	1.0	0.028
Back	2.2	5.8	8.6	2.0	9999.000
Puzzle	2.7	6.1	4.6	2.0	9999.000
Grafton	2.8	10.0	34.8	6.0	0.017
Liberty	9999.0	9999.0	6.0	9999.0	9999.000
Lower Silver	1.8	5.3	3.7	3.0	9999.000
George	2.4	8.5	8.8	319.0	9999.000
Upper Silver	2.3	5.8	3.5	1.4	9999.000

Lake Name	Tot Hg Unfiltered (ng/L)	Tot Hg Filtered (ng/L)	MeHg Unfiltered (ng/L)	MeHg Filtered (ng/L)	AR H2O Date	AR H2O Time
Frozen Ocean	9999.00	9999.00	9999.000	9999.000	11/4/1997	morning
Pebbleloggitch	3.59	3.02	0.082	0.097	11/3/1997	afternoon
Big Red	9999.00	9999.00	9999.000	9999.000	11/4/1997	morning
Poplar	9999.00	9999.00	9999.000	9999.000	11/4/1997	afternoon
Big Dam East	9999.00	9999.00	9999.000	9999.000	11/4/1997	morning
Peskawa	9999.00	9999.00	9999.000	9999.000	11/3/1997	afternoon
Big Dam West	2.93	2.49	0.113	0.084	11/4/1997	morning
Channel	9999.00	9999.00	9999.000	9999.000	11/4/1997	morning
Hilchemakaar	9999.00	9999.00	9999.000	9999.000	11/5/1997	noon
Cobrielle	9999.00	9999.00	9999.000	9999.000	11/5/1997	morning
Mountain	9999.00	9999.00	9999.000	9999.000	11/5/1997	noon
Loon	9999.00	9999.00	9999.000	9999.000	11/5/1997	morning
Kejimkujik	9999.00	9999.00	9999.000	9999.000	11/4/1997	morning
Peskowesk	9999.00	9999.00	9999.000	9999.000	11/5/1997	noon
Luxton	9999.00	9999.00	9999.000	9999.000	11/4/1997	morning
North Cranberry	1.11	0.90	0.093	0.051	11/5/1997	morning
Beaverskin	0.65	0.48	0.039	0.034	11/3/1997	afternoon
Back	9999.00	9999.00	9999.000	9999.000	11/3/1997	afternoon
Puzzle	9999.00	9999.00	9999.000	9999.000	11/5/1997	morning
Grafton	9999.00	9999.00	9999.000	9999.000	11/4/1997	afternoon
Liberty	9999.00	9999.00	9999.000	9999.000	11/4/1997	afternoon
Lower Silver	9999.00	9999.00	9999.000	9999.000	11/3/1997	afternoon
George	9999.00	9999.00	9999.000	9999.000	11/5/1997	morning
Upper Silver	9999.00	9999.00	9999.000	9999.000	11/5/1997	noon

Lake Name	AR H2O Color	AR H2O Temp	AR H2O pH	AR H2O DO	AR H2O Conductivity	AR H2O Alkalinity	AR H2O Turbulence
Frozen Ocean	clear	9.1	4.97	11.01	0.023	0.0	2
Pebbleloggitch	brown	10.7	4.32	10.82	0.025	0.0	4
Big Red	clear, brown	9.7	4.17	10.78	0.035	0.0	2
Poplar	clear	9.3	4.57	11.07	0.025	0.0	0
Big Dam East	clear	9.2	5.82	10.96	0.021	2.9	0
Peskawa	brown	9.2	4.64	11.09	0.020	0.0	1
Big Dam West	clear	9.1	5.20	11.05	0.025	1.0	3
Channel	clear	9.9	4.72	10.79	0.025	0.0	5
Hilchemakaar	clear	9.9	5.69	11.43	0.021	2.0	9999
Cobrielle	clear	9.5	5.34	11.02	0.018	1.0	9999
Mountain	clear	9.5	5.20	10.95	0.017	1.9	9999
Loon	clear, brown	9.7	5.23	10.71	0.022	1.2	9999
Kejimkujik	clear	9.2	5.15	11.00	0.022	0.0	0
Peskowesk	clear	9.2	4.86	11.23	0.020	0.0	9999
Luxton	clear	9.5	4.63	10.90	0.021	0.0	0
North Cranberry	clear	9.8	5.08	10.64	0.019	0.0	9999
Beaverskin	brown, clear	10.0	5.23	10.77	0.017	1.9	0
Back	brown, clear	10.1	5.46	11.21	0.017	3.4	2
Puzzle	clear	9.4	5.26	10.73	0.017	1.0	9999
Grafton	clear	9.5	6.09	10.78	0.031	1.5	1
Liberty	clear	9.1	5.37	11.05	0.019	1.4	0
Lower Silver	brown, clear	10.5	5.90	10.87	0.017	3.6	53
George	clear, brown	9.4	5.21	10.78	0.022	1.6	9999
Upper Silver	clear	9.5	5.94	10.84	0.019	1.7	9999

Lake Name	AR H2O DOC ppm	AR H2O Hg ppb	AR H2O Al^{27} ppb	AR H2O Fe^{54} ppb	AR H2O Mn^{55} ppb	AR H2O Co^{59} ppb	AR H2O Cu^{65} ppb
Frozen Ocean	5.64	0.008	121.4	152	16.61	0.101	0.28
Pebbleloggitch	7.06	0.003	169.8	116	8.19	0.077	1.02
Big Red	13.14	0.005	175.3	133	5.66	9999.000	0.51
Poplar	3.71	9999.000	102.4	60	9.48	0.071	0.24
Big Dam East	2.89	9999.000	14.1	23	4.98	9999.000	0.49
Peskawa	4.09	9999.000	134.9	51	18.61	0.114	0.18
Big Dam West	5.60	0.003	112.2	115	11.85	0.058	0.38
Channel	7.27	0.003	124.6	163	15.04	0.094	0.36
Hilchemakaar	3.72	9999.000	41.3	40	8.70	9999.000	1.76
Cobrielle	2.02	9999.000	15.7	19	11.12	9999.000	0.94
Mountain	2.66	9999.000	49.3	37	21.38	9999.000	1.56
Loon	4.20	9999.000	81.6	127	21.48	0.078	0.95
Kejimkujik	4.72	9999.000	96.8	214	30.00	0.116	0.20
Peskowesk	3.55	9999.000	135.2	46	22.87	0.109	1.53
Luxton	3.85	0.006	126.7	31	8.05	0.070	0.13
North Cranberry	2.89	9999.000	31.4	15	11.84	9999.000	0.84
Beaverskin	2.18	9999.000	9.2	11	5.86	9999.000	0.47
Back	3.03	9999.000	26.4	30	14.26	9999.000	1.11
Puzzle	2.85	9999.000	20.2	22	11.60	9999.000	1.07
Grafton	4.07	9999.000	36.7	246	76.38	0.067	0.34
Liberty	2.89	9999.000	51.4	66	9.93	9999.000	0.13
Lower Silver	3.27	0.000	15.5	18	4.37	9999.000	0.63
George	4.39	9999.000	91.3	133	24.54	0.168	1.64
Upper Silver	3.27	9999.000	16.4	15	5.24	9999.000	1.88

Lake Name	AR H2O Zn^{66} ppb	AR H2O As^{75} ppb	AR H2O Rb^{85} ppb	AR H2O Sr^{88} ppb	AR H2O Y^{89} ppb	AR H2O Ag^{107} ppb
Frozen Ocean	1.21	0.25	1.292	3.21	0.050	9999.000
Pebbleloggitch	1.88	0.28	0.936	2.85	0.064	9999.000
Big Red	1.62	0.31	1.343	2.37	0.072	9999.000
Poplar	1.18	0.17	1.018	2.99	0.047	9999.000
Big Dam East	0.62	0.33	0.665	4.87	0.014	9999.000
Peskawa	1.08	9999.00	0.978	2.42	0.044	9999.000
Big Dam West	2.59	0.35	1.221	3.81	0.062	9999.000
Channel	1.36	0.29	1.107	3.89	0.053	9999.000
Hilchemakaar	1.88	0.41	0.661	5.86	0.035	0.163
Cobrielle	2.15	0.23	0.738	3.56	9999.000	0.210
Mountain	3.20	0.26	0.757	3.33	0.026	0.998
Loon	1.97	0.31	0.849	3.89	0.047	0.156
Kejimkujik	1.02	0.29	0.887	3.55	0.059	9999.000
Peskowesk	3.60	0.17	0.994	3.03	0.063	1.342
Luxton	1.25	0.13	1.119	2.63	0.040	9999.000
North Cranberry	2.13	0.55	0.566	4.67	0.016	0.114
Beaverskin	1.47	9999.00	0.647	2.92	9999.000	9999.000
Back	1.98	0.30	0.831	4.16	0.014	9999.000
Puzzle	2.26	0.41	0.696	3.90	0.014	0.187
Grafton	0.73	0.86	0.551	5.60	0.024	9999.000
Liberty	0.86	0.10	0.953	3.14	0.030	9999.000
Lower Silver	1.85	0.25	0.774	4.85	0.014	9999.000
George	2.73	0.36	0.925	3.69	0.059	0.180
Upper Silver	2.73	0.40	0.768	5.50	0.018	0.901

Lake Name	AR H2O Cd^{114} ppb	AR H2O Pb^{208} ppb	AR H2O U^{238} ppb	Lks77 Copper	Lks77 Nickel	Lks77 Lead	Lks77 Zinc	Lks77 Cobalt
Frozen Ocean	9999.000	0.187	0.0307	1.00	2.80	5.20	20.00	1.00
Pebbleloggitch	0.072	0.417	0.0445	4.00	2.40	4.40	10.00	1.00
Big Red	9999.000	0.409	0.0401	6.00	1.00	4.00	10.00	1.00
Poplar	9999.000	0.230	0.0126	6.00	4.00	3.60	30.00	1.00
Big Dam East	9999.000	0.068	0.0058	6.00	19.20	6.00	60.00	2.80
Peskawa	9999.000	0.194	0.0256	6.00	4.80	9.60	20.00	1.00
Big Dam West	9999.000	0.214	0.0314	6.00	12.00	3.60	40.00	1.00
Channel	9999.000	0.250	0.0151	6.00	18.00	4.00	20.00	1.00
Hilchemakaar	0.207	0.621	0.0061	6.00	6.00	4.80	30.00	2.40
Cobrielle	0.226	0.522	9999.0000	6.00	8.40	6.40	60.00	4.00
Mountain	0.287	0.759	0.0131	6.00	12.80	6.40	20.00	1.00
Loon	0.229	0.686	0.0174	6.00	9.20	8.80	70.00	3.00
Kejimkujik	9999.000	0.205	0.0258	6.29	16.29	7.20	50.00	1.97
Peskowesk	0.347	0.981	0.0293	6.67	11.73	6.53	36.67	2.00
Luxton	9999.000	0.182	0.0154	8.00	17.60	8.40	20.00	1.00
North Cranberry	0.213	0.537	9999.0000	8.00	5.20	8.80	30.00	1.00
Beaverskin	0.060	0.080	9999.0000	8.00	11.20	4.40	50.00	2.80
Back	0.175	0.156	9999.0000	8.00	5.60	8.40	60.00	3.00
Puzzle	0.290	0.541	9999.0000	8.00	11.60	10.40	60.00	7.00
Grafton	9999.000	0.182	0.0058	8.00	42.80	13.20	160.00	78.00
Liberty	9999.000	0.118	0.0073	10.00	4.40	10.40	50.00	1.00
Lower Silver	9999.000	0.108	9999.0000	9999.00	9999.00	9999.00	9999.00	9999.00
George	0.227	0.676	0.0179	9999.00	9999.00	9999.00	9999.00	9999.00
Upper Silver	0.430	1.048	9999.0000	9999.00	9999.00	9999.00	9999.00	9999.00

Lake Name	Lks77 Iron	Lks77 Manganese	Lks77 Calcium	Lks77 Magnesium	Lks77 Molybdenum	Lks77 Mercury	Lks77 Uranium
Frozen Ocean	0.40	100.00	780.00	1160.00	2.00	0.34	1.90
Pebbleloggitch	0.20	20.00	220.00	160.00	1.00	0.48	4.30
Big Red	0.20	20.00	560.00	160.00	2.80	0.54	2.60
Poplar	0.20	40.00	580.00	400.00	2.80	0.40	3.20
Big Dam East	0.40	240.00	840.00	680.00	1.00	0.50	1.80
Peskawa	0.20	40.00	310.00	400.00	1.00	0.56	2.75
Big Dam West	0.60	200.00	760.00	1800.00	1.00	0.40	2.40
Channel	0.20	120.00	1000.00	840.00	1.00	0.32	1.80
Hilchemakaar	0.40	140.00	1480.00	900.00	1.00	0.20	0.80
Cobrielle	0.80	240.00	1060.00	1400.00	1.00	0.22	3.10
Mountain	0.20	600.00	1000.00	280.00	1.00	0.52	2.70
Loon	1.00	240.00	1000.00	1180.00	2.80	0.26	2.20
Kejimkujik	0.49	262.86	1174.29	2022.86	1.00	0.37	2.06
Peskowesk	0.40	86.67	626.67	546.67	2.00	0.45	3.27
Luxton	0.20	20.00	220.00	340.00	1.00	0.44	2.60
North Cranberry	0.20	40.00	1180.00	480.00	2.40	0.22	1.10
Beaverskin	0.20	140.00	460.00	440.00	1.00	0.52	2.30
Back	0.80	100.00	1600.00	520.00	4.00	0.26	10.20
Puzzle	0.80	120.00	2180.00	760.00	2.80	0.22	1.60
Grafton	5.40	800.00	1160.00	2680.00	2.80	0.32	1.80
Liberty	0.80	100.00	480.00	880.00	2.80	0.56	1.70
Lower Silver	9999.00	9999.00	9999.00	9999.00	9999.00	9999.00	9999.00
George	9999.00	9999.00	9999.00	9999.00	9999.00	9999.00	9999.00
Upper Silver	9999.00	9999.00	9999.00	9999.00	9999.00	9999.00	9999.00

Lake Name	Lks77 Arsenic	Wpine Mo ppm (avg wshed)	Wpine Cu ppm (avg wshed)	Wpine Pb ppm (avg wshed)	Wpine Zn ppm (avg wshed)
Frozen Ocean	2.70	0.6583	3.3450	1.1283	45.8833
Pebbleloggitch	2.00	0.0500	3.2500	0.2300	18.6000
Big Red	0.50	0.0250	4.4700	0.2250	32.5000
Poplar	5.20	9999.0000	9999.0000	9999.0000	9999.0000
Big Dam East	9.10	0.9000	3.3500	1.9500	23.4500
Peskawa	4.15	0.0433	2.9267	0.2700	39.5333
Big Dam West	3.00	0.6700	2.9950	1.0850	27.8500
Channel	0.50	9999.0000	9999.0000	9999.0000	9999.0000
Hilchemakaar	2.60	0.4400	3.4200	1.0667	34.2333
Cobrielle	4.00	0.9000	4.5000	2.2000	26.0000
Mountain	6.90	1.1500	3.5000	2.2500	29.9500
Loon	1.20	0.0433	6.1067	0.1800	24.3000
Kejimkujik	2.84	0.3392	3.0977	0.9638	32.2000
Peskowesk	5.63	0.5875	2.8475	1.1950	29.4000
Luxton	0.50	0.0200	2.5300	0.2900	23.3000
North Cranberry	4.80	0.8500	3.4500	1.7000	39.8500
Beaverskin	2.70	0.9000	3.6500	2.0000	45.0000
Back	4.80	0.6000	2.6000	1.3500	31.8500
Puzzle	16.40	1.0000	2.9000	1.4000	36.1000
Grafton	41.20	0.0450	4.8050	0.3100	33.7750
Liberty	1.60	9999.0000	9999.0000	9999.0000	9999.0000
Lower Silver	9999.00	9999.0000	9999.0000	9999.0000	9999.0000
George	9999.00	9999.0000	9999.0000	9999.0000	9999.0000
Upper Silver	9999.00	0.5000	2.8750	1.5750	25.7250

Lake Name	Wpine Ag ppb (avg wshed)	Wpine Mn ppm (avg wshed)	Wpine Fe % (avg wshed)	Wpine As ppm (avg wshed)
Frozen Ocean	28.0000	372.0000	0.0100	0.2500
Pebbleloggitch	1.0000	255.0000	9999.0000	9999.0000
Big Red	6.2500	196.2500	9999.0000	9999.0000
Poplar	9999.0000	9999.0000	9999.0000	9999.0000
Big Dam East	57.0000	317.5000	0.0100	0.2500
Peskawa	7.6667	123.3333	9999.0000	9999.0000
Big Dam West	16.0000	128.5000	0.0100	0.2500
Channel	9999.0000	9999.0000	9999.0000	9999.0000
Hilchemakaar	40.6667	459.6667	0.0100	0.2500
Cobrielle	64.0000	80.0000	0.0100	0.8000
Mountain	51.0000	116.0000	0.0100	0.4750
Loon	6.0000	635.3333	0.0100	9999.0000
Kejimkujik	20.6154	295.6154	0.0163	0.2500
Peskowesk	27.0000	148.2500	0.0100	0.2500
Luxton	8.0000	122.0000	9999.0000	9999.0000
North Cranberry	15.0000	96.5000	0.0100	0.4750
Beaverskin	35.0000	170.5000	0.0100	0.2500
Back	51.5000	216.5000	0.0100	0.2500
Puzzle	15.0000	643.0000	0.0100	0.2500
Grafton	9.5000	634.5000	0.0100	9999.0000
Liberty	9999.0000	9999.0000	9999.0000	9999.0000
Lower Silver	9999.0000	9999.0000	9999.0000	9999.0000
George	9999.0000	9999.0000	9999.0000	9999.0000
Upper Silver	51.7500	99.5000	0.0100	0.2500

