Hydrogeochemistry of the Jemseg Grand Lake Watershed

by

Jillian Hudgins

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Introduction

The quality of water may be described in terms of the concentration and state (dissolved or particulate) of organic and inorganic material present, together with physical characteristics of the water. It is determined by *in situ* measurements and by analyses of water samples in the laboratory. Ground and surface water can be affected by natural and anthropogenic influences. Natural influences include the geology, topography, hydrology, weather, and climate, which all affect the quantity and quality of water available. Specific natural processes that affect water quality include rock weathering, wind deposition, mineral leaching from soil, run-off due to hydrological factors, and biological processes. Anthropogenic processes include but are not limited to agriculture, the use of fertilizer, pesticide, and other chemicals, forestry, aquaculture, pollution due to effluents from industry, mining, water treatment, and septic systems.

The composition of surface and ground waters can also vary with seasonal differences in runoff, weather conditions, and water level. These factors can vary the type and quantity of dissolved material contributed by an area and the amount of sediment carried by a stream. Floods and droughts may change water quality through dilution (during flooding) or concentration (during drought) of dissolved substances.

When looking at lake water, an important influence is thermal stratification. Deep lakes and reservoirs are characterised by alternating periods of temperature dependant stratification and vertical mixing. In lake, water currents may be multi-directional and are generally much slower than in rivers. Wind can also have an important effect on the movement of the upper layers of lake and reservoir water.

A lake that has a surface outlet represents a holding and mixing basin for the streamflow that emerges. The residence time of water in lakes is often more than six months and may be as much as several hundred years (Meybeck at al., 1996). The long residence time provides an opportunity for slow chemical reactions to come closer to completion than they can in rapidly moving stream water. Mixing of waters in lakes, however, may not be complete. Therefore, the water in one part of the lake may differ greatly in composition and properties from that in other parts of the lake (Hem, 1985).

How geology affects water quality

Watersheds are influenced by regional land use, by underlying geology (bedrock), and surficial geology (soils). The baseline geochemistry of stream in the headwater areas of a watershed is controlled primarily by the chemical composition of the underlying bedrock. Each lithology (rock composition type) produces a unique range of water chemistries. Rocks are complex mixtures of minerals that differ widely in their stability toward, or solubility in, water. As water moves through geologic materials, it causes chemical reactions, which lead to the leaching of minerals from rocks. Though all rocks can dissolve in water, many are made up of minerals that are not readily soluble.

Natural waters contain a variety of contaminants arising from erosion, leaching, and weathering processes of rocks. However, rock composition is only part of the story. The chemical composition of water is determined by contact with weatherable minerals as it flows through rocks and soils as well as by organic matter and nutrients released by soils and vegetation (Nelson et al., 2011). Other factors, such as precipitation, temperature, topography, grain size, porosity, degree of fissuring/fracturing, and biotic activity are important (Hem, 1985). These processes mainly influence the rates of chemical reactions not which elements are present in the water (Miller, 2002).

Soil and rock erodibility can influence the mobilization of salts and nutrients as can the pH, temperature, alkalinity, and electrical conductivity of the water. Similarly, as water moves though organic materials like leaves, it reacts with them (along with soil bacteria or algae). Rock weathering can be affected by temperature, and quantity and distribution of precipitation. Increased temperature raises the solubility and the rate of dissolution of most minerals (Hem, 1985). The influence and link of climate and geology on water quality is indicated by the quality and type of dissolved materials contributed from an area and amount if sediment carried by stream (AmericanGeosciences.org).

The complexity of rock-water-air systems imposes difficulties in applying a chemical-equilibrium model. It is extremely difficult to classify water based on the chemical composition of the rocks that the waters have flowed through. It is unrealistic to expect that any correlation system can succeed without considering the wide differences in weathering products and weathering rates that characterize similar rock terranes exposed in different climatic environments (Hem, 1985).

Rock types

There are three main rocks types: igneous, metamorphic, and sedimentary. Igneous rocks form when molten lava (magma) cools either inside in the Earth's crust (known as intrusive) or on the Earth's surface (known as extrusive). Metamorphic rocks result when existing rocks of any type are subjected to high temperature, pressure, or reactive fluids such as hot, mineral-laden water. Sedimentary rocks form when rock or mineral particles settle out of water or air or by the precipitation of minerals out of water.

Igneous Rocks

Rocks of igneous origin like granite or basalt consist predominantly of silicate minerals. Surface water originating in areas where igneous rocks are exposed is low in dissolved solids because, in general, the weathering of igneous rocks is slow. Concentrations are likely to be a function of contact time and area of solid surface exposed per unit volume of water (Hem, 1985). Igneous bedrock may be associated with more acidic (lower pH) waters.

Resistate Sedimentary Rocks

Sandstone is an example of a resistate sedimentary rock. They are composed of silicate minerals like quartz and feldspars that do not erode easily or dissolve rapidly. They are some of the most resistant minerals to weathering. Salts like gypsum or halite (rock salt) are the easiest to dissolve and add total dissolved solids (TDS) to the water, reducing water quality (Hoch, 2008). Fine-grained sedimentary rocks such as clays or shales can also dissolve easily and add TDS to the water. Generally, carbonate-rich and sedimentary rocks such as sandstone, siltstone, and shale are associated with water with higher pH levels.

Metamorphic Rocks

Rocks of any kind may be metamorphosed. The process as considered here consists of the alteration of rock by heat and pressure to change the physical properties and, sometimes, the mineral composition. As metamorphic rocks can have a wide range of mineral compositions, it is difficult to make broad stroke assumptions of how they can contribute contaminants to waters that flow through them.

Common geological sources of water quality parameters:

Potassium: Potassium (K) is derived from the dissolution of K-bearing minerals like K-feldspar (orthoclase and microcline) in areas underlain by granite. It is also abundant in sedimentary rocks.

Calcium: Calcium (Ca) is the most abundant of the alkaline-earth metals and is a major constituent of many common rock minerals. It is an essential element for plant and animal life forms and is a major component of the solutes in most natural water. Calcium is an essential constituent of many igneous rock minerals, especially pyroxene, amphibole, and plagioclase feldspars. Calcium also occurs in other silicate minerals that are produced in metamorphism. Some calcium is, therefore, to be expected in water that has been in contact with igneous and metamorphic rock. The most common forms of calcium in sedimentary rock are calcium carbonates present as a cement between particles or a partial filling of interstices (Hem, 1985)

Sodium: Sodium (Na) is an abundant metal in the Earth's crust. It can be derived from Na-feldspar (albite) and Na-rich silicate rocks (nepheline and sodalite) including sediments and clays. Road salt is a major source of sodium in water (Hem, 1985).

Magnesium: Magnesium (Mg) is a common element and is essential for plant and animal life. In igneous rock, magnesium is typically a major constituent minerals olivine, pyroxene, amphibole, mica (Hem, 1985). It can be derived from sedimentary rocks such as dolomite and marls

pH: the pH of water in contact with minerals such as silicates and carbonates generally increases with duration of contact

Conductivity: a measurement of the concentration of charged ions in water. It is strongly influenced by the underlying geology, which is the source of the ions

Aluminum: although aluminum (Al) is the third most abundant element in the Earth outer crust it rarely occurs in solution in concentrations greater than a few tenths or hundredths of a milligram per litre except in very acidic waters. Al occurs in substantial amounts in many silicate igneous rock minerals such as feldspars, micas, and amphiboles. The most common of the sedimentary aluminium rich rocks are clays (Hem, 1985).