Lake Name	Wpine U ppm (avg wshed)	Wpine Au ppb (avg wshed)	Wpine Th ppm (avg wshed)	Wpine Ca % (avg wshed)
Frozen Ocean	5.0000	2.4833	2.0000	0.3800
Pebbleloggitch	9999.0000	1.3000	9999.0000	0.2000
Big Red	9999.0000	1.5250	9999.0000	0.3500
Poplar	9999.0000	9999.0000	9999.0000	9999.0000
Big Dam East	5.0000	11.5000	2.0000	0.3050
Peskawa	9999.0000	1.0500	9999.0000	0.2033
Big Dam West	5.0000	2.7500	2.0000	0.2300
Channel	9999.0000	9999.0000	9999.0000	9999.0000
Hilchemakaar	5.0000	4.7667	2.0000	0.3667
Cobrielle	5.0000	3.0000	2.0000	0.1900
Mountain	5.0000	5.0000	2.0000	0.2000
Loon	9999.0000	2.1000	9999.0000	0.3100
Kejimkujik	5.5714	8.5000	2.0000	0.3654
Peskowesk	5.3333	7.5000	2.0000	0.3925
Luxton	9999.0000	0.7000	9999.0000	0.2400
North Cranberry	5.0000	4.5000	2.0000	0.2450
Beaverskin	5.5000	2.5000	2.0000	0.3500
Back	5.0000	4.0000	2.0000	0.2950
Puzzle	5.0000	3.0000	2.0000	0.4300
Grafton	9999.0000	0.6667	9999.0000	0.3025
Liberty	9999.0000	9999.0000	9999.0000	9999.0000
Lower Silver	9999.0000	9999.0000	9999.0000	9999.0000
George	9999.0000	9999.0000	9999.0000	9999.0000
Upper Silver	5.2500	13.7500	2.0000	0.3475

Lake Name	Wpine Hg ppb (avg wshed)	Wpine W ppm (avg wshed)	Rmaple Mo ppm (avg wshed)	Rmaple Cu ppm (avg wshed)
Frozen Ocean	32.6667	2.0000	0.5000	8.9100
Pebbleloggitch	33.0000	9999.0000	0.0500	4.6600
Big Red	29.7500	9999.0000	0.0267	5.6867
Poplar	9999.0000	9999.0000	9999.0000	9999.0000
Big Dam East	15.0000	2.0000	0.4320	7.1520
Peskawa	23.6667	9999.0000	0.0433	7.8167
Big Dam West	20.5000	2.0000	0.3650	6.8000
Channel	9999.0000	9999.0000	9999.0000	9999.0000
Hilchemakaar	28.6667	2.0000	0.3800	7.1667
Cobrielle	25.0000	2.0000	0.7000	9.6000
Mountain	23.5000	2.0000	0.8000	13.1000
Loon	24.3333	0.4000	0.0350	7.4700
Kejimkujik	23.4615	1.7875	0.2000	7.2954
Peskowesk	25.5000	2.0000	0.4487	7.3937
Luxton	19.0000	0.0000	0.0400	7.8700
North Cranberry	19.5000	2.0000	0.6500	6.9000
Beaverskin	19.5000	2.0000	0.4433	6.1633
Back	22.5000	2.0000	0.5000	6.4500
Puzzle	32.0000	2.0000	0.4350	6.5550
Grafton	22.7500	0.9000	0.0633	11.0033
Liberty	9999.0000	9999.0000	9999.0000	9999.0000
Lower Silver	9999.0000	9999.0000	9999.0000	9999.0000
George	9999.0000	9999.0000	9999.0000	9999.0000
Upper Silver	28.2500	2.0000	0.4000	7.5667

Lake Name	Rmaple Pb ppm (avg wshed)	Rmaple Zn ppm (avg wshed)	Rmaple Ag ppb (avg wshed)	Rmaple Mn ppm (avg wshed)
Frozen Ocean	0.8880	16.2600	11.0000	308.8000
Pebbleloggitch	0.4500	17.1000	1.0000	546.0000
Big Red	0.2200	23.3667	25.6667	470.3333
Poplar	9999.0000	9999.0000	9999.0000	9999.0000
Big Dam East	0.8260	28.5400	11.0000	767.0000
Peskawa	0.2700	26.6667	3.0000	315.0000
Big Dam West	0.7100	40.6500	17.0000	309.0000
Channel	9999.0000	9999.0000	9999.0000	9999.0000
Hilchemakaar	1.1367	24.7000	70.3333	484.6667
Cobrielle	1.4000	19.0000	87.0000	69.0000
Mountain	1.1333	19.1000	32.3333	119.6667
Loon	0.1950	21.0000	4.5000	546.5000
Kejimkujik	0.7608	23.2615	10.4615	486.3846
Peskowesk	1.3288	22.3250	44.3750	464.5000
Luxton	0.2100	13.5000	5.0000	260.0000
North Cranberry	1.7000	22.8000	15.0000	341.0000
Beaverskin	1.1033	19.0667	48.6667	427.0000
Back	1.4000	18.7500	47.5000	374.5000
Puzzle	0.8250	19.9500	12.0000	794.0000
Grafton	0.5567	20.4333	8.6667	682.3333
Liberty	9999.0000	9999.0000	9999.0000	9999.0000
Lower Silver	9999.0000	9999.0000	9999.0000	9999.0000
George	9999.0000	9999.0000	9999.0000	9999.0000
Upper Silver	1.5000	22.6333	52.3333	288.0000

Lake Name	Rmaple Fe % (avg wshed)	Rmaple As ppm (avg wshed)	Rmaple U ppm (avg wshed)	Rmaple Au ppb (avg wshed)
Frozen Ocean	0.0140	0.8167	5.0000	3.0200
Pebbleloggitch	0.0000	9999.0000	9999.0000	0.5000
Big Red	0.0000	9999.0000	9999.0000	1.2667
Poplar	9999.0000	9999.0000	9999.0000	9999.0000
Big Dam East	0.0060	0.2500	5.0000	1.4000
Peskawa	0.0033	9999.0000	9999.0000	2.2000
Big Dam West	0.0100	0.2500	5.0000	1.0000
Channel	9999.0000	9999.0000	9999.0000	9999.0000
Hilchemakaar	0.0067	0.4250	6.0000	1.7000
Cobrielle	0.0200	0.5000	5.0000	5.0000
Mountain	0.0100	0.2500	5.0000	3.0000
Loon	0.0000	9999.0000	9999.0000	2.6500
Kejimkujik	0.0092	0.3500	5.0000	1.2000
Peskowesk	0.0075	0.7667	5.1667	1.3250
Luxton	0.0000	9999.0000	9999.0000	3.6000
North Cranberry	0.0250	0.7500	5.0000	2.0000
Beaverskin	0.0067	0.2500	5.0000	5.0667
Back	0.0100	0.7000	5.5000	1.0000
Puzzle	0.0050	0.2500	5.0000	1.0000
Grafton	0.0100	9999.0000	9999.0000	0.5667
Liberty	9999.0000	9999.0000	9999.0000	9999.0000
Lower Silver	9999.0000	9999.0000	9999.0000	9999.0000
George	9999.0000	9999.0000	9999.0000	9999.0000
Upper Silver	0.0200	0.5833	5.0000	2.0000

Lake Name	Rmaple Th ppm (avg wshed)	Rmaple Ca % (avg wshed)	Rmaple Hg ppb (avg wshed)	Rmaple W ppm (avg wshed)
Frozen Ocean	2.0000	0.6300	17.4000	1.2000
Pebbleloggitch	9999.0000	0.7500	23.0000	0.0000
Big Red	9999.0000	0.5700	24.0000	0.0000
Poplar	9999.0000	9999.0000	9999.0000	9999.0000
Big Dam East	2.0000	0.6620	18.6000	1.2000
Peskawa	9999.0000	0.4700	16.0000	0.0000
Big Dam West	2.0000	0.6800	16.5000	1.0000
Channel	9999.0000	9999.0000	9999.0000	9999.0000
Hilchemakaar	2.0000	0.8000	19.0000	1.4000
Cobrielle	2.0000	0.3800	5.0000	2.0000
Mountain	2.0000	0.3467	10.3333	2.0000
Loon	9999.0000	0.4050	24.5000	0.1000
Kejimkujik	2.0000	0.5854	19.8462	1.0769
Peskowesk	2.0000	0.7050	19.5000	1.5000
Luxton	9999.0000	0.4100	24.0000	0.0000
North Cranberry	2.0000	0.8050	8.0000	2.0000
Beaverskin	2.0000	0.5233	27.6667	1.3333
Back	2.0000	0.5800	22.0000	2.0000
Puzzle	2.0000	0.5850	20.0000	1.0000
Grafton	9999.0000	0.3800	26.3333	0.3000
Liberty	9999.0000	9999.0000	9999.0000	9999.0000
Lower Silver	9999.0000	9999.0000	9999.0000	9999.0000
George	9999.0000	9999.0000	9999.0000	9999.0000
Upper Silver	2.0000	0.8133	16.0000	2.0000

Lake Name	Deep Marsh (% wshd)	Shallow Marsh (% wshd)	Seasonally Flooded Flats (% wshd)	Meadow (% wshd)	Shrub Swamp (% wshd)
Frozen Ocean	0.00	0.00	0.00	0.00	0.00
Pebbleloggitch	0.00	0.00	0.00	0.00	0.00
Big Red	0.00	0.00	0.00	0.00	0.00
Poplar	0.00	0.00	0.00	0.00	0.00
Big Dam East	0.00	0.00	0.00	0.00	0.00
Peskawa	0.00	0.00	0.00	0.00	0.00
Big Dam West	0.29	0.00	0.00	0.00	0.02
Channel	0.00	0.00	0.00	0.00	0.00
Hilchemakaar	0.00	0.00	0.00	0.00	0.00
Cobrielle	0.00	0.00	0.00	0.00	0.00
Mountain	0.00	0.00	0.00	0.00	0.02
Loon	0.00	0.00	0.00	0.00	0.00
Kejimkujik	0.02	0.00	0.07	0.00	0.36
Peskowesk	0.00	0.00	0.00	0.00	0.04
Luxton	0.00	0.00	0.00	0.00	0.00
North Cranberry	0.00	0.00	0.00	0.00	0.00
Beaverskin	0.00	0.00	0.00	0.00	0.00
Back	0.00	0.00	0.00	0.00	0.00
Puzzle	0.00	0.00	0.00	0.00	0.00
Grafton	0.05	0.00	0.00	0.00	0.00
Liberty	0.00	0.00	0.00	0.00	0.00
Lower Silver	0.00	0.00	0.00	0.00	0.00
George	0.00	0.00	0.00	0.00	0.00
Upper Silver	0.00	0.00	0.00	0.00	0.00

Lake Name	Wooded Swamp (% wshd)	Lakeshore Wetland (% wshd)	Bog (% wshd)	Fen (% wshd)	Total (% wshd)	Goldenville (% wshd)
Frozen Ocean	0.00	0.39	3.66	2.70	6.91	45.96
Pebbleloggitch	0.00	0.00	4.96	10.02	14.99	11.80
Big Red	0.00	0.00	2.49	0.04	2.53	0.00
Poplar	0.00	0.00	0.54	0.00	0.54	26.06
Big Dam East	0.00	0.00	0.00	0.00	0.00	8.73
Peskawa	0.00	0.00	1.18	0.52	3.59	19.05
Big Dam West	0.00	0.00	1.65	3.06	5.04	48.00
Channel	0.00	0.00	10.15	2.01	12.22	68.16
Hilchemakaar	0.00	0.00	7.96	0.01	7.99	79.00
Cobrielle	0.00	0.24	8.17	0.58	9.13	58.00
Mountain	0.00	0.00	9.40	0.00	11.95	49.80
Loon	0.00	0.00	3.65	2.94	10.50	37.80
Kejimkujik	0.00	0.40	3.38	2.00	6.31	15.94
Peskowesk	0.00	0.01	1.90	1.19	3.23	46.00
Luxton	0.00	0.00	0.90	0.00	0.91	0.00
North Cranberry	0.00	0.00	11.39	1.55	13.52	100.00
Beaverskin	0.00	0.00	0.00	0.00	0.00	100.00
Back	0.00	0.00	0.58	0.00	0.58	100.00
Puzzle	0.00	0.00	20.64	0.00	26.06	62.00
Grafton	0.00	5.10	0.97	1.40	7.75	0.00
Liberty	0.00	1.33	5.71	0.00	7.08	11.51
Lower Silver	0.00	0.00	1.71	0.00	1.71	100.00
George	0.00	8.26	2.90	0.00	14.11	43.18
Upper Silver	0.00	0.00	0.26	0.00	0.26	82.00

Lake Name	Halifax (% wshd)	Biotite Monzogranite (% wshd)	Leucomonzogranite (% wshd)	Musc Biot Monzogranite (% wshd)
Frozen Ocean	0.00	54.04	0.00	0.00
Pebbleloggitch	0.00	0.00	88.20	0.00
Big Red	0.00	0.00	0.00	100.00
Poplar	0.00	46.78	0.94	26.22
Big Dam East	91.27	0.00	0.00	0.00
Peskawa	0.00	0.56	63.05	17.34
Big Dam West	1.46	50.55	0.00	0.00
Channel	31.84	0.00	0.00	0.00
Hilchemakaar	21.00	0.00	0.00	0.00
Cobrielle	42.00	0.00	0.00	0.00
Mountain	0.17	0.00	0.00	50.03
Loon	62.20	0.00	0.00	0.00
Kejimkujik	44.65	17.13	2.55	19.73
Peskowesk	1.00	0.00	0.00	56.00
Luxton	0.00	0.00	0.00	100.00
North Cranberry	0.00	0.00	0.00	0.00
Beaverskin	0.00	0.00	0.00	0.00
Back	0.00	0.00	0.00	0.00
Puzzle	38.00	0.00	0.00	0.00
Grafton	100.00	0.00	0.00	0.00
Liberty	0.00	88.49	0.00	0.00
Lower Silver	0.00	0.00	0.00	0.00
George	56.82	0.00	0.00	0.00
Upper Silver	18.00	0.00	0.00	0.00

APPENDIX 4.2

Column Name in KEJI DATASETS COMBINED.XLS	Column Name in KEJI DATASETS COMBINED.DBF	Field Definition
Lake Name	LAKE_NAME	The name of the lake
Easting Nad83	EAST_83	Easting (UTM Nad83)
Northing Nad83	NORTH_83	Northing (UTM Nad83)
Adult Loon Blood (ug/g)	AD_LN_BL	Hg in adult loon blood (ug/g wet wt)
Juvenile Loon Blood (ug/g)	JUV_LN_BL	Hg in juvenile loon blood (ug/g wet wt)
Adult Loon Feathers (ug/g)	AD_LN_FT	Hg in adult loon feather (ug/g dry wt)
Wperch Avg Conc/Wt (%)	WP_CN_WT	Hg in white perch (concentration – ug Hg/g wet wt) (weight – g)
Wperch Avg Conc/Lgth (%)	WP_CN_LGT	Hg in white perch (concentration – ug Hg/g wet wt) (length – cm)
Yperch Avg Conc/Wt (%)	YP_CN_WT	Hg in yellow perch (concentration – ug Hg/g wet wt) (weight – g)
Yperch Avg Conc/Lgth (%)	YP_CN_LGT	Hg in yellow perch (concentration – ug Hg/g wet wt) (length – cm)
Trout Avg Conc/Wt (%)	TR_CN_WT	Hg in trout (concentration – ug Hg/g wet wt) (weight – g)
Trout Avg Conc/Lgth (%)	TR_CN_LGT	Hg in trout (concentration – ug Hg/g wet wt) (length – cm)
Perch Tot Hg (10cm)	P_HG_10CM	Hg in 10 cm perch (mean Hg concentration in ug/g wet wt for whole perch, given fork lgth)
Perch Tot Hg (20cm)	P_HG_20CM	Hg in 20 cm perch (mean Hg concentration in ug/g wet wt for whole perch, given fork lgth)
SW Alkalinity (mg/L)	SW_ALK	Alkalinity in lake surface water (measured by Gran titration, mg/L CaCO3)
SW pH	SW_PH	pH in lake surface water
SW Color (Hazens)	SW_COLOR	Color in lake surface water (hazens)
SW Specific Conductance (uS/cm)	SW_SC	Specific conductance in lake surface water (uS/cm)
SW Total Organic Carbon (mg/L)	SW_TOC	Total organic carbon in unfiltered lake surface water (mg/L)
SW Dissolved Cl (mg/L)	SW_CL	Dissolved Cl in lake surface water (mg/L)
SW Dissolved SO_4 (mg/L)	SW_SO4	Dissolved SO_4 in lake surface water (mg/L)
SW Total N_2 (mg/L)	SW_ N2	Total N_2 in lake surface water (mg/L)
SW Dissolved Na (mg/L)	SW_NA	Dissolved Na in lake surface water (mg/L)
SW Dissolved K (mg/L)	SW_K	Dissolved K in lake surface water (mg/L)
SW Dissolved Ca (mg/L)	SW_CA	Dissolved Ca in lake surface water (mg/L)
SW Dissolved Mg (mg/L)	SW_MG	Dissolved Mg in lake surface water (mg/L)
SW Extractable Al (mg/L)	SW_AL	Extractable Al in lake surface water (mg/L)
SW Extractable Fe (mg/L)	SW_FE	Extractable Fe in lake surface water (mg/L)
SW Extractable Mn (mg/L)	SW_MN	Extractable Mn in lake surface water (mg/L)
SW Total Hg - unfiltered (ng/L)	SW_HG	Total Hg - in unfiltered lake surface water (ng/L)
Lake Sediment Hg (mg/kg)	LAKE_SED	Hg concentrations in lake sediment (mg/kg dry wt)
PC Lake Elevation (m)	PC_ELEV	Lake physical characteristics - elevation above sea level (m)