Iron: Iron (Fe) is the second most abundant metallic element in the Earth's outer crust. However, concentrations in water are generally small. The solubility of iron is strongly dependant on the pH and the oxidation intensity of the water. Iron is an essential element for the metabolism of animals and plants. Igneous rocks minerals whose iron content is relatively high include pyroxenes, amphiboles, biotite, magnetite, and, especially, olivine (Hem, 1985). Iron can be dissolved from practically all rocks and soils.

Manganese: Manganese (Mn) is an undesirable impurity in water, mainly owing to a tendency to deposit black oxide stains. Many igneous and metamorphic minerals contain minor amounts of manganese. It is a significant constituent of basalt rocks in the minerals olivines, pyroxene, and amphibole. Small amounts commonly are present in dolomite and limestone (Hem, 1985)

Sulphate: Can be derived from feldspathic igneous and sedimentary rocks (Hem, 1985) or those containing gypsum, iron sulfides and other sulfur compounds

Chloride: Chloride (Cl) is highly soluble in water and is derived from rocks such as sodalite and minerals such as apatite (Hem, 1985)

Fluoride: Fluoride (F) can be dissolved in small quantities from igneous and sedimentary due to leaching by natural weathering and rainwater (Hem, 1985).

Phosphorus: Phosphorus is a common element in igneous and sedimentary rocks and levels are generally higher in areas draining sedimentary rock deposits.

TDS: Total dissolved solids or TDS is the total quantity of mineral constituents dissolved from rocks or soils, including organic matter.

Hardness: The hardness of water is related to calcium and magnesium content, which in turn is related to the alkalinity and the buffering capacity of water

Colour: A measure of the appearance of water free from suspended matter, colour results from decaying organic matter such as roots and leaves.

Geology of the Jemseg Grand Lake Watershed

The Grand Lake Lowlands are the hotspot in the province of New Brunswick with the longest growing season as Grand Lake, the largest lake in the Maritimes, acts as a heat sink. The lakes and waterways of the region course roughly north-easterly, following the prevailing structural grain of the bedrock (Zelazny, 2003).

The Grand Lake Lowlands are almost entirely underlain by late Carboniferous [300 – 311 million years ago (Ma)] non-calcareous terrestrial sedimentary rocks and rich alluvial soils. The major rock group in the region is the late Carboniferous Pictou Group (light green colour in Figure 1). It is dominated by red and grey, fine- to medium-grained sandstone, red and grey conglomerate, and red mudstone with coal horizons. The finer-grained sedimentary rocks would contribute major ions and metals to water flowing through them, which would result in relatively high hardness, alkalinity, and conductivity in the background water chemistry. However, the contributed quantities are difficult to determine without much further in-depth studies. In addition, erosion of geological materials is strongly influenced by anthropogenic processes upstream and at the sampling site (such as clearing of land for residential or industrial purposes) as well as climate change (increasingly drying summers, heavier precipitation events, change in the timing and frequency of spring freshet floods).

There are small outcrops of early Carboniferous [311 – 355 Ma] mafic volcanic rocks in the central watershed (near Salmon and Newcastle Creeks – dark green in Figure 1), deep water clastic rocks near Coal Creek (peach/orange colour in Figure 1), and felsic intrusive volcanic rocks south of Cumberland Bay (pink in Figure 1) (Zelazny, 2003). Volcanic rocks are of the Mabou Group include maroon trachyte, maroon feldspar porphyry, volcanic breccia, lapilli tuff, and pink to grey rhyolite in the Cumberland Hill region as well as purplish grey olivine basalt and basaltic andesite in the Hardwood Ridge area (GeoNB).

In the Newcastle Creek region, there is reddish-brown conglomerate interbedded with coarse grained sandstone, siltstone, and mudstone. In the northeast there are older late Silurian [418 – 424 Ma] sedimentary and metamorphic rocks including grey and green slate, very fine- to medium-grained sandstone (GeoNB).