PC Surface Area (hectares)	PC_SURF	Lake physical characteristics – surface area including islands (hectares)
PC Total Catchment Area (km^2)	PC_CATCH	Lake physical characteristics – watershed catchment area excluding lake surface area (km^2)
PC Volume (m^3)	PC_VOL	Lake physical characteristics – volume (m^3)
PC Mean Depth (m)	PC_X_DEP	Lake physical characteristics – mean depth (m)
PC Max Depth (m)	PC_MAX_DEP	Lake physical characteristics – maximum depth (m)
PC Shoreline Length (km)	PC_LENGTH	Lake physical characteristics – shoreline length (km)
PC Flushing Rate (times/yr)	PC_FLUSH	Lake physical characteristics - flushing rate (water removal rate) times per year
Tot Hg dragonfly larvae (ug/g)	DRAGONFLY	Total Hg in dragonfly larvae (ug/g wet wt)
Tot Hg Unfiltered (ng/L)	HG_UNF	Total Hg in unfiltered lake water (ng/L)
Tot Hg Filtered (ng/L)	HG_FIL	Total Hg in filtered lake water (ng/L)
MeHg Unfiltered (ng/L)	MEHG_UNF	Methylmercury in unfiltered water (ng/L)
MeHg Filtered (ng/L)	MEHG_FIL	Methylmercury in filtered water (ng/L)
AR H2O Date	AR_DATE	A. Rencz lake water – sample collection date
AR H2O Time	AR_TIME	A. Rencz lake water – sample collection time
AR H2O Color	AR_COLOR	A. Rencz lake water – color
AR H2O Temp	AR_TEMP	A. Rencz lake water – degrees Celsius
AR H2O pH	AR_PH	A. Rencz lake water – pH
AR H2O DO	AR_DO	A. Rencz lake water – dissolved oxygen (no units provided)
AR H2O Conductivity	AR_COND	A. Rencz lake water – conductivity (no units provided)
AR H2O Alkalinity	AR_ALK	A. Rencz lake water – alkalinity (no units provided)
AR H2O Turbulence	AR_TURB	A. Rencz lake water – turbulence (no units provided)
AR H2O DOC ppm	AR_DOC	A. Rencz lake water – dissolved organic content (ppm)
AR H2O Hg ppb	AR_HG	A. Rencz lake water – Hg (ppb)
AR H2O Al^{27} ppb	AR_AL27	A. Rencz lake water – Al^{27} (ppb)
AR H2O Fe^{54} ppb	AR_FE54	A. Rencz lake water – Fe^{54} (ppb)
AR H2O Mn^{55} ppb	AR_MN55	A. Rencz lake water – Mn^{55} (ppb)
AR H2O Co^{59} ppb	AR_CO59	A. Rencz lake water – Co^{59} (ppb)
AR H2O Cu^{65} ppb	AR_CU65	A. Rencz lake water – Cu^{65} (ppb)
AR H2O Zn^{66} ppb	AR_ZN66	A. Rencz lake water – Zn^{66} (ppb)
AR H2O As^{75} ppb	AR_AS75	A. Rencz lake water – As^{75} (ppb)
AR H2O Rb^{85} ppb	AR_RB85	A. Rencz lake water – Rb^{85} (ppb)
AR H2O Sr^{88} ppb	AR_SR88	A. Rencz lake water – Sr^{88} (ppb)
AR H2O Y^{89} ppb	AR_Y89	A. Rencz lake water – Y^{89} (ppb)
AR H2O Ag^{107} ppb	AR_AG107	A. Rencz lake water – Ag^{107} (ppb)
AR H2O Cd^{114} ppb	AR_CD114	A. Rencz lake water – Cd^{114} (ppb)
AR H2O Pb^{208} ppb	AR_PB208	A. Rencz lake water – Pb^{208} (ppb)
AR H2O U^{238} ppb	AR_U238	A. Rencz lake water – U^{238} (ppb)

Lks77 Copper (ppm)	77_CU	1977 lake sediment data – copper (ppm)
Lks77 Nickel (ppm)	77_NI	1977 lake sediment data – nickel (ppm)
Lks77 Lead (ppm)	77_PB	1977 lake sediment data – lead (ppm)
Lks77 Zinc (ppm)	77_ZN	1977 lake sediment data – zinc (ppm)
Lks77 Cobalt (ppm)	77_CO	1977 lake sediment data – cobalt (ppm)
Lks77 Iron (%)	77_FE	1977 lake sediment data – iron (%)
Lks77 Manganese (ppm)	77_MN	1977 lake sediment data – manganese (ppm)
Lks77 Calcium	77_CA	1977 lake sediment data – calcium (no units provided)
Lks77 Magnesium	77_MG	1977 lake sediment data – magnesium (no units provided)
Lks77 Molybdenum (ppm)	77_MO	1977 lake sediment data – molybdenum (ppm)
Lks77 Mercury (ppm)	77_HG	1977 lake sediment data – mercury (ppm)
Lks77 Uranium (ppm)	77_U	1977 lake sediment data –uranium (no units provided)
Lks77 Arsenic (ppm)	77_AS	1977 lake sediment data – arsenic (no units provided)
Wpine Mo ppm (avg wshed)	WPINE_MO	Mo in white pine (ppm) – average value for the watershed
Wpine Cu ppm (avg wshed)	WPINE_CU	Cu in white pine (ppm) – average value for the watershed
Wpine Pb ppm (avg wshed)	WPINE_PB	Pb in white pine (ppm) – average value for the watershed
Wpine Zn ppm (avg wshed)	WPINE_ZN	Zn in white pine (ppm) – average value for the watershed
Wpine Ag ppb (avg wshed)	WPINE_AG	Ag in white pine (ppb) – average value for the watershed
Wpine Mn ppm (avg wshed)	WPINE_MN	Mn in white pine (ppm) – average value for the watershed
Wpine Fe % (avg wshed)	WPINE_FE	Fe in white pine (%) – average value for the watershed
Wpine As ppm (avg wshed)	WPINE_AS	As in white pine (ppm) – average value for the watershed
Wpine U ppm (avg wshed)	WPINE_U	U in white pine (ppm) – average value for the watershed
Wpine Au ppb (avg wshed)	WPINE_AU	Au in white pine (ppb) – average value for the watershed
Wpine Th ppm (avg wshed)	WPINE_TH	Th in white pine (ppm) – average value for the watershed
Wpine Ca % (avg wshed)	WPINE_CA	Ca in white pine (%) – average value for the watershed
Wpine Hg ppb (avg wshed)	WPINE_HG	Hg in white pine (ppb) – average value for the watershed
Wpine W ppm (avg wshed)	WPINE_W	W in white pine (ppm) – average value for the watershed
Rmaple Mo ppm (avg wshed)	RMAP_MO	Mo in red maple (ppm) – average value for the watershed
Rmaple Cu ppm (avg wshed)	RMAP_CU	Cu in red maple (ppm) – average value for the watershed
Rmaple Pb ppm (avg wshed)	RMAP_PB	Pb in red maple (ppm) – average value for the watershed
Rmaple Zn ppm (avg wshed)	RMAP_ZN	Zn in red maple (ppm) – average value for the watershed
Rmaple Ag ppb (avg wshed)	RMAP_AG	Ag in red maple (ppb) – average value for the watershed
Rmaple Mn ppm (avg wshed)	RMAP_MN	Mn in red maple (ppm) – average value for the watershed
Rmaple Fe % (avg wshed)	RMAP_FE	Fe in red maple (%) – average value for the watershed
Rmaple As ppm (avg wshed)	RMAP_AS	As in red maple (ppm) – average value for the watershed
Rmaple U ppm (avg wshed)	RMAP_U	U in red maple (ppm) – average value for the watershed
Rmaple Au ppb (avg wshed)	RMAP_AU	Au in red maple (ppb) – average value for the watershed

Rmaple Th ppm (avg wshed)	RMAP_TH	Th in red maple (ppm) – average value for the watershed
Rmaple Ca % (avg wshed)	RMAP_CA	Ca in red maple (%) – average value for the watershed
Rmaple Hg ppb (avg wshed)	RMAP_HG	Hg in red maple (ppb) – average value for the watershed
Rmaple W ppm (avg wshed)	RMAP_W	W in red maple (ppm) – average value for the watershed
Deep Marsh (% wshd)	DMARSH	Percent of deep marsh that falls in the watershed
Shallow Marsh (% wshd)	SMARSH	Percent of shallow marsh that falls in the watershed
Seasonally Flooded Flats (% wshd)	SFFLAT	Percent of seasonally flooded flats that falls in the watershed
Meadow (% wshd)	MDOW	Percent of meadow that falls in the watershed
Shrub Swamp (% wshd)	SSWAMP	Percent of shrub swamp that falls in the watershed
Wooded Swamp (% wshd)	WSWAMP	Percent of wooded swamp that falls in the watershed
Lakeshore Wetland (% wshd)	LWETLAND	Percent of lakeshore wetland that falls in the watershed
Bog (% wshd)	BOG	Percent of bog that falls in the watershed
Fen (% wshd)	FEN	Percent of fen that falls in the watershed
Total (% wshd)	TOT_WET	Percent of total wetland that falls in the watershed
Goldenville (% wshd)	GOLDEN	Percent of Goldenville Formation that falls in the watershed
Halifax (% wshd)	HALIFAX	Percent of Halifax Formation that falls in the watershed
Biotite Monzogranite (% wshd)	BIO_MONZ	Percent of Biotite Monzogranite that falls in the watershed
Leucomonzogranite (% wshd)	LEUCO	Percent of Leucomonzogranite that falls in the watershed
Musc Biot Monzogranite (% wshd)	MB_MONZ	Percent of Muscovite Biotite Monzogranite that falls in the watershed

APPENDIX 4.3

The **RECLASS_WSHED_KEJI.AML** (see below) was ran from the ARC/INFO command line using the following arguments:

```
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Mo Mo
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Cu Cu
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Pb Pb
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Zn Zn
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Ag Ag
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Mn Mn
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Fe Fe
Arc> &R reclass_wshed_keji.aml wpine_wat wpine As As
Arc> &R reclass_wshed_keji.aml wpine_wat wpine U U
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Au Au
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Th Th
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Ca Ca
Arc> &R reclass_wshed_keji.aml wpine_wat wpine Hg Hg
Arc> &R reclass_wshed_keji.aml wpine_wat wpine W W
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Mo Mo
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Cu Cu
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Pb Pb
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Zn Zn
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Ag Ag
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Mn Mn
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Fe Fe
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple As As
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple U U
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Au Au
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Th Th
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Ca Ca
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple Hg Hg
Arc> &R reclass_wshed_keji.aml rmaple_wat rmaple W W
```

Note: WPINE_WAT and RMAPLE_WAT were created in Figure 4.19.

```
/*****************************************************************************
/* Program Name: RECLASS_WSHED_KEJI.AML
/* Author: Krista Page
/* Date: March, 2000
/*
/* Main Tasks: To take an element in a specified point coverage and reclass the item
/*             into the final watershed table based on polygon watershed number.
/*
/* Variables:
/*    cov - the current point coverage
/*    element - the item name for the element
/*    cov_name - what to call the new coverage
/*    element_name - what to call the new element
/*    n_sel - the number of selected records per watershed
/*    min - the minimum value for the selected set
/*    max - the maximum value for the selected set
/*    mean - the mean value of the selected set
/*    std - the standard deviation of the selected set
/*    selected - flag indicating if any records fall in any given watershed
/*
/*****************************************************************************
```

```
/*-----------------------------------------------------------------------------
/* Pass in the point coverage and the element from the point coverage to reclassify.
/*-----------------------------------------------------------------------------

&ARGS cov cov_name element element_name

/*-----------------------------------------------------------------------------
/* If the statistic items for the element already exist from a previous run, then
/* delete them.
/*-----------------------------------------------------------------------------

DROPITEM ar_kejiarea.pat ar_kejiarea.pat
   %element_name%_%cov_name%_freq
   %element_name%_%cov_name%_min
   %element_name%_%cov_name%_max
   %element_name%_%cov_name%_mean
   %element_name%_%cov_name%_std
   END

/*-----------------------------------------------------------------------------
/* Include the return statement if items are only to be dropped and no further
/* processing is required.
/*-----------------------------------------------------------------------------

/* &RETURN

/*-----------------------------------------------------------------------------
/* Add a number of items to the final watershed coverage to hold the frequency,
/* minimum, maximum, mean, and standard deviation of the current element for the
/* current coverage.
/*-----------------------------------------------------------------------------

ADDITEM ar_kejiarea.pat ar_kejiarea.pat %element_name%_%cov_name%_freq 5 5 I
ADDITEM ar_kejiarea.pat ar_kejiarea.pat %element_name%_%cov_name%_min 8 8 F 4
ADDITEM ar_kejiarea.pat ar_kejiarea.pat %element_name%_%cov_name%_max 8 8 F 4
ADDITEM ar_kejiarea.pat ar_kejiarea.pat %element_name%_%cov_name%_mean 8 8 F 4
ADDITEM ar_kejiarea.pat ar_kejiarea.pat %element_name%_%cov_name%_std 8 8 F 4

/*-----------------------------------------------------------------------------
/* Set all the values in the new statistic items to -9999. This will enable the
/* distinction between values of 0 and null values.
/*-----------------------------------------------------------------------------

TABLES
   SELECT ar_kejiarea.pat
   RESELECT %element_name%_%cov_name%_freq = 0
   CALC %element_name%_%cov_name%_freq = 9999
   ASELECT
   RESELECT %element_name%_%cov_name%_min = 0
   CALC %element_name%_%cov_name%_min = 9999
   ASELECT
   RESELECT %element_name%_%cov_name%_max = 0
   CALC %element_name%_%cov_name%_max = 9999
   ASELECT
   RESELECT %element_name%_%cov_name%_mean = 0
   CALC %element_name%_%cov_name%_mean = 9999
   ASELECT
   RESELECT %element_name%_%cov_name%_std = 0
   CALC %element_name%_%cov_name%_std = 9999
   Q

/*-----------------------------------------------------------------------------
/* Start Arcedit. Run the loop through as many times as there are watersheds. The
/* final watershed coverage had 374 records. Start at record 2 to avoid the world
/* polygon.
/*-----------------------------------------------------------------------------
```

```
AE
&DO i = 2 &TO 502

   /*-----------------------------------------------------------------------------
   /* Select all the points that fall in the current watershed. Do not select the
   /* points that are less than 0.
   /*-----------------------------------------------------------------------------

   EC %cov%
   EF point
   &S selected = TRUE
   SELECT ALL
   RESELECT FOR constant# = %i% AND %element% GE 0

   /*-----------------------------------------------------------------------------
   /* If no points were selected for the current watershed than select for another
   /* watershed by exiting the loop (selected flag set to false).
   /*-----------------------------------------------------------------------------

   &S n_sel = [SHOW NUMBER SELECTED]
   &IF %n_sel% = 0 &THEN &S selected = FALSE

   /*-----------------------------------------------------------------------------
   /* Generate statistics for each watershed (minimum, maximum, mean, and standard
   /* deviation). Assign the results to variables.
   /*-----------------------------------------------------------------------------

   &IF %selected% = TRUE &THEN &DO
      STATISTICS
         MIN %element%
         MAX %element%
         MEAN %element%
         STD %element%
         END
      &S min = [SHOW STATISTIC 1 1]
      &S max = [SHOW STATISTIC 2 1]
      &S mean = [SHOW STATISTIC 3 1]
      &S std = [SHOW STATISTIC 4 1]
      Q

      /*-----------------------------------------------------------------------------
      /* In Tables, select the current watershed and place the count, min, max,
      /* mean, and std values into the items created above. Start Arcedit again for
      /* the next iteration of the loop.
      /*-----------------------------------------------------------------------------

      TABLES
         SELECT ar_kejiarea.pat
         RESELECT constant# = %i%
         CALC %element_name%_%cov_name%_freq = %n_sel%
         CALC %element_name%_%cov_name%_min = %min%
         CALC %element_name%_%cov_name%_max = %max%
         CALC %element_name%_%cov_name%_mean = %mean%
         CALC %element_name%_%cov_name%_std = %std%
         Q
      AE
   &END

/*-----------------------------------------------------------------------------
/* End the loop, save changes made in Arcedit, and return to the Arc prompt.
/*-----------------------------------------------------------------------------

&END
SAVE
QUIT
&RETURN
```

APPENDIX 4.4

(Summarized from NSDNR (1999), NS Wet Places (1998, http), Osmond (1995, http), Wood et al (1991), R. Milton (personal communication, April 4, 2000))