The deep-water clastic rocks near Coal Creek include early Devonian [395 – 419 Ma] slate interbedded with sandstone, mudstone, and shale (GeoNB). Coal mining has occurred in the region since 1639 with large scale strip mining starting in 1904. On April 19, 2012 the Grand Lake Generating Station was demolished and by this time all coal mining in Minto had ended. [Wikipedia article https://en.wikipedia.org/wiki/Minto,_New_Brunswick].

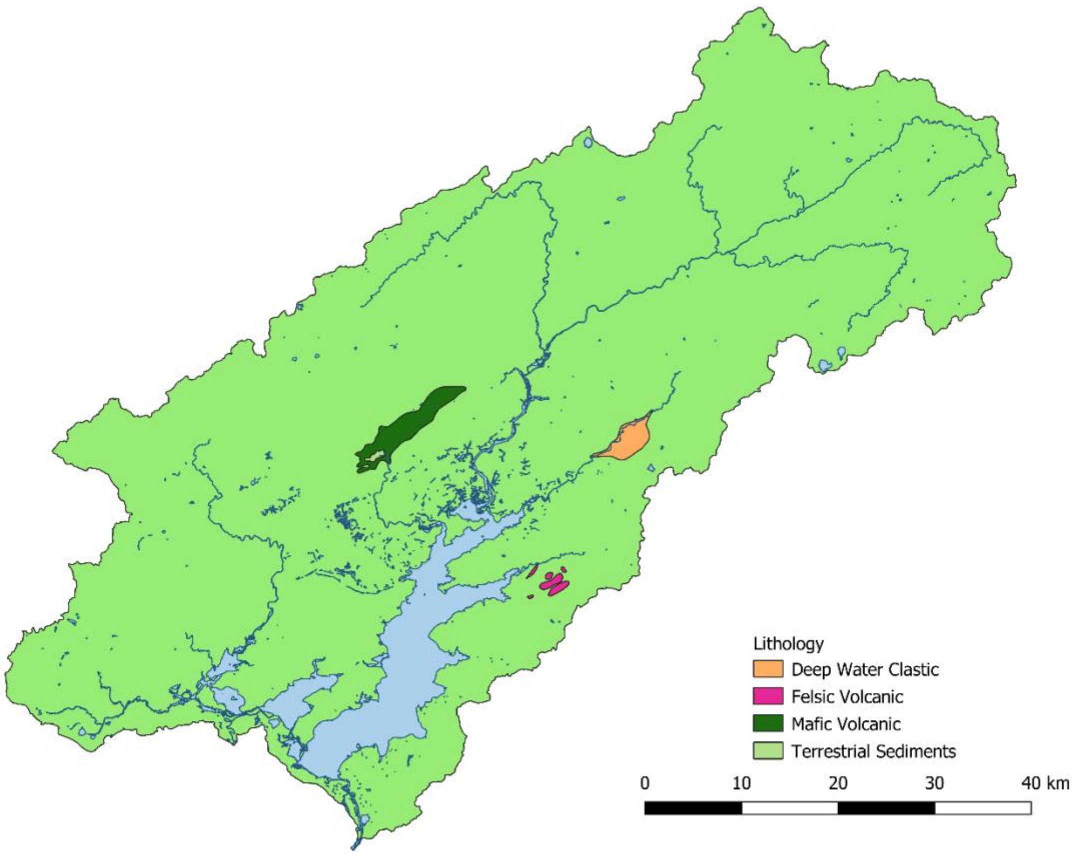

Figure 1. Lithology (rock type) of the Jemseg Grand Lake Watershed

JGLWA Stations

Six sampling stations were established in the Jemseg Grand Lake watershed in 2020. The stations are as follows:

JGLP01 Northeast Arm, Salmon River
JGLP02 Grand Lake Newcastle Bay
JGLP03 Grand Lake Cumberland Point
JGLP04 Grand Lake SW of Grand Point Bar
JGLP05 Jemseg River Entrance
JGLP06 Maquapit Lake Exit, Lower Thoroughfare