TYPE	WETLAND COVERAGE DESCRIPTION	CHARCTERISTICS	ORGANIC CONTENT	NUTRIENTS	WILDLIFE	VEGETATION
Deep Marsh	This type applies to wetlands with an average water depth between 15 cm and 1 m during the growing season. Emergent marsh vegetation is usually dominant, with surface and submergent plants present in open areas. If shrubs cover less than 50 percent of the area, the wetland is classified as a Deep Marsh. It is classified as a Shrub Swamp (see below) if the shrub cover is 50 percent or greater.	• marshes are wetter swamps • unlike swamps covered by water year round • by late summer some marshes dry out, however water normally remains in the rooting zone of plants • water depths averaging between 15 - 90 cm during the summer	• inflow from ground water and surface water, less organics than bogs and fens	• nutrient-rich • seasonal flooding continually adds nutrient-rich water and sediments	• biologically productive • black ducks, muskrats, bullheads, diving beetles, pickerel frogs, snails	• non-woody aquatic plants (too wet for trees and shrubs) • cattails, rushes, and pondweeds • most conspicuous types of plants are emergents
Shallow Marsh	This type applies to wetlands usually dominated by robust or marsh emergents, with an average water depth less than 15 cm during the growing season. Surface water may be absent during the late summer and abnormally dry periods. Floating-leaved plants and submergents are often present in open areas.	• marshes are wetter swamps • unlike swamps, covered by water year round • by late summer some marshes dry out, however water normally remains in the rooting zone of plants • average less than 15 cm in depth	• inflow from ground water and surface water, less organics than bogs and fens	• nutrient-rich • seasonal flooding continually adds nutrient-rich water and sediments	• biologically productive • black ducks, muskrats, bullheads, diving beetles, pickerel frogs, snails	• non-woody aquatic plants (too wet for trees and shrubs) • cattails, rushes, and pondweeds • covered with emergent plants during the summer
Seasonally Flooded Flats	This types applies to extensive river floodplains (i.e. any stream wide enough to be shown as a double line on a map) where flooding to a depth of 30 or more cm occurs annually during late fall, winter and spring. During the summer, the soil is saturated, with a few cm of surface water occurring locally. Except for its flood plain location, this class incorporates vegetative components of the classes Meadow and Shrub Swamp. Dominant vegetation usually is emergent, but shrubs and scattered, trees may be present.	• often form at points where large rivers slow down as they enter lakes • much larger than the meadow because it experiences more intense flooding • in summer appears mainly as grassland meadows, may contain shrubs and trees	• depend on water in the spring • once they are drained, they depend on what is in the soil (based on the mineralization)	• high nutrient-level • flood waters deposit fine soil particles on floodplains (thus ensuring the habitat is full of nutrients)	• unique productive habitat for wildlife (result of high nutrients, high moisture, and regular physical disturbance)	• similar vegetation to meadows • tall grasses are dominant • support more diverse plant life than meadows • tress, shrubs, ferns and marsh plants may be present

Meadow	This type applies to wetlands dominated by meadow emergents with up to 15 cm of surface water during the late fall winter and early spring. During the growing season the soil is saturated and the surface exposed, except in shallow depressions and drainage ditches. This wetland class can occur in two major locations: on agricultural land and on the floodplains of small streams (i.e. any stream not wide enough to be shown as a double line on a map). In the latter site, the meadows resemble miniature seasonally flooded flats. In the former, structural differences in meadow vegetation often results from grazing.	• in summer appears mainly as grassland meadows, may contains shrubs and trees • form along small streams in woodlands and on low lying agricultural land	• depend on water in the spring • once they are drained, they depend on what is in the soil (based on the mineralization)	• high nutrient-level	• unique productive habitat for wildlife (result of high nutrients, high moisture, and regular physical disturbance	• dense stands of grasses • rushes, sedges, and broad leaf plants may be present
Shrub Swamp	This type applies to wetlands dominated by shrubs where the soil surface is seasonally or permanently flooded with as much as 30 cm of water. Shrubs cover more than 50 percent of the wetland area. *Carex sp*.(Sedge) is the characteristic ground cover beneath shrubs. Meadow or marsh emergents may occupy open areas.	• a wetland dominated by shrubs • similar to marshes in form and function, main distinction is water level (swaps are just moist on the surface, marshes are covered by water all year) • shrub swamps are permanently or seasonally flooded areas • over time shrub swamps tend to evolve into wooded swamps	• inflow from ground water and surface water, less organics than bogs and fens	• nutrient rich • spring flooding of nearby streams and lakes assure that swamps are constantly supplied with nutrients	• superb habitat for wood frog, yellow-spotted salamander, bats and birds • support a variety of wildlife	• dominated by shrubs (mosses, grasses, and ferns) • dominant plants are tall bushes like alder, and low bushy shrubs like sweet gale and rhodora
Wooded Swamp	This type applies to wetlands dominated by trees. The soil surface is seasonally flooded with up to 30 cm of water. Several levels of vegetation are usually present, including trees, shrubs and herbaceous plants. In mature wooded swamps, micro-topography is very pronounced. Trees and many shrubs grow on well developed wind-throw mounds while marsh emergents and ferns occupy the vernal pools.	• a wetland dominated by trees • similar to marshes in form and function, main distinction is water level (swaps are just moist on the surface, marshes are covered by water all year) • wooded swamps usually experience flooding during spring and fall and tend not to be as wet as shrub swamps	• inflow from ground water and surface water, less organics than bogs and fens	• nutrient rich • spring flooding of nearby streams and lakes assure that swamps are constantly supplied with nutrients	• superb habitat for wood frog, yellow-spotted salamander, bats and birds • support a variety of wildlife	• dominated by trees (red maple, black spruce, and larch) • deciduous and coniferous trees common, shrubs flourish in wetter spots
Lakeshore Wetland	These are wetlands of variable water depth that occur along the margins or in coves of lakes and rivers. A number of these wetlands will be flowages, i.e. areas of water impounded by a dam for power.	• develop in protected shallow margins along lake shorelines • essentially pockets of marshy habitat that occur along lakeshores • often link with nearby marshes, swamp, and fens		• range from low to moderately high • generally nutrient-low (most of Nova Scotia's lakes are low in nutrients) • plants boost nutrients in lakes	• ring-necked ducks, yellow perch, and sandpipers • the wide variety of vegetation attracts animals (waterfowls, fish, frog, marshbirds)	• variety of aquatic plants (pickerelweed, waterlilies, rushes) • wide variety of plants grow in low-rocky and minimal wave action zones

Bog	This type applies to wetlands where the accumulation of *Sphagnum* moss, as peat, determines the nature of the plant community. Young bogs commonly have floating peat mats that creep outward from shore over the surface of open water. *Sarracenia purpurea* (Pitcher-plant) and *Eriphorum spp*. (Cotton-grass) are characteristic plants found in bogs. Bogs generally do not have open watercourses associated with them.	• poorly drained area • self-contained • typically develop in shallow low lying areas over layers of bedrock • most common type of wetland in Nova Scotia • absorbs water during wet periods and then later releases it during times of drought • remove toxic chemicals from the water • cold • distinctly tea-colored due to staining by peat • oxygen-poor due to presence of moss and peat • decomposition requires oxygen and the slow breakdown of peat uses most of the oxygen	• filled with peat • it is the overwhelming presence of peat that distinguishes bogs and fens from other wetlands • bogs are like bowls full of peat and water	• lacking in nutrients because precipitation is main water source • most nutrient poor type of wetland	• marginal because of low nutrients • low diversity also results from low oxygen	• mainly sphagnum moss, knee-high shrubs • coniferous trees border edge
Fen	This type includes peat wetlands typically covered by *Carex sp*. (sedges), having a saturated water regime, and having an open drainage system. These appear similar to bogs but can be readily distinguished by the watercourses that pass through them.	• poorly drained area • connected to small streams an lakeshores • unlike bogs, water slowly moves through a fen • absorb water during wet periods and then later releases it during times of drought • remove toxic chemicals from the water • cool • oxygen-poor due to presence of moss and peat • decomposition requires oxygen and the slow breakdown of peat uses most of the oxygen	• a fen may be an earlier stage of a bog, not as much peat has accumulated (this allows some ground water interaction) • it is the overwhelming presence of peat that distinguishes bogs and fens from other wetlands	• water flows through, therefore more nutrients than bogs • still low-nutrient compared to other wetlands	• higher than bogs because increased nutrients • still low because of low oxygen	• sedge predominant plant • support lusher vegetation than in bogs (more nutrients)

Additional Notes:

1. Bogs and fens are the biggest area of bound mercury.
2. Marshes release mercury in the summertime when things dry out; in the wintertime it is binding.
3. Mercury gets bound up in organics; organics can bind heavy metals.
4. If bogs start to oxidize (drop in water table in dry conditions), the peat oxidizes and the Hg becomes soluble so it can be flushed out into the system.
5. Once you get down to the deep part of the peat, there is little movement. All the flow is in the top 30 cm.

pH summary:

FEN • acidic • pH range from 4.0 - 8.0 depending on vegetation and peat type • about 4.8 in Nova Scotia

BOG • acidic • pH can be as low as 3.0 - 4.0 • usually about 4.5

APPENDIX 4.5

```
/*****************************************************************************
/* Program Name: ADDITEM_KEJI.AML
/* Author: Krista Page
/* Date: May, 2000
/*
/* Main Tasks: To take all the unique values in the geology layer and create a new
/*             item in the ar_kejiarea coverage for each one. The list was generated
/*             by performing the frequency function on the geo wshed coverage using
/*             the txt_label item. The values were listed and copied and pasted into
/*             this AML.
/*
/* Variables:
/*    i = holds the current item to add to the ar_kejiarea coverage.
/*
/*****************************************************************************

&DO i &LIST COMg COMh M-LDbmg M-LDlmg M-LDmbmg
   ADDITEM ar_kejiarea.pat ar_kejiarea.pat %i% 8 8 F 2
&END

&RETURN

/*****************************************************************************
/* Program Name: GEOLOGY_KEJI.AML
/* Author: Krista Page
/* Date: May, 2000
/*
/* Main Tasks: To create percents of each geological unit for each watershed in the
/*             the Keji study area.
/*
/* Variables:
/*    k - an incrementer for each record in the geo_wshed coverage
/*    selected - flag indicating if a record has been selected
/*    i - an incrementer for each watershed
/*    n_sel - the number of currently selected polygons that belong to a watershed
/*    total_area - the total area of the current watershed
/*    j - an incrementer for each polygon that belongs to the same watershed
/*    rn - the current record number
/*    area - the area of the current polygon
/*    type - the geological type for the current polygon
/*    percent - percentage that the current polygon takes in the whole watershed
/*
/*****************************************************************************

/*----------------------------------------------------------------------------
/* Initialize the record incrementer to 1.
/*----------------------------------------------------------------------------

&S k = 33

/*----------------------------------------------------------------------------
/* Go into Arcedit and select the geo_wshed coverage. This coverage holds the
/* watershed number, the increment number, and the geological type.
/*----------------------------------------------------------------------------

AE
EC geo_wshedK
EF polygon

/*----------------------------------------------------------------------------
/* Repeat the loop 373 times, once for each watershed.
/*----------------------------------------------------------------------------

&DO i = 5 &TO 374
```

```
/*-----------------------------------------------------------------------------
/* Set the selected flag to true. The constant number is unique for each
/* watershed. Select all the polygons in the coverage that belong to a given
/* watershed.
/*-----------------------------------------------------------------------------

&S selected = TRUE
SELECT ALL
RESELECT FOR constant# = %i%

/*-----------------------------------------------------------------------------
/* Assign a variable to the number of polygons selected. If no records were
/* selected, loop back to the top.
/*-----------------------------------------------------------------------------

&S n_sel = [SHOW NUMBER SELECTED]

&IF %n_sel% = 0 &then &s selected = FALSE

/*-----------------------------------------------------------------------------
/* Find the total area for a given watershed. This area is used to determine
/* what percentage of the total area belongs to each geological type.
/*-----------------------------------------------------------------------------

&IF %selected% = TRUE &THEN &DO

   STATISTICS
      SUM area
      END

   /*--------------------------------------------------------------------------
   /* Assign the total area to a variable.
   /*--------------------------------------------------------------------------

   &S total_area = [SHOW STATISTIC 1 1]

   /*--------------------------------------------------------------------------
   /* Repeat the loop for every polygon that belongs to a watershed.
   /*--------------------------------------------------------------------------

   &DO j = 1 &to %n_sel%

      /*-----------------------------------------------------------------------
      /* Select each polygon for a given watershed. Note: the increment number
      /* was created by ordering the constant# and assigning a unique value from
      /* 1 to 1349 to the increment# item.
      /*-----------------------------------------------------------------------

      SELECT ALL
      RESELECT FOR increment# = %k%

      /*-----------------------------------------------------------------------
      /* Assign the record number of the currently selected polygon to a
      /* variable. Leave Arcedit.
      /*-----------------------------------------------------------------------

      &S rn = [SHOW SELECT 1]
      QUIT

      /*-----------------------------------------------------------------------
      /* Go into Tables and select the geo_wshed coverage. Extract the area and
      /* geological type for the current polygon. Calculate the percentage that
      /* this polygon takes up for the total watershed.
      /*-----------------------------------------------------------------------

      TABLES
         SELECT geo_wshedK.pat
```

```
            &S area = [SHOW RECORD %rn% ITEM area]
            &S type = [SHOW RECORD %rn% ITEM TXT_LABEL]
            &S percent = [calc [calc %area% / %total_area%] * 100]

            /*-----------------------------------------------------------------
            /* Select the final_wshed coverage and the current watershed. Assign the
            /* percentage to the appropriate geological type. Leave tables.
            /*-----------------------------------------------------------------

            SELECT ar_kejiarea.pat
            RESELECT constant# = %i%
            CALC %type% = %percent% + %type%
            QUIT

          /*-----------------------------------------------------------------
          /* Go back into Arcedit, increment the counter, and loop again.
          /*-----------------------------------------------------------------

          AE
          EC geo_wshedK
          EF polygon
          &S k = %k% + 1

          &END        /* end the inner do loop for number of polygons for a watershed
       &END           /* end the if..then loop
    &END              /* end the outer do loop for number of watersheds
QUIT
```

APPENDIX 4.6

```
/*****************************************************************************
/* Program Name: ADDITEM_KEJI.AML
/* Author: Krista Page
/* Date: May, 2000
/*
/* Main Tasks: To take all the unique values in the geology layer and create a new
/*             item in the ar_kejiarea coverage for each one. The list was generated
/*             by performing the frequency function on the geo wshed coverage using
/*             the txt_label item. The values were listed and copied and pasted into
/*             this AML.
/*
/* Variables:
/*    i = holds the current item to add to the ar_kejiarea coverage.
/*
/*****************************************************************************

&DO i &LIST COMg COMh M-LDbmg M-LDlmg M-LDmbmg
   ADDITEM ar_kejiarea.pat ar_kejiarea.pat %i% 8 8 F 2
&END

&RETURN

/*****************************************************************************
/* Program Name: GEOLOGY_KEJI.AML
/* Author: Krista Page
/* Date: May, 2000
/*
/* Main Tasks: To create percents of each geological unit for each watershed in the
/*             the Keji study area.
/*
/* Variables:
/*    k - an incrementer for each record in the geo_wshed coverage
/*    selected - flag indicating if a record has been selected
/*    i - an incrementer for each watershed
/*    n_sel - the number of currently selected polygons that belong to a watershed
/*    total_area - the total area of the current watershed
/*    j - an incrementer for each polygon that belongs to the same watershed
/*    rn - the current record number
/*    area - the area of the current polygon
/*    type - the geological type for the current polygon
/*    percent - percentage that the current polygon takes in the whole watershed
/*
/*****************************************************************************

/*----------------------------------------------------------------------------
/* Initialize the record incrementer to 1.
/*----------------------------------------------------------------------------

&S k = 33

/*----------------------------------------------------------------------------
/* Go into Arcedit and select the geo_wshed coverage. This coverage holds the
/* watershed number, the increment number, and the geological type.
/*----------------------------------------------------------------------------

AE
EC geo_wshedK
EF polygon

/*----------------------------------------------------------------------------
/* Repeat the loop 373 times, once for each watershed.
/*----------------------------------------------------------------------------

&DO i = 5 &TO 374
```

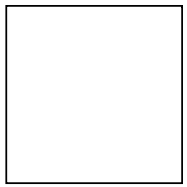
```
/*-----------------------------------------------------------------------------
/* Set the selected flag to true. The constant number is unique for each
/* watershed. Select all the polygons in the coverage that belong to a given
/* watershed.
/*-----------------------------------------------------------------------------

&S selected = TRUE
SELECT ALL
RESELECT FOR constant# = %i%

/*-----------------------------------------------------------------------------
/* Assign a variable to the number of polygons selected. If no records were
/* selected, loop back to the top.
/*-----------------------------------------------------------------------------

&S n_sel = [SHOW NUMBER SELECTED]

&IF %n_sel% = 0 &then &s selected = FALSE

/*-----------------------------------------------------------------------------
/* Find the total area for a given watershed. This area is used to determine
/* what percentage of the total area belongs to each geological type.
/*-----------------------------------------------------------------------------

&IF %selected% = TRUE &THEN &DO

   STATISTICS
      SUM area
      END

   /*--------------------------------------------------------------------------
   /* Assign the total area to a variable.
   /*--------------------------------------------------------------------------

   &S total_area = [SHOW STATISTIC 1 1]

   /*--------------------------------------------------------------------------
   /* Repeat the loop for every polygon that belongs to a watershed.
   /*--------------------------------------------------------------------------

   &DO j = 1 &to %n_sel%

      /*-----------------------------------------------------------------------
      /* Select each polygon for a given watershed. Note: the increment number
      /* was created by ordering the constant# and assigning a unique value from
      /* 1 to 1349 to the increment# item.
      /*-----------------------------------------------------------------------

      SELECT ALL
      RESELECT FOR increment# = %k%

      /*-----------------------------------------------------------------------
      /* Assign the record number of the currently selected polygon to a
      /* variable. Leave Arcedit.
      /*-----------------------------------------------------------------------

      &S rn = [SHOW SELECT 1]
      QUIT

      /*-----------------------------------------------------------------------
      /* Go into Tables and select the geo_wshed coverage. Extract the area and
      /* geological type for the current polygon. Calculate the percentage that
      /* this polygon takes up for the total watershed.
      /*-----------------------------------------------------------------------

      TABLES
         SELECT geo_wshedK.pat
```

```
            &S area = [SHOW RECORD %rn% ITEM area]
            &S type = [SHOW RECORD %rn% ITEM TXT_LABEL]
            &S percent = [calc [calc %area% / %total_area%] * 100]

            /*-----------------------------------------------------------------
            /* Select the final_wshed coverage and the current watershed. Assign the
            /* percentage to the appropriate geological type. Leave tables.
            /*-----------------------------------------------------------------

            SELECT ar_kejiarea.pat
            RESELECT constant# = %i%
            CALC %type% = %percent% + %type%
            QUIT

          /*-----------------------------------------------------------------
          /* Go back into Arcedit, increment the counter, and loop again.
          /*-----------------------------------------------------------------

          AE
          EC geo_wshedK
          EF polygon
          &S k = %k% + 1

          &END        /* end the inner do loop for number of polygons for a watershed
       &END           /* end the if..then loop
    &END              /* end the outer do loop for number of watersheds
QUIT
```

APPENDIX 4.7

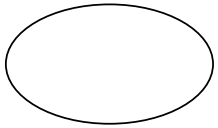
Symbol Legend

Idrisi Raster File

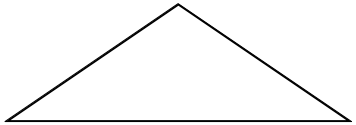


Idrisi Database

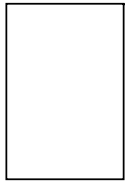
ArcView Shapefile



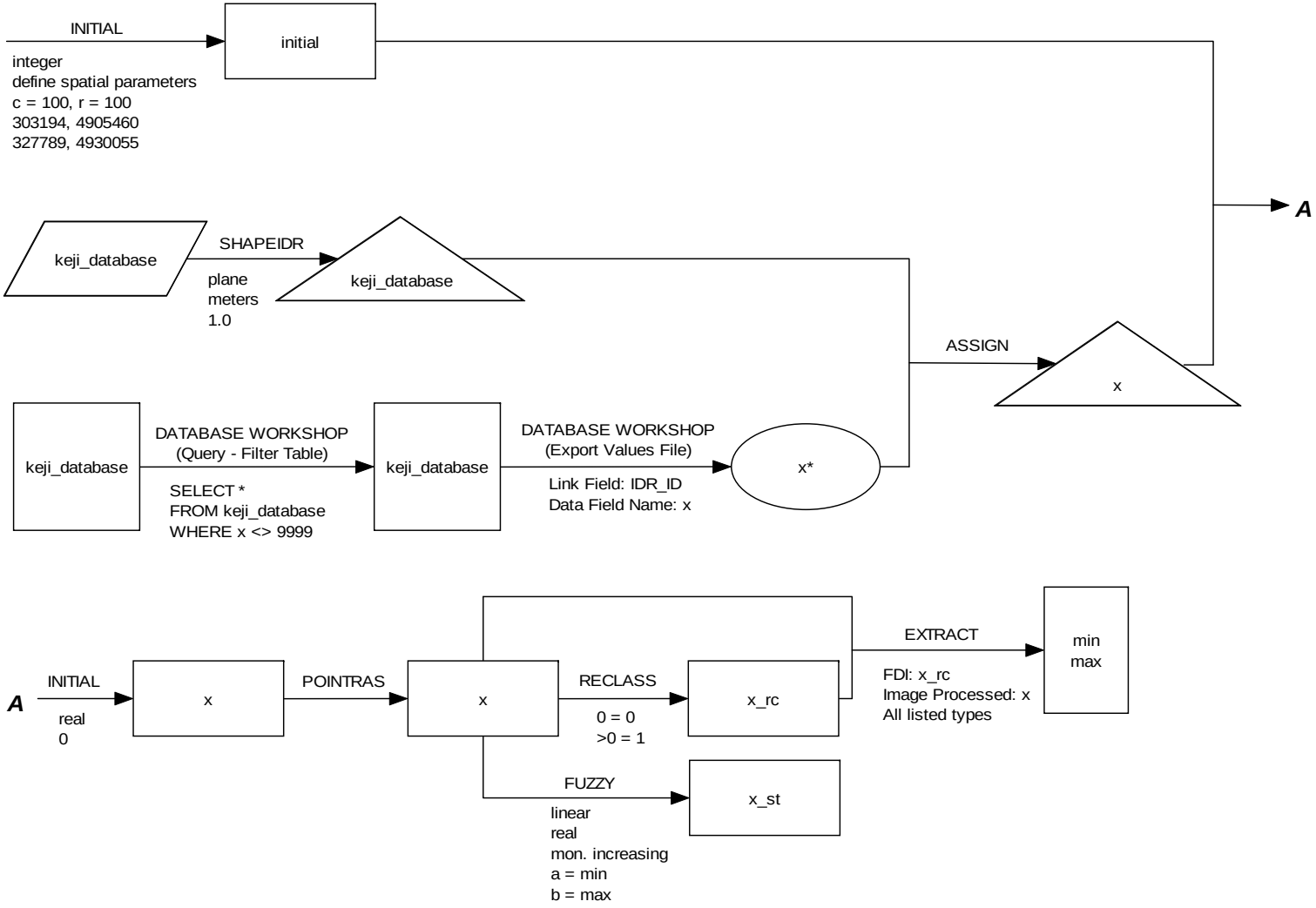
Idrisi Attribute Value File



Idrisi Vector File

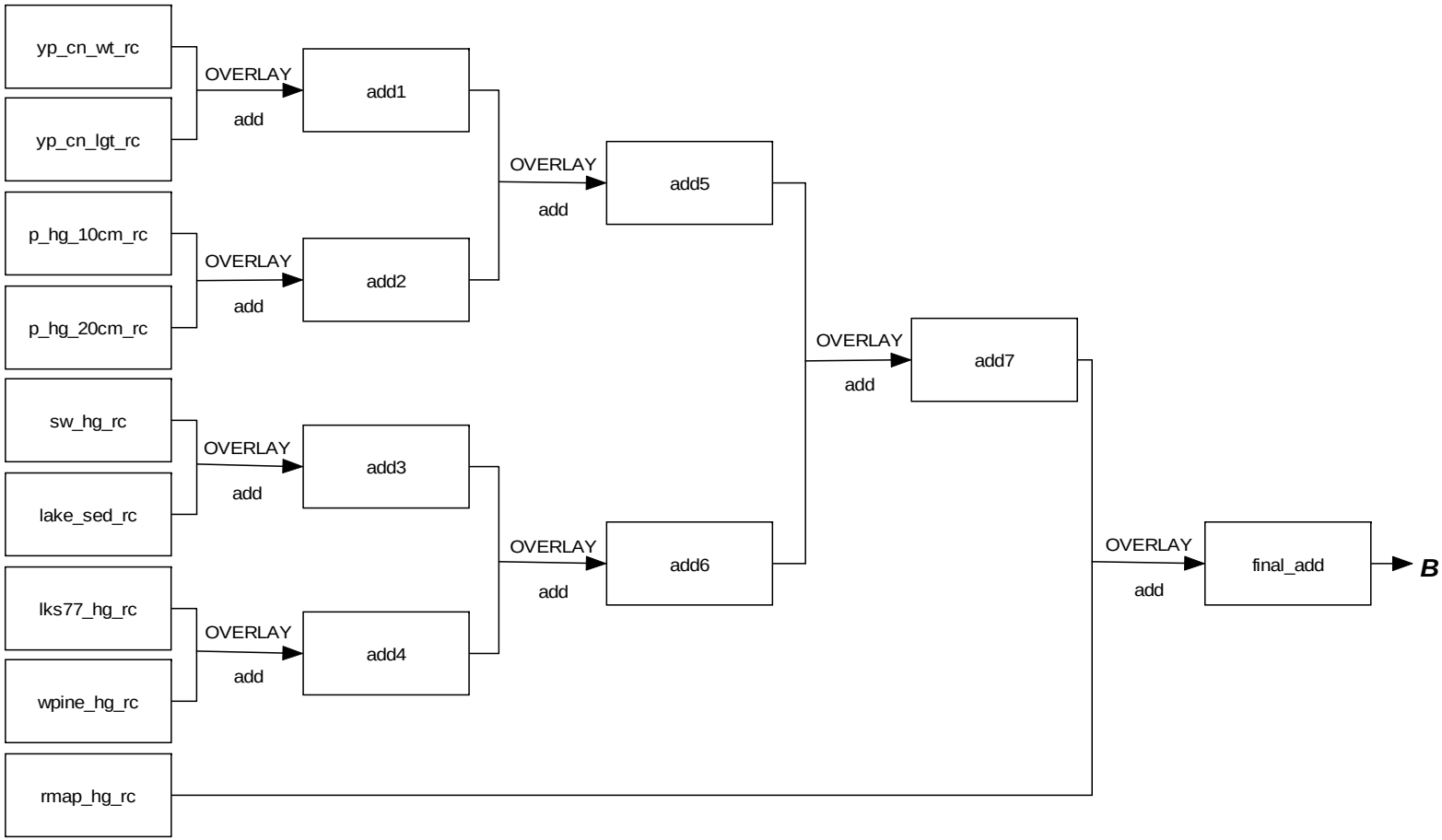


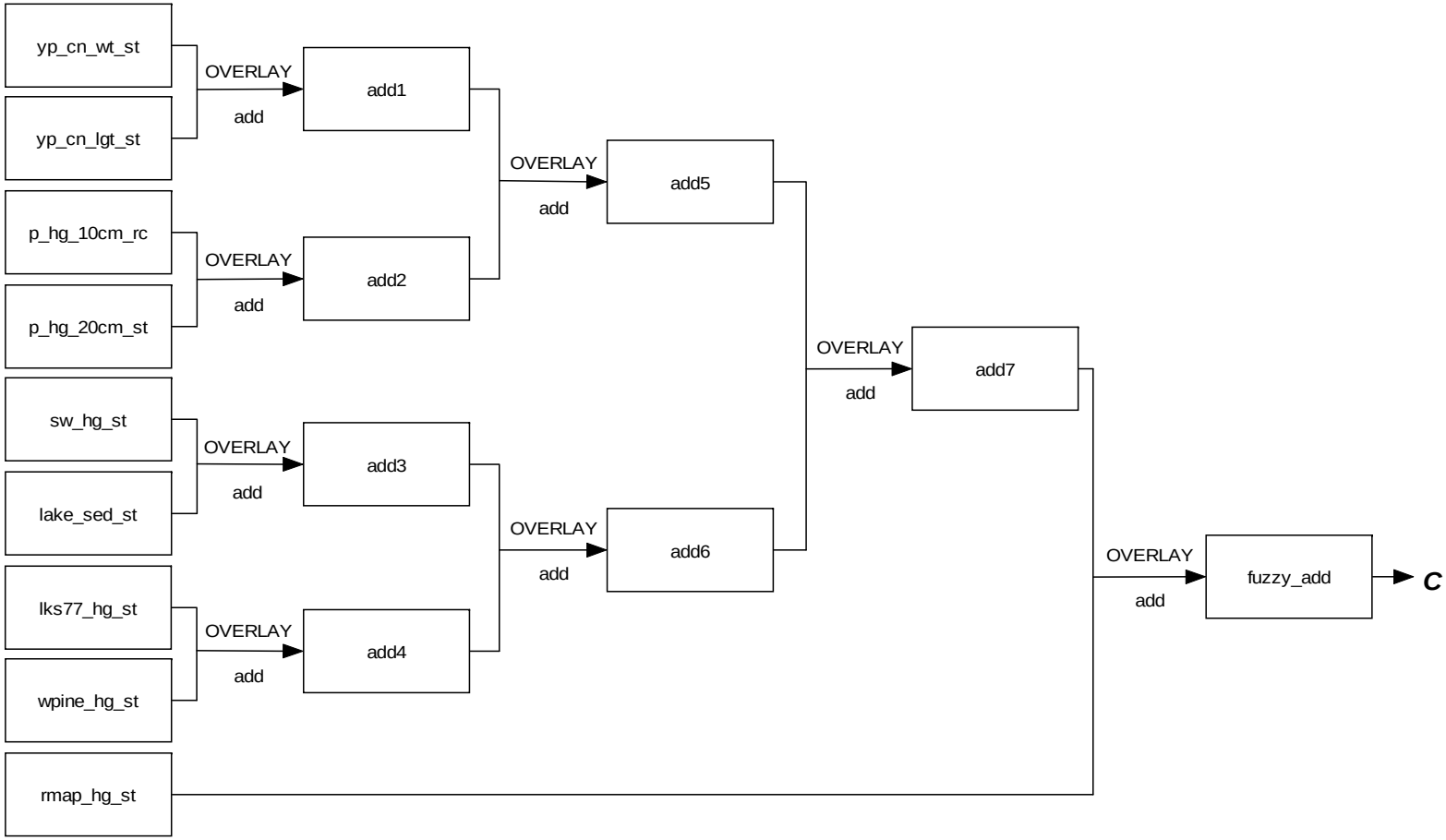
Idrisi Table

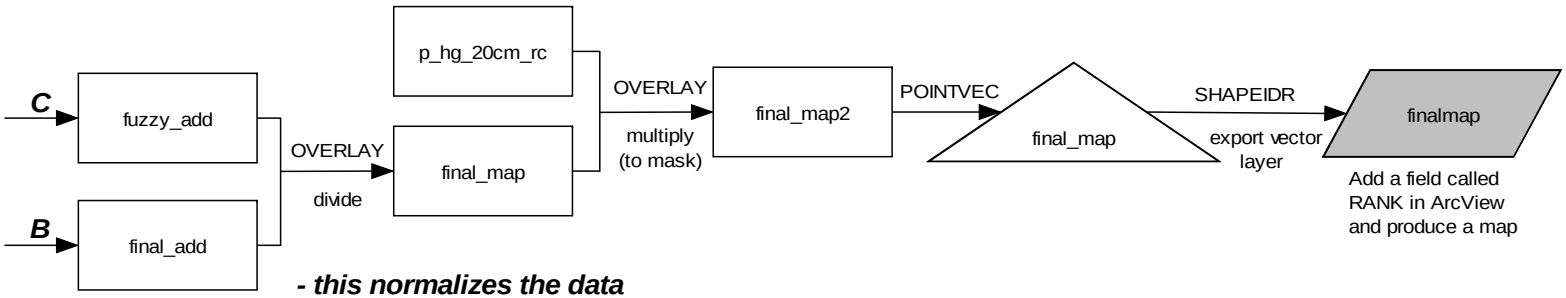


**** NOTE: This analysis was run 9 times, once for each Hg data set (Table 4.bb). 'x' represents the current Hg data set. x = (1) yp_cn_lgt, (2) yp_cn_wt, (3) p_hg_10cm, (4) p_hg_20cm, (5) sw_hg, (6) lake_sed, (7) lks77_hg, (8) wpine_hg, and (9) rmap_hg.***