The interpretation of the water quality data in terms of the direct influence of the parent bedrock geology is difficult because:

-the bedrock geology is almost uniformly terrestrial sediments

-the temporal and geographic paucity of data
-there was no direct sampling of tributaries in 2020 (samples taken in the lake would reflect mixing of tributaries)
-various anthropogenic influences likely disguise the influence(s) of geology

Some water quality parameter from each JGLWA sampling station will be presented and discussed below in relation to other sites. Sites JGLP02, 03, 04, and 05 have been grouped together since these sites showed very similar water quality results, likely because they were located in central or southern Grand Lake; therefore, contributions from any one tributary flowing into the lake would have been diluted. Sites JGLP01 and JGLP06 are presented separately.

Table 1. Water quality parameter levels of JGLWA sampling sites in comparison to each other

Water quality parameter	JGLP01	JGLP02 – JGLP05	JGLP06
Major ions (Ca, Na, K, Mg)	High	Moderate	Low
Metals (Al, Fe)	Moderate	Low	High
Nutrients (NO3, TPL)	Low	Moderate	High
Sulfate	High	Moderate	Low
Fluoride	High	Moderate	Low
Chloride	Moderate	High	Low
Total Dissolved Solids	High	Moderate	Low
Conductivity	High	Moderate	Low
Hardness	High	Moderate	Low
Alkalinity	High	Moderate	Low
Colour	Low	Moderate	High
Turbidity	Moderate	Low	High

JGLP01: In addition to the terrestrial sedimentary rocks that dominate the watershed, this sampling station is taking in water from Coal Creek, which flows through an area of deep-water clastic rocks as well as from Salmon Creek, which flows through an area of mafic volcanic rock. Compared to the other sampling sites, JGLP01 has higher concentrations of major ions, which results in elevated total dissolved solids concentration, as well as high conductivity, hardness, and alkalinity at this site. The sedimentary and deep-water clastic rocks in the drainage area above this site could be contributing to the elevated concentrations of major ions.

JGLP02-JGLP05: these four sites showed similar water quality results, likely because they were located in central or southern Grand Lake; therefore, they would reflect the combined composition of the catchment above. There are two small geologic features of note that would drain into these stations: Newcastle Creek, which flows through an area underlain by mafic volcanic rocks and Cumberland Bay Stream, which flows through an area underlain by felsic volcanic rocks. These sites showed moderate levels of most parameters sampled, consistent with the assumption that contributions from different areas would be diluted in Grand Lake.

JGLP06: This site is influenced by the large peatlands in the Maquapit Lake, French Lake, Portobello Creek area above it. The influence of wetlands and peatlands on water chemistry is discussed below.

How wetlands and peatlands affect water chemistry

A wetland is a landscape that is saturated or flooded by water either permanently or for large parts of the year. Wetlands provide important ecosystem services like flood storage, ground water recharge, habitat for animals, and pollution control. The Maquapit area is dominated by peatlands, a terrestrial wetland ecosystem in which waterlogged conditions prevent plant material from fully decomposing to the extent that dead plants accumulate to form peat. Generally, vegetation is dominated by *Sphagnum* mosses, sedges, and shrubs. The Maquapit area is a minerotrophic peatland meaning that it is hydrologically connected to other streams and this water supplies dissolved minerals.

According to Cameron et al. (1989) minerotrophic peatlands derive water for their vegetation from rock or soil, which serves as the substrate. This suggests that the nutrients and minerals are derived from the underlying rock or soil substrate, which in turn, is dependent on the bedrock geology, hydrology, and water quality. Thus, the peatlands are primarily fed by groundwater recharge but secondarily may be fed by runoff or flood-rich nutrients from adjoining river channels (Flores, 2014).

Wetlands generally lower the pH, calcium, hardness, and total dissolved solids and raise the dissolved organic carbon (DOC), ammonia, and phosphorus levels of the waters passing through them. Peatlands generally have very high DOC levels, which leads to a brown colour. Waters can have an increased sediment load (Glooschenko, 1990). These water quality characteristics are seen at JGLP06.