NON-WEIGHTED ANALYSIS - Figure 4.46

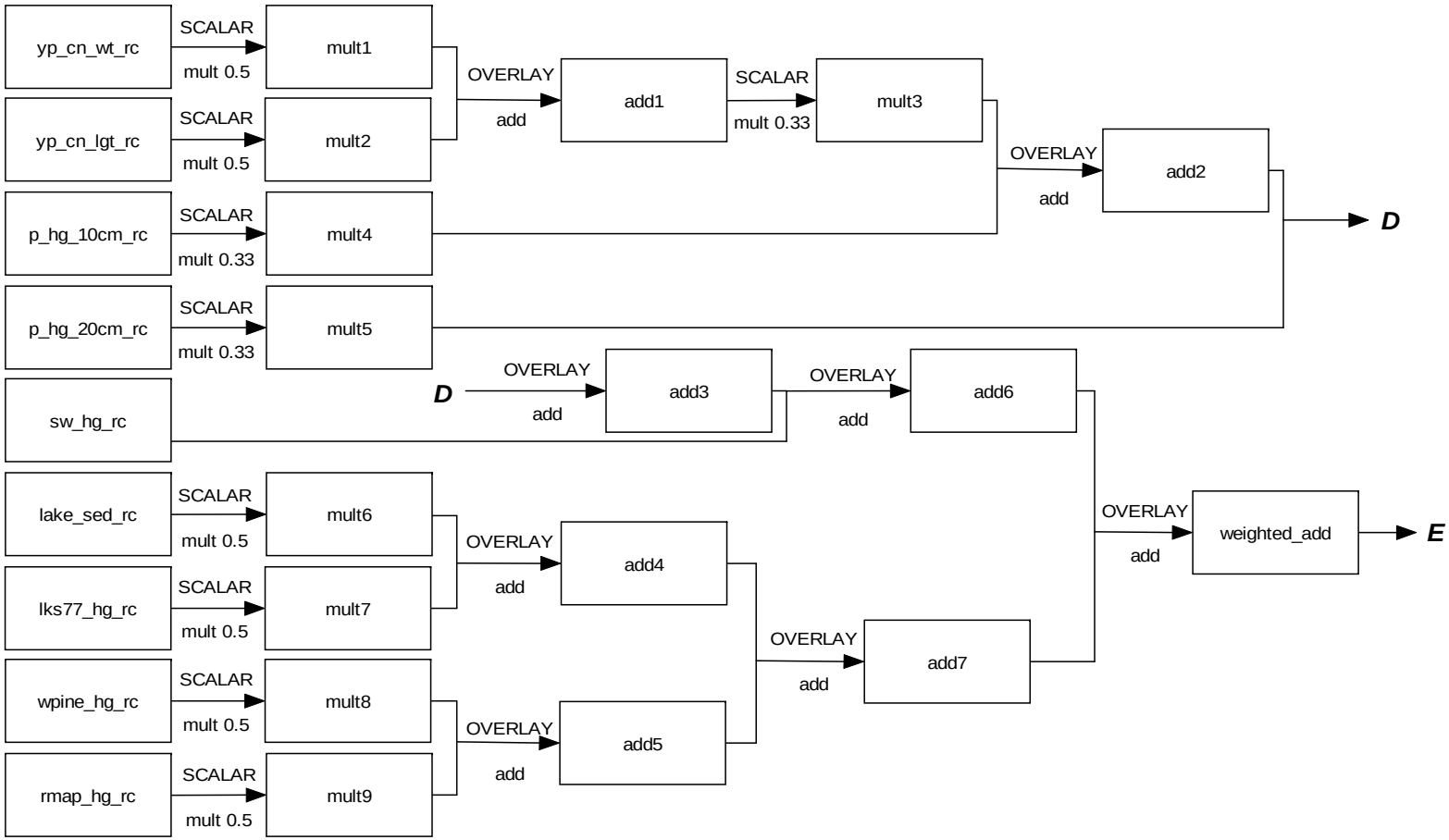


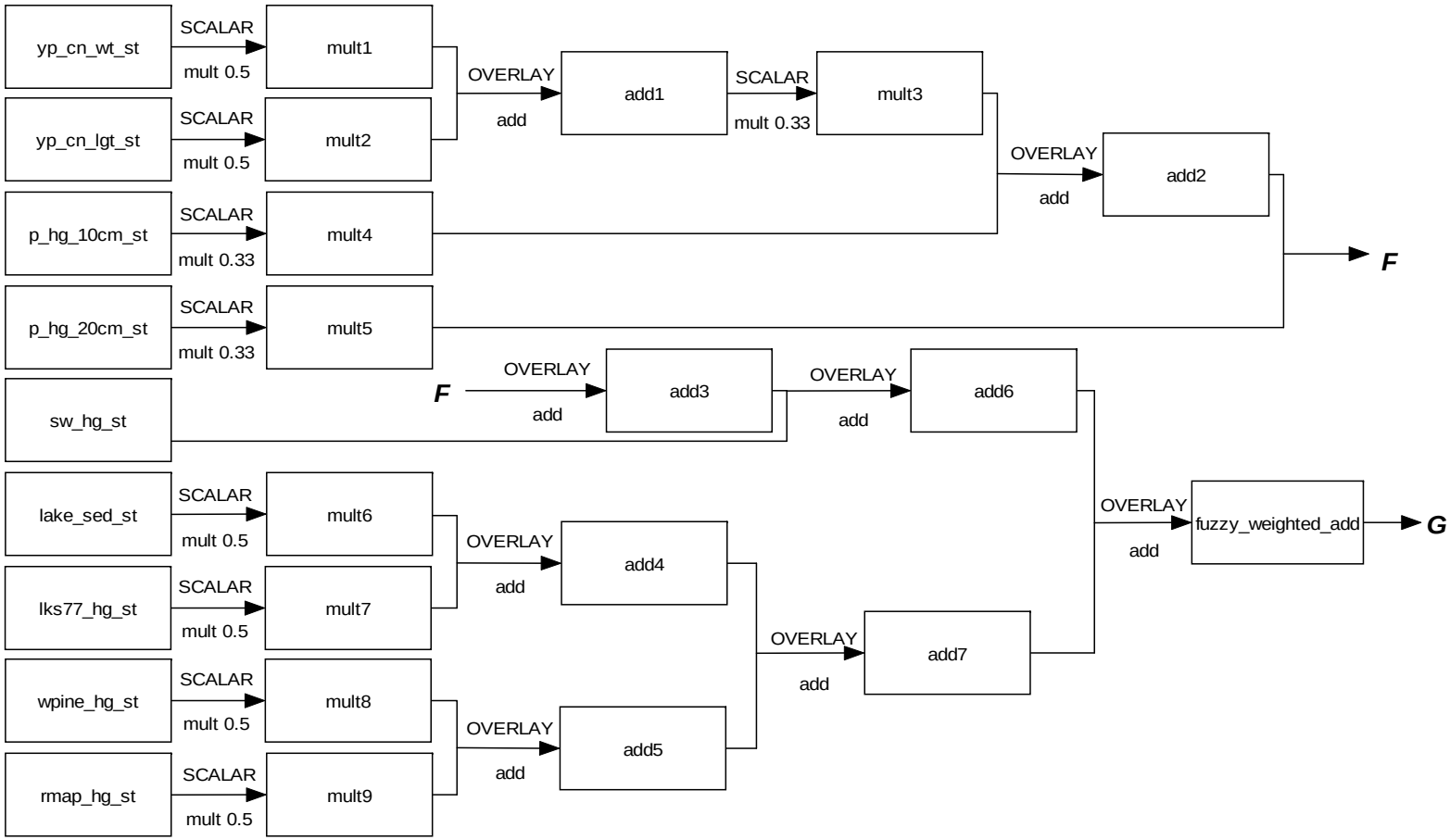

yp_cn_wt_st
yp_cn_lgt_st
p_hg_10cm_rc
p_hg_20cm_st
sw_hg_st
lake_sed_st
lks77_hg_st
wpine_hg_st
rmap_hg_st
OVERLAY
add
add1
add2
add3
add4
add5
add6
add7
fuzzy_add
C

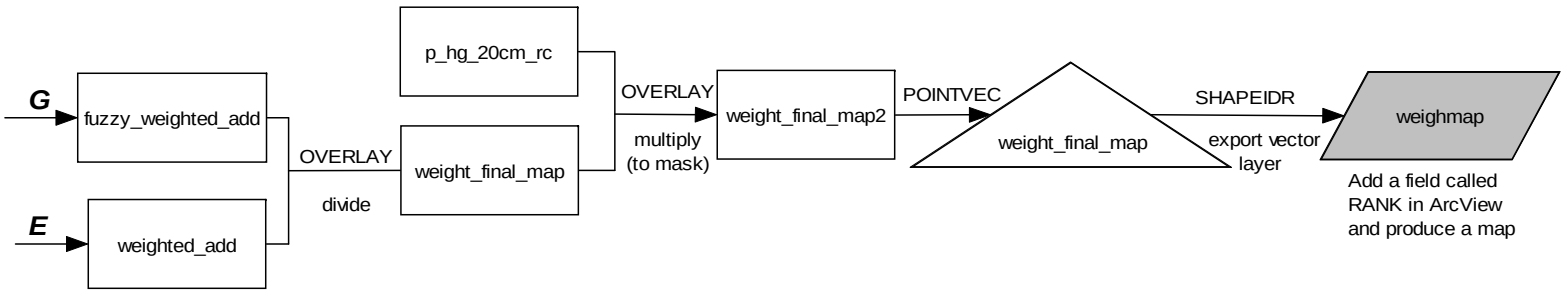


- this normalizes the data

WEIGHTED ANALYSIS - Figure 4.47

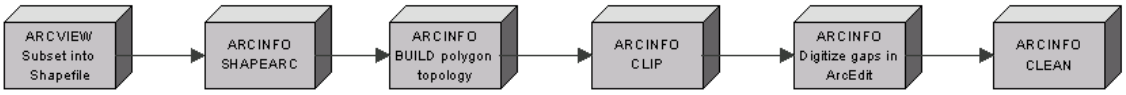



yp_cn_wt_st
SCALAR
mult 0.5
mult1
yp_cn_lgt_st
SCALAR
mult 0.5
mult2
OVERLAY
add
add1
SCALAR
mult 0.33
mult3
p_hg_10cm_st
SCALAR
mult 0.33
mult4
OVERLAY
add
add2
F
p_hg_20cm_st
SCALAR
mult 0.33
mult5
F
OVERLAY
add
add3
OVERLAY
add
add6
sw_hg_st
lake_sed_st
SCALAR
mult 0.5
mult6
lks77_hg_st
SCALAR
mult 0.5
mult7
OVERLAY
add
add4
wpine_hg_st
SCALAR
mult 0.5
mult8
rmap_hg_st
SCALAR
mult 0.5
mult9
OVERLAY
add
add5
OVERLAY
add
add7
OVERLAY
add
fuzzy_weighted_add
G


G
fuzzy_weighted_add
E
weighted_add
OVERLAY
divide
weight_final_map
p_hg_20cm_rc
OVERLAY
multiply
(to mask)
weight_final_map2
POINTVEC
weight_final_map
SHAPEIDR
export vector
layer
weighmap
Add a field called
RANK in ArcView
and produce a map

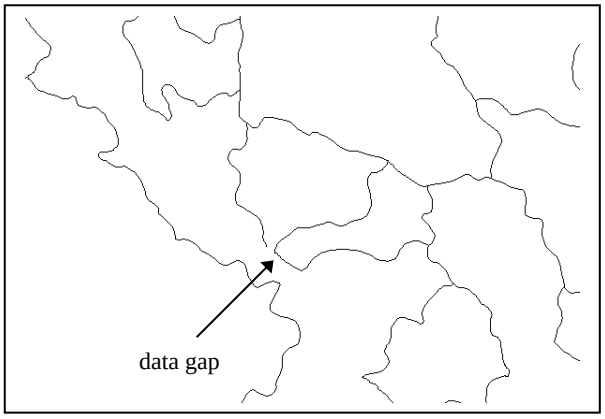
APPENDIX 4.8

Pre-processing for the NSDOE Watershed Data



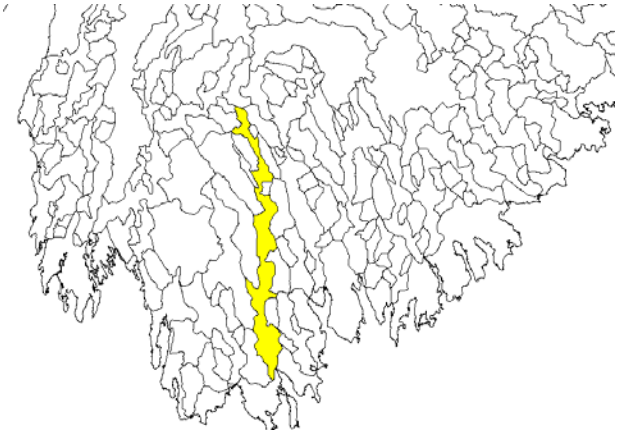
This watershed layer is a 1:50,000 line ARC/INFO coverage with a UTM NAD83 projection. The coverage was obtained from the Nova Scotia Geomatics Center (NSGC) and belongs to NSDOE. Below is an explanation of how the watershed layer was prepared.

Selected items were extracted from the watershed layer in order to obtain a watershed layer without lakes, streams, and county boundaries. The extracted items include the coastline and primary, secondary, and tertiary watershed boundaries (with a few watershed boundaries falling into the subtertiary category). Upon visual examination of the watershed categories, the tertiary class was chosen, along with the few subtertiary classes that were available. This class represents the highest level of detail, and thus the most appropriate for this study. The new theme was converted to an ARC/INFO coverage so further processing could take place (ARC/INFO does not work with ArcView's shapefiles). Polygon topology was built for the coverage; as the original coverage was in line form. The coverage was clipped to the desired study area, and taken into Arcedit for editing (see figure below). Finally, the coverage was cleaned to re-establish topology.



This is a subset of the NSDOE watershed coverage. This example shows the gaps that had to be digitized in order for polygon topology to be built.

There are also some other discrepancies with the watershed data. The main one is the delineation of elongate, narrow watersheds. Although this is uncharacteristic of most of the watersheds in the coverage area (see figure below), they may be legitimate, and for the purposes of this study they have not been modified.



Most of the watersheds in the coverage area tend to be equi-dimensional. A few are remarkably elongate (i.e. where there is a high perimeter to area ratio). The highlighted watershed is an example of one of these elongate watersheds.

APPENDIX 4.9

Pre-processing

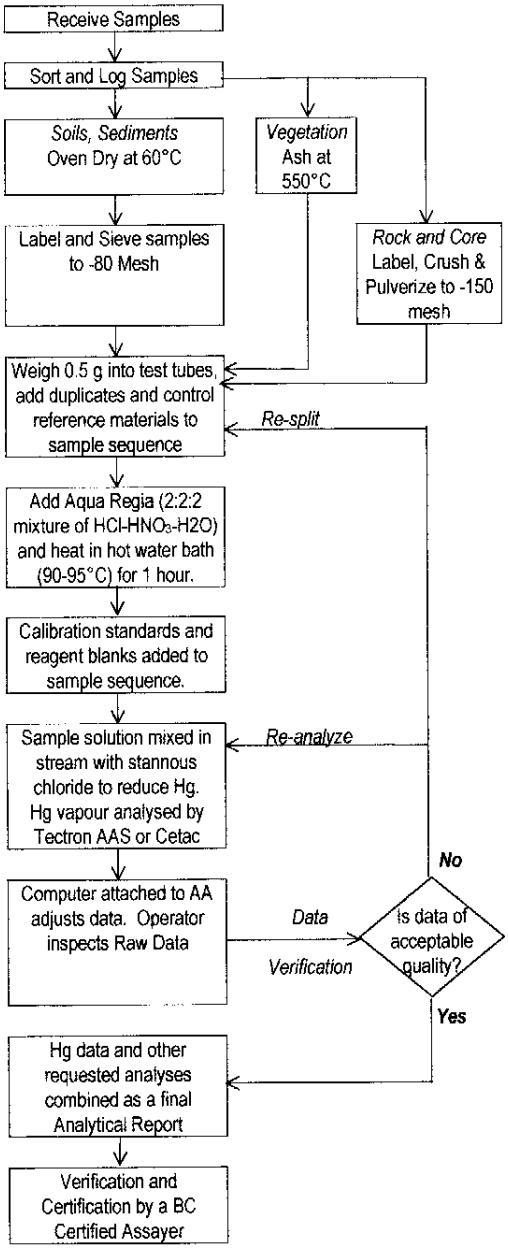
ARC: **INTERSECT lks77_wat 500geology hg_geolc POINT # JOIN**

```
/*****************************************************************************
/* Program Name: HG_GEOL.AML
/* Author: Krista Page
/* Date: June, 2000
/*
/* Main Tasks: Determine the average mercury value for each geological unit and print
/*             the values out to the screen. NOTE: hg_geolc is a clipped area that
/*             corresponds mainly to areas that might drain into the park).
/*
/* Variables:
/*    i - an incrementer for each geological unit in the study area
/*
/*****************************************************************************

/*----------------------------------------------------------------------------
/* Go into tables. This section deletes all the previous statistic files that have
/* been created.
/*----------------------------------------------------------------------------

TABLES

&DO i &LIST 'COMg' 'COMh' 'M-LDbmg' 'M-LDflmg' 'M-LDgd' 'M-LDlmg' 'M-LDmbmg'
   SELECT hg_%i%.sta
   ERASE hg_%i%.sta
   Y
&END

/*----------------------------------------------------------------------------
/* Leave tables. Go into Arcplot. Set the map extent to the specified point
/* coverage (that represents the intersection of Hg and geology).
/*----------------------------------------------------------------------------

QUIT
ARCPLOT
MAPE hg_geolc

/*----------------------------------------------------------------------------
/* For each geological unit that is present in the study area (determined by using
/* the FREQUENCY command on the point coverage), select out each unit and generate
/* statistics for mercury.
/*----------------------------------------------------------------------------

&DO i &LIST 'COMg' 'COMh' 'M-LDbmg' 'M-LDflmg' 'M-LDgd' 'M-LDlmg' 'M-LDmbmg'
   RESELECT hg_geolc point
   ASELECT hg_geolc point txt_label = %i%
   STATISTICS hg_geolc point # hg_%i%.sta
      MEAN mercury
      MAX mercury
      MIN mercury
      STANDARDDEVIATION mercury
      END
&END

/*----------------------------------------------------------------------------
/* For each geological unit that is present in the study area, print the results of
/* the STATISTICS command to the screen. Copy these results into a text file.
/*----------------------------------------------------------------------------

&DO i &LIST 'COMg' 'COMh' 'M-LDbmg' 'M-LDflmg' 'M-LDgd' 'M-LDlmg' 'M-LDmbmg'
   LIST hg_%i%.sta
&END
&RETURN
```

APPENDIX 5.1

ANALYTICAL METHODS FROM ACME LABORATORIES - HG

Analytical Process



Comments

Sample Preparation

Samples are dried (default is 60°C unless specified otherwise by client). Soil, sediments and moss mats are pounded to disaggregate the fine grained material then screened (default is -80 mesh ASTM [-177 microns]). Rocks and drill core are crushed and pulverized (default is 95% -150 mesh ASTM [-100 microns]). Sample splits are weighed (0.5 g) into test tubes. Duplicate splits of crushed (rejects) and pulverized (pulp) fractions are included with every 34 rock samples to define sample homogeneity (reject split) and analytical precision (pulp split). Duplicate pulp splits are included in each batch of 34 soil or sediment samples. A blank and standard STD C3 are included in each batch of samples to monitor accuracy.

Sample Digestion

The Aqua regia mixture of 2:2:2 H_2O-HCl-HNO_3 (ACS grade) is added to each sample. Solutions are then heated in a hot water (90-95°C) bath for 60 minutes.

Sample Analysis

The sample solution is mixed on stream with a 5% stannous chloride solution which is then swept by a carrier gas into the cold vapour cell of a Tectron atomic absorption spectrometer or a Cetac Hg Analyser. Results are adjusted based on standards included in each batch. Quality is evaluated at three separate levels based on results of reference materials, duplicates and prep and analytical blanks included in each batch.

Data Evaluation

Raw and final data undergoes a final verification by a British Columbia Certified Assayer who then signs the Analytical Report before it is released to the client. Chief Assayer is Clarence Leong, other certified assayers are Dean Toye and Jacky Wang.

ANALYTICAL METHODS FROM BONDAR CLEGG LABORATORIES (TRACE ELEMENTS)

SCOPE:

This method is suitable for the semi-quantitative analysis of geological samples within the defined analytical ranges where the limitation of strong mineral acid apply.

PRINCIPLE:

The sample (0.5 grams) is digested with a mixture of hydrochloric and nitric acids. The samples are heated in a hot water bath (90 °C). After the digestion step the samples are cooled, bulked to the final volume and mixed well. The resulting solution is analyzed by ICP-AES. A slightly modified version of this method has been set up for clients with sample matrices containing high total dissolved solids (i.e. high Iron (Fe) concentrations >10%).

APPLICABLE ANALYTE RANGES FOR ICP-AES:

Element	Ag	Bi	Cr	K	Mn	Ni	Sn	Ti	Zr	Al	Ca
Detection Limit	0.2	5	1	0.01	1	1	20	0.01	1	0.01	0.01
Upper Limit	200.0	2000	20000	10.00	20000	20000	2000	10.00	5000	10.00	10.00
Units	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm	%	%
Element	Cu	La	Mo	Pb	Sr	V	Zn	As	Cd	Fe	Li
Detection Limit	1	1	1	2	1	1	1	5	0.2	0.01	1
Upper Limit	10000	2000	10000	10000	2000	20000	10000	10000	2000.0	10.00	20000
Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm
Element	Na	Sb	Ta	W	Ba	Co	Ga	Mg	Nb	Sc	Te
Detection Limit	0.01	5	10	20	1	1	2	0.01	1	5	10
Upper Limit	10.00	2000	1000	2000	2000	20000	10000	10.00	10000	2000	2000
Units	%	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm

Element	Y
Detection Limit	1
Upper Limit	2000
Units	ppm

PRECISION:

The tolerance criteria for variation of analytical data result from all stages of the analysis and are subject to the sample matrix and the specific technique used.

Expected tolerance criteria at various concentrations for this method are as follows:

Element	Duplicate of Reference Value		Tolerance
Ag, Cd	Detection Limit	0.2	+/- 100%
(ppm)	0.4	1.0	50%
	1.2	5.0	25%
	5.2	50.0	15%
	50.2	200.0	10%
		>200.0	15%
Bi, Sb, Sc, As, Ce	Detection Limit	5	+/- 100%
(ppm)	10	25	50%
	30	50	25%
	55	500	15%
	505	2000	10%
		>2000	15%
Cr, V, Zn, Li, Y, Nb,	Detection Limit	1	+/- 100%
Ba, La, Sr, Zr	2	10	50%
(ppm)	11	20	25%
	21	200	15%
	201	2000	10%
		> 2000	15%
K, Ti, Al, Ca, Fe, Na,	Detection Limit	0.01	+/- 100%
Mg, S	0.02	0.05	50%
(%)	0.06	0.10	25%
	0.11	1.00	15%
	1.01	10.00	10%
		>10.00	15%
Sn, W	Detection Limit	20	+/- 100%
(ppm)	40	100	50%
	120	200	25%
	220	2000	10%
		>2000	15%
Ni, Cu, Co, Mn, Mo,	Detection Limit	1	+/- 100%
Sr(ppm)	2	5	50%
	6	10	25%
	11	100	15%
	101	1000	10%
		>1000	15%
Pb, Ga	Detection Limit	2	+/- 100%
(ppm)	4	10	50%
	12	20	25%
	22	200	15%
	202	2000	10%
		> 2000	15%
Te, Ta, P, Se	Detection Limit	10	+/- 100%
(ppm)	20	50	50%
	60	100	25%
	110	1000	10%
		>1000	15%
Be, Hg	Detection Limit	0.5	+/- 100%
(ppm)	1.0	2.5	50%
	2.0	25.0	25%
	25.5	500.0	10%
		>500.0	15%

This table is intended as a guideline in the absence of repeatability and reproducibility data.

ANALYTICAL METHODS FROM BONDAR CLEGG LABORATORIES (AU)

SCOPE:

This method is suitable for the semi-quantitative analysis of gold, platinum and palladium in geochemical samples within the defined analytical ranges where the limitations of a fire assay preconcentration are acceptable.

PRINCIPLE:

The sample (either 30 gram or 50 gram) is weighted into the fire assay pot. Litharge is added to the sample and the mixture is fluxed in a furnace. The precious metals are collected with lead. The lead button is cupelled to an Ag/Au bead. The bead is hot digested with 50% HNO3 followed by concentrated HCl. The sample is bulked to the final volume and analyzed by Induced Coupled Plasma Atomic Emissions Spectrometer (ICP-AES).

APPLICABLE ANALYTE RANGES FOR ICP-ATOMIC EMISSION SPECTROSCOPY:

Element Code	Unit	Detection Limit	Upper Limit
AuD	ppb	1	2000
AuD5	ppb	1	1400
PDD	ppb	1	10000
PDD5	ppb	1	10000
PTD	ppb	5	10000
PTD5	ppb	5	10000

PRECISION:

The tolerance criteria for variation of analytical data result from all stages of the analysis and are subject to the sample matrix and the specific technique used. Expected tolerance criteria at various concentrations for this method are as follows:

Element Code	Standard Value	Tolerance
AuD, AuD5, PDD, PDD5 (ppb)	Detection Limit 1	+/- 100%
	2 - 4	50%
	5 - 10	25%
	11 - 15	20%
	16 - 100	15%
	101 - 1000	10%
	>1000	15%
PTD, PTD5 (ppb)	Detection Limit 5	+/- 100%
	10 - 15	50%
	20 - 100	25%
	105 - 200	15%
	205 - 1000	10%
	>1000	15%

This table is intended as a guideline in the absence of repeatability and reproducibility data.

APPENDIX 5.2

Sample ID	UTM_83 Easting	UTM_83 Northing	NTS Map Sheet	Rock Type	Hg (ppb)	Au (ppb)
KP-R002	303018	4952871	21A11	Mafic Porphyry (DCmp)	2	2
KP-R003	286920	4943750	21A12	Mafic Intrusion (ODM)	19.9	1
KP-R004	286920	4943750	21A12	Mafic Intrusion (ODM)	24	< 1
KP-R005	288350	4942187	21A12	Mafic Intrusion (ODM)	2	< 1
KP-R007	290236	4939284	21A12	Mafic Intrusion (ODM)	0.8	2
KP-R009	280074	4930357	21A05	Mafic Intrusion (ODM)	3	2
KP-R010	283089	4940308	21A12	Mafic Intrusion (ODM)	8.7	2
KP-R011	281500	4940395	21A12	Mafic Intrusion (ODM)	1.8	4
KP-R012	264682	4897388	21A04	Mafic Intrusion (DM)	1.9	1
KP-R013	290956	4886173	21A04	Davis Lake Leucomonzogranite (DClmDL)	0.9	< 1
KP-R014	290956	4886173	21A04	Davis Lake Leucomonzogranite (DClmDL)	2	2
KP-R015	290956	4886173	21A04	Davis Lake Leucomonzogranite (DClmDL)	1.9	2
KP-R018	391009	4960517	21A16	Lake Lewis Leucogranite (DClgLL)	0.8	< 1
KP-R020	392356	4961507	21A16	Lake Lewis Leucogranite (DClgLL)	1.5	< 1
KP-R023	380101	4953330	21A10	Keddy-Reeves Leucogranite (DClgKR)	1.3	1
KP-R024	363932	4949374	21A10	Mafic Porphyry (DCmp)	0.6	1
KP-R025	363932	4949374	21A10	Mafic Porphyry (DCmp)	0.8	2
KP-R026	364098	4962888	21A15	Murphy Lake Leucogranite (DClgML)	1.9	< 1
KP-R029	335081	4971022	21A14	Mafic Intrusion (DM)	< 0.1	< 1
KP-R030	334750	4971664	21A14	Mafic Intrusion (DM)	2.5	< 1
KP-R031	338422	4973798	21A14	Mafic Intrusion (DM)	9.3	5
KP-R033	312170	4910072	21A06	Undifferentiated Mafic Granitoid (u)	1.3	< 1
KP-R034	371686	4975296	21A15	Murphy Lake Leucogranite (DClgML)	2.6	< 1
KP-R035	371302	4977376	21A15	Murphy Lake Leucogranite (DClgML)	0.6	4
KP-R037	355474	4972865	21A15	Mafic Porphyry (DCgdmp)	< 0.1	< 1
KP-R038	350283	4969852	21A15	Mafic Porphyry (DCgdmp)	4.1	< 1
KP-R040	349867	4970053	21A15	Mafic Porphyry (DCgdmp)	1.5	< 1
KP-R041	349867	4970053	21A15	Mafic Porphyry (DCgdmp)	2	< 1
KP-R042	341877	4971339	21A14	Mafic Intrusion (DM)	< 0.1	< 1
KP-R043	355182	4969821	21A15	Boot Lake Granodiorite (DCgdBL)	9.6	< 1
Dup R024					< 0.1	8
Dup R042					< 0.1	< 1
Dup R020 (lab)					0.9	
CH-REF-1					3.6	807
CH-REF-1(standard)					4.1	528
SO-2 (lab)					78.1	
SO-2 (lab)					79.3	
SO-2 (standard)					82	

Sample ID	Ag (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Mo (ppm)	Ni (ppm)	Co (ppm)	Cd (ppm)	Bi (ppm)	As (ppm)
KP-R002	< 0.2	19	48	186	5	20	13	2.7	< 5	12
KP-R003	< 0.2	10	2	78	3	17	32	0.3	< 5	< 5
KP-R004	< 0.2	24	2	97	5	34	30	0.4	< 5	< 5
KP-R005	< 0.2	59	4	74	3	80	41	0.3	< 5	< 5
KP-R007	< 0.2	72	< 2	29	< 1	9	8	< 0.2	< 5	< 5
KP-R009	< 0.2	50	2	31	2	90	20	< 0.2	< 5	< 5
KP-R010	< 0.2	86	< 2	49	2	184	47	0.5	< 5	< 5
KP-R011	< 0.2	32	9	118	3	64	40	0.9	< 5	< 5
KP-R012	< 0.2	41	9	45	3	15	21	0.4	< 5	19
KP-R013	< 0.2	2	4	43	< 1	< 1	2	< 0.2	< 5	< 5
KP-R014	< 0.2	2	4	40	< 1	1	2	< 0.2	< 5	< 5
KP-R015	< 0.2	2	3	18	< 1	< 1	1	< 0.2	< 5	< 5
KP-R018	< 0.2	2	3	18	< 1	< 1	< 1	< 0.2	< 5	< 5
KP-R020	< 0.2	3	2	5	< 1	< 1	< 1	< 0.2	< 5	< 5
KP-R023	< 0.2	1	< 2	12	< 1	< 1	< 1	< 0.2	< 5	< 5
KP-R024	< 0.2	4	3	63	< 1	10	8	0.4	< 5	66
KP-R025	< 0.2	10	3	61	< 1	9	7	0.4	< 5	28
KP-R026	< 0.2	2	2	5	< 1	< 1	< 1	< 0.2	< 5	< 5
KP-R029	< 0.2	38	3	57	1	10	18	0.2	< 5	< 5
KP-R030	< 0.2	65	7	69	3	20	21	2	< 5	< 5
KP-R031	< 0.2	55	4	26	1	59	16	< 0.2	< 5	< 5
KP-R033	< 0.2	5	10	73	< 1	9	8	0.3	< 5	< 5
KP-R034	< 0.2	1	2	14	< 1	2	< 1	< 0.2	< 5	< 5
KP-R035	< 0.2	2	< 2	9	< 1	< 1	< 1	< 0.2	< 5	< 5
KP-R037	< 0.2	6	7	86	< 1	14	12	0.3	< 5	8
KP-R038	< 0.2	3	8	94	< 1	11	10	0.3	< 5	20
KP-R040	< 0.2	8	5	64	< 1	10	8	0.2	< 5	< 5
KP-R041	< 0.2	3	< 2	30	< 1	6	8	< 0.2	< 5	< 5
KP-R042	< 0.2	69	< 2	27	1	96	29	0.3	< 5	< 5
KP-R043	< 0.2	25	5	83	1	32	18	0.4	< 5	14
Dup R024	< 0.2	3	5	64	< 1	11	9	0.5	< 5	70
Dup R042	< 0.2	63	< 2	25	< 1	88	26	0.3	< 5	< 5
Dup R020 (lab)										
CH-REF-1	< 0.2	10	25	45	2	9	5	12.8	< 5	5438
CH-REF-1(standard)	< 0.2	10	24	44	2	9	3	< 5	< 2	4535
SO-2 (lab)										
SO-2 (lab)										
SO-2 (standard)										

Sample ID	Sb (ppm)	Fe (%)	Mn (ppm)	Te (ppm)	Ba (ppm)	Cr (ppm)	V (ppm)	Sn (ppm)	W (ppm)	La (ppm)
KP-R002	< 5	3.9	633	< 10	156	34	58	< 20	< 20	20
KP-R003	< 5	7.04	1166	13	37	24	117	< 20	< 20	25
KP-R004	< 5	6.32	886	14	324	65	119	< 20	< 20	34
KP-R005	< 5	7.56	835	< 10	24	86	160	< 20	< 20	11
KP-R007	< 5	1.89	332	< 10	31	17	56	< 20	< 20	5
KP-R009	< 5	2.48	202	< 10	167	157	50	< 20	< 20	13
KP-R010	< 5	5.18	476	12	23	51	58	< 20	< 20	4
KP-R011	< 5	7.76	743	< 10	100	93	165	< 20	< 20	21
KP-R012	< 5	3.25	308	< 10	10	22	85	< 20	< 20	14
KP-R013	< 5	0.63	133	< 10	3	6	1	< 20	< 20	7
KP-R014	< 5	0.96	140	< 10	9	6	3	< 20	< 20	13
KP-R015	< 5	0.85	154	< 10	2	4	< 1	< 20	< 20	< 1
KP-R018	< 5	0.3	135	< 10	12	7	< 1	< 20	< 20	2
KP-R020	< 5	0.23	158	< 10	7	6	< 1	< 20	< 20	3
KP-R023	< 5	0.19	84	< 10	4	4	< 1	< 20	< 20	2
KP-R024	< 5	2.86	342	< 10	103	25	40	< 20	< 20	17
KP-R025	< 5	2.75	305	< 10	78	27	39	< 20	< 20	17
KP-R026	< 5	0.16	55	< 10	2	6	< 1	< 20	< 20	< 1
KP-R029	< 5	3.47	343	< 10	13	2	121	< 20	< 20	9
KP-R030	< 5	3.41	419	< 10	23	5	77	< 20	< 20	6
KP-R031	< 5	1.69	138	< 10	35	38	27	< 20	< 20	4
KP-R033	< 5	2.78	395	< 10	80	21	35	< 20	< 20	15
KP-R034	< 5	0.22	87	< 10	5	5	< 1	< 20	< 20	< 1
KP-R035	< 5	0.14	75	< 10	2	6	< 1	< 20	< 20	< 1
KP-R037	< 5	3.83	733	< 10	338	27	51	< 20	< 20	21
KP-R038	< 5	3.22	603	< 10	270	24	43	< 20	< 20	16
KP-R040	< 5	2.63	523	< 10	214	23	35	< 20	< 20	12
KP-R041	< 5	2.15	517	< 10	62	18	21	< 20	< 20	17
KP-R042	< 5	3.53	297	< 10	13	30	59	< 20	< 20	6
KP-R043	< 5	4.06	840	< 10	157	69	76	< 20	< 20	8
Dup R024	< 5	2.86	355	< 10	108	23	40	< 20	< 20	16
Dup R042	< 5	3.46	270	< 10	13	30	57	< 20	< 20	6
Dup R020 (lab)										
CH-REF-1	< 5	1.44	336	< 10	24	21	11	< 20	< 20	2
CH-REF-1(standard)	3	1.6	312	0.1	28	29	15	N/A	< 10	2
SO-2 (lab)										
SO-2 (lab)										
SO-2 (standard)										

Sample ID	Al (%)	Mg (%)	Ca (%)	Na (%)	K (%)	Sr (ppm)	Y (ppm)	Ga (ppm)	Li (ppm)	Nb (ppm)
KP-R002	2.05	0.89	0.25	0.04	1.29	5	17	8	78	3
KP-R003	2.51	1.91	5.06	0.04	0.13	178	13	11	64	7
KP-R004	2.94	2.77	3.22	0.06	0.87	150	11	14	54	9
KP-R005	4.46	3.33	2.91	0.25	0.03	110	12	12	73	12
KP-R007	2.67	0.43	1.65	0.39	0.03	65	5	5	9	3
KP-R009	2.15	1.73	1.32	0.27	0.5	108	6	5	15	2
KP-R010	4.14	3.75	1.4	0.23	0.15	119	6	7	44	2
KP-R011	3.27	3.4	2.52	0.05	0.22	125	9	19	43	14
KP-R012	1.78	0.95	1.7	0.14	0.07	31	9	6	28	6
KP-R013	0.39	0.03	0.29	0.03	0.26	4	5	2	47	< 1
KP-R014	0.52	0.06	0.28	0.03	0.32	6	13	3	60	2
KP-R015	0.42	0.03	0.38	0.04	0.18	6	6	4	28	2
KP-R018	0.47	0.02	0.26	0.04	0.27	6	5	2	139	< 1
KP-R020	0.5	0.03	0.47	0.04	0.19	4	5	3	26	< 1
KP-R023	0.37	< 0.01	0.37	0.03	0.2	5	3	< 2	99	< 1
KP-R024	1.72	0.71	0.19	0.04	1.01	5	8	8	93	2
KP-R025	1.73	0.71	0.17	0.03	1.08	5	8	7	61	2
KP-R026	0.23	< 0.01	0.19	0.03	0.17	5	1	< 2	28	< 1
KP-R029	1.44	0.81	1.37	0.19	0.06	11	7	7	28	8
KP-R030	1.88	1.2	1.53	0.18	0.08	13	6	7	54	5
KP-R031	1.78	0.98	0.93	0.21	0.08	37	4	4	18	< 1
KP-R033	1.69	0.61	0.19	0.05	1.12	8	10	9	80	2
KP-R034	0.31	< 0.01	0.19	0.04	0.18	9	2	2	60	1
KP-R035	0.25	< 0.01	0.25	0.02	0.14	13	1	< 2	44	< 1
KP-R037	2.12	0.79	0.28	0.04	1.24	6	18	10	74	3
KP-R038	1.75	0.67	0.19	0.03	1	6	16	9	86	2
KP-R040	1.49	0.54	0.15	0.04	1	4	12	7	77	2
KP-R041	1.12	0.54	0.15	0.03	0.31	4	17	6	59	< 1
KP-R042	3.26	1.96	1.4	0.22	0.09	83	4	7	81	4
KP-R043	2.63	1.19	0.13	0.04	1.26	6	5	9	75	5
Dup R024	1.78	0.74	0.2	0.03	1.03	5	8	8	93	2
Dup R042	3	1.8	1.31	0.22	0.09	83	4	6	79	3
Dup R020 (lab)										
CH-REF-1	0.62	0.34	0.94	0.03	0.16	45	2	2	12	< 1
CH-REF-1(standard)	0.45	0.44	0.78	0.02	0.13	47	N/A	2	N/A	N/A
SO-2 (lab)										
SO-2 (lab)										
SO-2 (standard)										