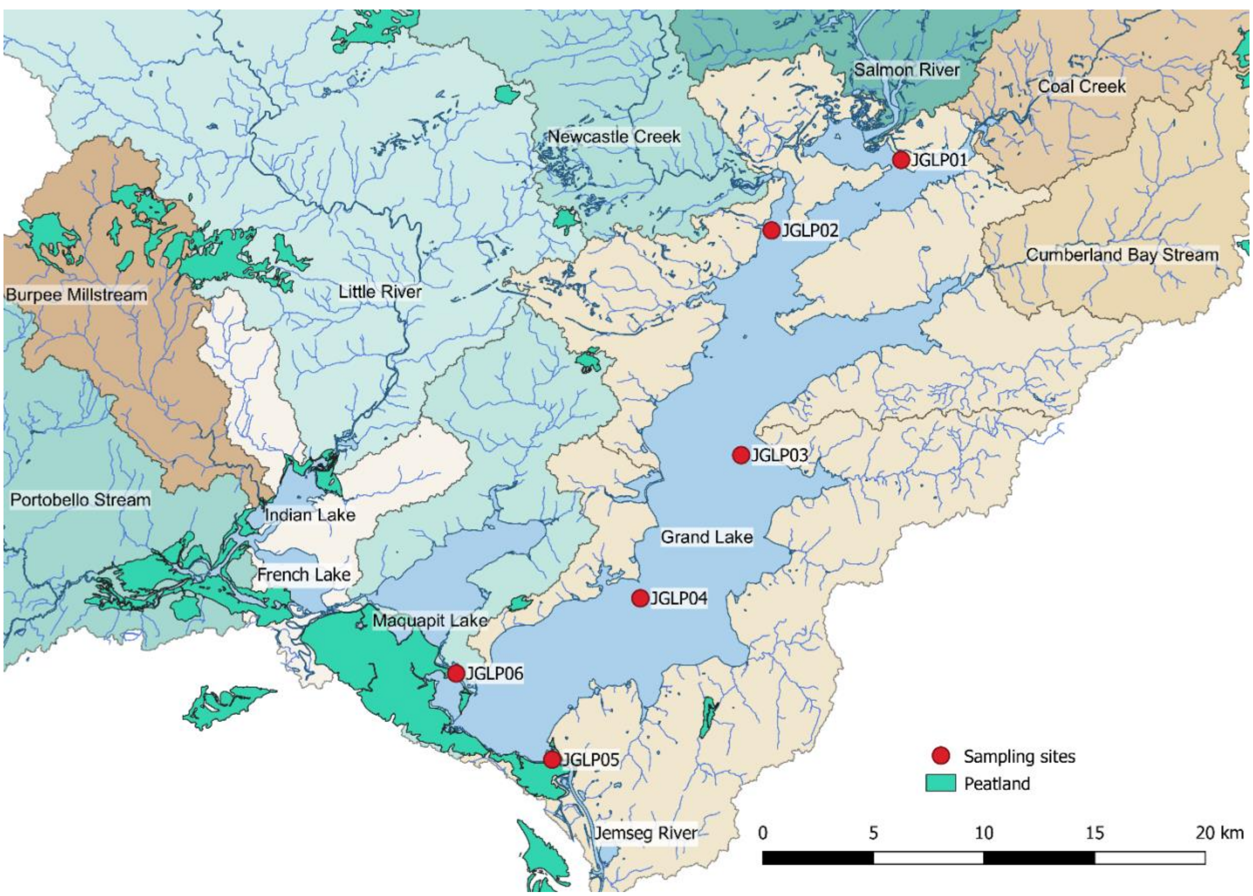

Figure 2 Peatlands in the Jemseg Grand Lake Watershed 2020 water sampling area

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