Sample ID	Sc (ppm)	Ta (ppm)	Ti (%)	Zr (ppm)	S (%)
KP-R002	9	< 10	0.282	< 1	0.14
KP-R003	8	< 10	< 0.01	6	0.2
KP-R004	7	< 10	0.408	3	0.2
KP-R005	14	< 10	0.287	8	0.27
KP-R007	< 5	< 10	0.212	14	< 0.01
KP-R009	< 5	< 10	0.109	< 1	< 0.01
KP-R010	< 5	< 10	0.091	< 1	0.06
KP-R011	11	< 10	0.309	16	0.2
KP-R012	6	< 10	0.097	< 1	0.03
KP-R013	< 5	< 10	0.012	8	< 0.01
KP-R014	< 5	< 10	0.04	13	< 0.01
KP-R015	< 5	< 10	< 0.01	5	< 0.01
KP-R018	< 5	< 10	< 0.01	6	< 0.01
KP-R020	< 5	< 10	< 0.01	11	< 0.01
KP-R023	< 5	< 10	< 0.01	4	< 0.01
KP-R024	7	< 10	0.219	< 1	< 0.01
KP-R025	7	< 10	0.218	< 1	0.01
KP-R026	< 5	< 10	< 0.01	2	< 0.01
KP-R029	< 5	< 10	0.137	2	< 0.01
KP-R030	< 5	< 10	0.126	< 1	< 0.01
KP-R031	< 5	< 10	0.053	< 1	< 0.01
KP-R033	9	< 10	0.264	< 1	< 0.01
KP-R034	< 5	< 10	< 0.01	2	< 0.01
KP-R035	< 5	< 10	< 0.01	1	< 0.01
KP-R037	10	< 10	0.369	< 1	< 0.01
KP-R038	9	< 10	0.215	8	< 0.01
KP-R040	7	< 10	0.232	3	< 0.01
KP-R041	< 5	< 10	0.079	5	< 0.01
KP-R042	< 5	< 10	0.115	< 1	< 0.01
KP-R043	10	< 10	0.294	< 1	0.18
Dup R024	7	< 10	0.226	< 1	< 0.01
Dup R042	< 5	< 10	0.105	< 1	< 0.01
Dup R020 (lab)					
CH-REF-1	< 5	< 10	0.014	< 1	0.37
CH-REF-1(standard)	1	0.1	0.012	N/A	0.28
SO-2 (lab)					
SO-2 (lab)					
SO-2 (standard)					

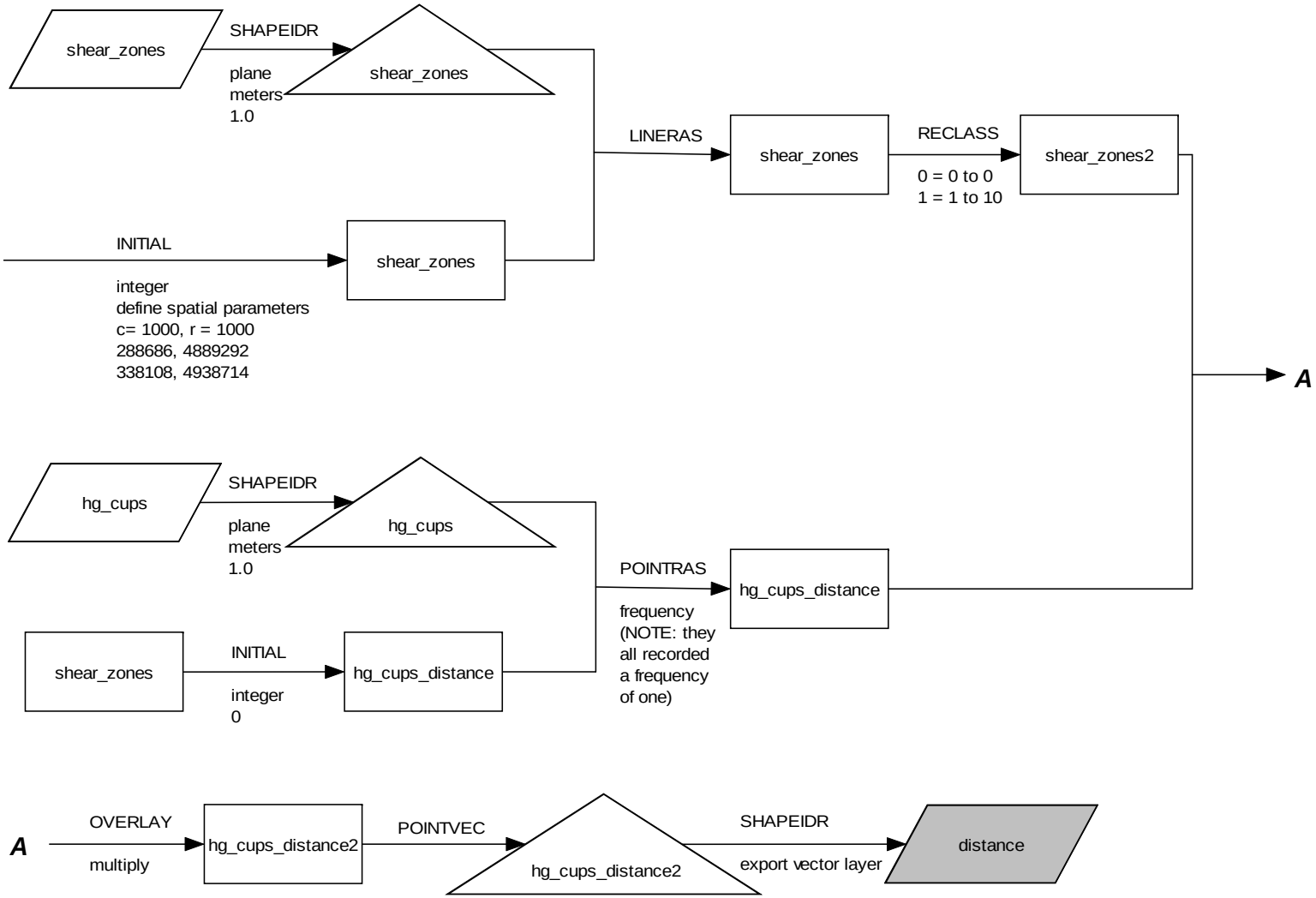
APPENDIX 6.2

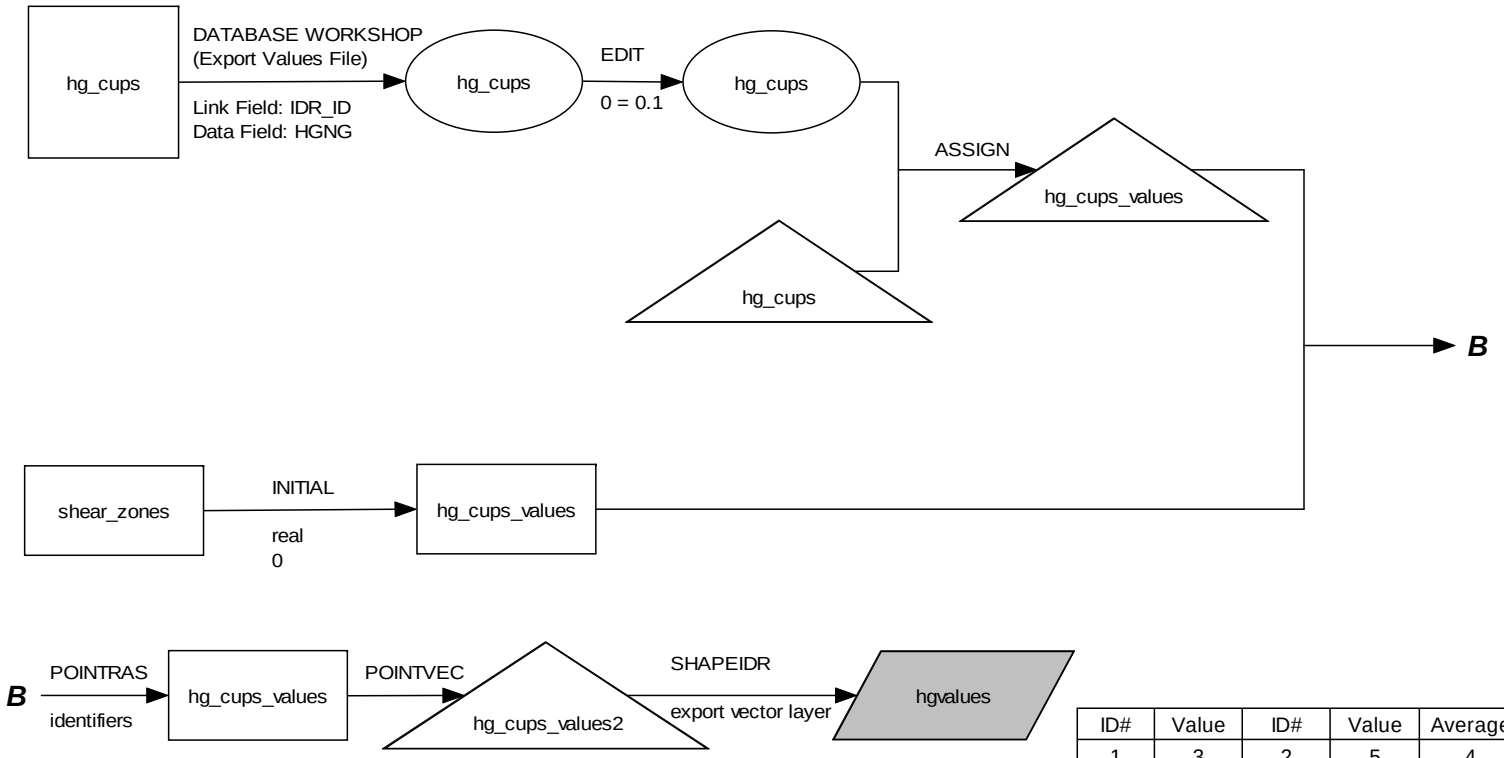
ID	DATE	UTM_E83	UTM_N83	UTM_E27	UTM_N27	FIELD_DUPE	HGNG
K-001	Sept 11/00	317961	4905133	317908	4904909		3
K-002	Sept 11/00	317961	4905133	317908	4904909	K-001	5
K-003	Sept 11/00	318148	4905127	318095	4904903		5
K-004	Sept 11/00	318308	4905036	318255	4904812		4
K-005	Sept 11/00	318479	4904914	318426	4904690		1
K-006	Sept 11/00	318627	4904773	318574	4904549		8
K-007	Sept 11/00	318765	4904639	318712	4904415		11
K-008	Sept 11/00	318900	4904497	318847	4904273		1
K-009	Sept 11/00	319047	4904361	318994	4904137		3
K-010	Sept 11/00	319173	4904205	319120	4903981		2
K-011	Sept 11/00	319173	4904205	319120	4903981	K-010	10
K-012	Sept 11/00	319349	4904111	319296	4903887		4
K-013	Sept 11/00	319407	4904039	319354	4903815		1
K-014	Sept 11/00	319467	4903953	319414	4903729		1
K-015	Sept 11/00	319536	4903874	319483	4903650		13
K-016	Sept 11/00	319595	4903795	319542	4903571		5
K-017	Sept 11/00	319634	4903699	319581	4903475		2
K-018	Sept 11/00	319689	4903616	319636	4903392		11
K-019	Sept 11/00	319675	4903503	319622	4903279		1
K-020	Sept 11/00	319637	4903409	319584	4903185		1
K-021	Sept 11/00	319633	4903308	319580	4903084		2
K-022	Sept 11/00	319622	4903203	319569	4902979		4
K-023	Sept 11/00	319661	4903120	319608	4902896		12
K-024	Sept 11/00	319751	4903051	319698	4902827		1
K-025	Sept 11/00	319805	4902955	319752	4902731		2
K-026	Sept 11/00	319863	4902878	319810	4902654		2
K-027	Sept 11/00	319950	4902827	319897	4902603		3
K-028	Sept 11/00	320051	4902796	319998	4902572		8
K-029	Sept 11/00	320224	4902709	320171	4902485		9
K-030	Sept 11/00	320224	4902709	320171	4902485	K-029	3
K-031	Sept 11/00	320412	4902684	320359	4902460		1
K-032	Sept 11/00	320590	4902573	320537	4902349		15
K-033	Sept 11/00	320721	4902424	320668	4902200		1
K-034	Sept 11/00	320903	4902365	320850	4902141		4
K-035	Sept 11/00	321089	4902379	321036	4902155		5
K-036	Sept 11/00	321300	4902375	321247	4902151		1
K-037	Sept 11/00	321488	4902309	321435	4902085		3
K-038	Sept 11/00	321654	4902239	321601	4902015		2
K-039	Sept 11/00	321799	4902143	321746	4901919		1
K-040	Sept 11/00	321799	4902143	321746	4901919	K-039	4
K-041	Sept 11/00	327426	4911515	327373	4911291		1
K-042	Sept 11/00	327426	4911515	327373	4911291	K-041	7
K-043	Sept 11/00	327341	4911331	327288	4911107		6
K-044	Sept 11/00	327329	4911111	327276	4910887		6
K-045	Sept 11/00	327322	4911016	327269	4910792		4
K-046	Sept 11/00	327342	4910911	327289	4910687		0
K-047	Sept 11/00	327404	4910822	327351	4910598		1
K-048	Sept 11/00	327409	4910702	327356	4910478		1
K-049	Sept 11/00	327409	4910702	327356	4910478	K-048	4

K-050	Sept 11/00	327389	4910595	327336	4910371		4
K-051	Sept 11/00	327375	4910495	327322	4910271		1
K-052	Sept 11/00	327412	4910401	327359	4910177		3
K-053	Sept 11/00	327482	4910328	327429	4910104		1
K-054	Sept 11/00	327537	4910136	327484	4909912		2
K-055	Sept 11/00	327634	4909969	327581	4909745		2
K-056	Sept 11/00	327634	4909969	327581	4909745	K-055	6
K-057	Sept 11/00	327704	4909787	327651	4909563		1
K-058	Sept 11/00	327744	4909582	327691	4909358		1
K-059	Sept 11/00	327708	4909381	327655	4909157		3
K-060	Sept 11/00	327708	4909381	327655	4909157	K-059	2
K-061	Sept 12/00	322141	4928060	322088	4927836		3
K-062	Sept 12/00	322141	4928060	322088	4927836	K-061	1
K-063	Sept 12/00					BLANK	0
K-064	Sept 12/00	321858	4928641	321805	4928417		2
K-065	Sept 12/00	321552	4929258	321499	4929034		3
K-066	Sept 12/00	321364	4929680	321311	4929456		4
K-067	Sept 12/00	321054	4930212	321001	4929988		2
K-068	Sept 12/00	322373	4927426	322320	4927202		4
K-069	Sept 12/00	322737	4926794	322684	4926570		3
K-070	Sept 12/00	323225	4926414	323172	4926190		0
K-071	Sept 12/00	323577	4925917	323524	4925693		1
K-072	Sept 12/00	323577	4925917	323524	4925693	K-071	0
K-073	Sept 12/00					BLANK	0
K-074	Sept 12/00	330769	4915186	330716	4914962		4
K-075	Sept 12/00	330563	4915627	330510	4915403		78
K-076	Sept 12/00	330389	4916073	330336	4915849		46
K-077	Sept 12/00	330334	4916576	330281	4916352		0
K-078	Sept 12/00	330153	4917039	330100	4916815		4
K-079	Sept 12/00	330073	4917607	330020	4917383		2
K-080	Sept 12/00	329866	4918069	329813	4917845		5
K-081	Sept 12/00	332231	4905405	332178	4905181		8
K-082	Sept 12/00	332231	4905405	332178	4905181	K-081	5
K-083	Sept 12/00					BLANK	0
K-084	Sept 12/00	331807	4905513	331754	4905289		5
K-085	Sept 12/00	331341	4905504	331288	4905280		2
K-086	Sept 12/00	331084	4905971	331031	4905747		11
K-087	Sept 12/00	330609	4906164	330556	4905940		1
K-088	Sept 12/00	330377	4906842	330324	4906618		4
K-089	Sept 12/00	330140	4907289	330087	4907065		3
K-090	Sept 12/00	329772	4907643	329719	4907419		1
K-091	Sept 12/00	329517	4908052	329464	4907828		2
K-092	Sept 12/00	329517	4908052	329464	4907828	K-091	3
K-093	Sept 12/00					BLANK	0
K-094	Sept 12/00	329139	4908274	329086	4908050		1
K-095	Sept 12/00	328721	4908284	328668	4908060		1
K-096	Sept 12/00	328316	4908154	328263	4907930		1
K-097	Sept 12/00	328183	4908563	328130	4908339		2
K-098	Sept 12/00	327975	4908989	327922	4908765		1

APPENDIX 6.3

Shape legend available in Appendix 4.7





NOTES on original shape files:
- shear_zones is a line vector file of the shear zone traces shown in Figure 6.2
- hg_cups is a point vector file of the hg vapor units
all of the blanks were removed, duplicates were averaged as shown in this table

Once these steps are complete, LINK the distance and hgvalues shape files in ArcView, EXPORT as a dbase file in Excel, plot as a scatterplot. Results are shown in Figure 6.7a-b.

ID#	Value	ID#	Value	Average
1	3	2	5	4
10	2	11	10	6
29	9	30	3	6
39	1	40	4	3
41	1	42	7	4
48	1	49	4	3
55	2	56	6	4
59	3	60	2	3
61	3	62	1	2
71	1	72	0	1
81	8	82	5	7
91	2	92	3	3

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