GEOTHERMAL INFLUENCES ON WATER QUALITY AT STILLWATER NATIONAL WILDLIFE REFUGE, NEVADA

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ABSTRACT

Over the centuries, geothermal surface activity has introduced high levels of chemical constituents such as boron, arsenic, mercury, lithium, and sodium to the Stillwater area. It is suggested that the source of toxins detected in Stillwater lakes and reservoirs may be derived from leaching of paleosols composed of layers of successive evaporite deposits containing geothermally-introduced chemical constituents. A direct interception of hydrothermal fluids by unlined canals draining into the Stillwater wetlands system may be another source.

INTRODUCTION

Stillwater National Wildlife Refuge, one of only eight shorebird reserves found in the Western Hemisphere, consists of interconnecting marshes, small lakes and open ponds. Home to many diversified wetland species, Stillwater Lakes provides a habitat so critical that loss would threaten migrations, breeding and the survival of hundreds of species of waterfowl. Stillwater Lakes, with a potential of 45,000 acres of total wetland habitat, has shrunk from 14,000 acres in 1985 to less than 4,000 acres today due to recent drought conditions and water diversion for irrigation purposes. With the decline in water levels, dissolved constituents have been concentrated to levels toxic to fish and waterfowl. From 1986 to 1989, over seven million fish and 18,000 birds have died from drought-induced disease and suspected toxic poisoning.

Previous analysis of water quality data from the Stillwater region (Oleson and Carr, 1990) indicates high levels of chemical constituents commonly associated with thermal waters. Our objective is to offer an explanation for these high levels of toxins found at Stillwater and to establish the role that geothermal activity plays in contributing to these high levels.

PHYSICAL SETTING

Stillwater Lakes, located in western Nevada (Fig. 1), is situated in the southern Carson Desert and lies within the Carson Sink, a large playa characterized by an interior drainage system and an arid or semi-arid climate where evaporation exceeds precipitation and surface inflow. The Carson Desert, formed by high-angle faulting that began in Miocene time producing alternating horsts and grabens, provides a terminus (the Carson Sink) for both the Carson and Humboldt rivers. Stillwater Lakes is located at the base of the Stillwater Range comprised mainly of Triassic sediments and Tertiary volcanics.

During the Pleistocene and continuing until about 10,000 years ago, the climate in the region was much more humid leading to the formation of Lake Lahontan, a large lake covering about 8,500 square miles. The extent of the lake is evidenced by shoreline remnants, recording a maximum depth of 4,380 feet. Lake Lahontan underwent numerous cycles of expansion and recession related to regional climatic changes coinciding with Sierra Nevada Pleistocene glacial fluctuations. Lake Lahontan reworked sediments brought in by the Carson and Humboldt Rivers resulting in complex interbedded, interfingered, deposits of fluvial, lacusterine, deltaic, and eolian origin. During intermittently dry periods, large quantities of eolian sands derived from neighboring areas were deposited.

In the Carson Desert, with the advent of the present arid climate, Lake Lahontan eventually evaporated and precipitated large quantities of soluble material. Today, repeated evaporation of the Carson Sink has led to additional precipitation of dissolved solids. Evaporite deposits, often composed of authigenic minerals of

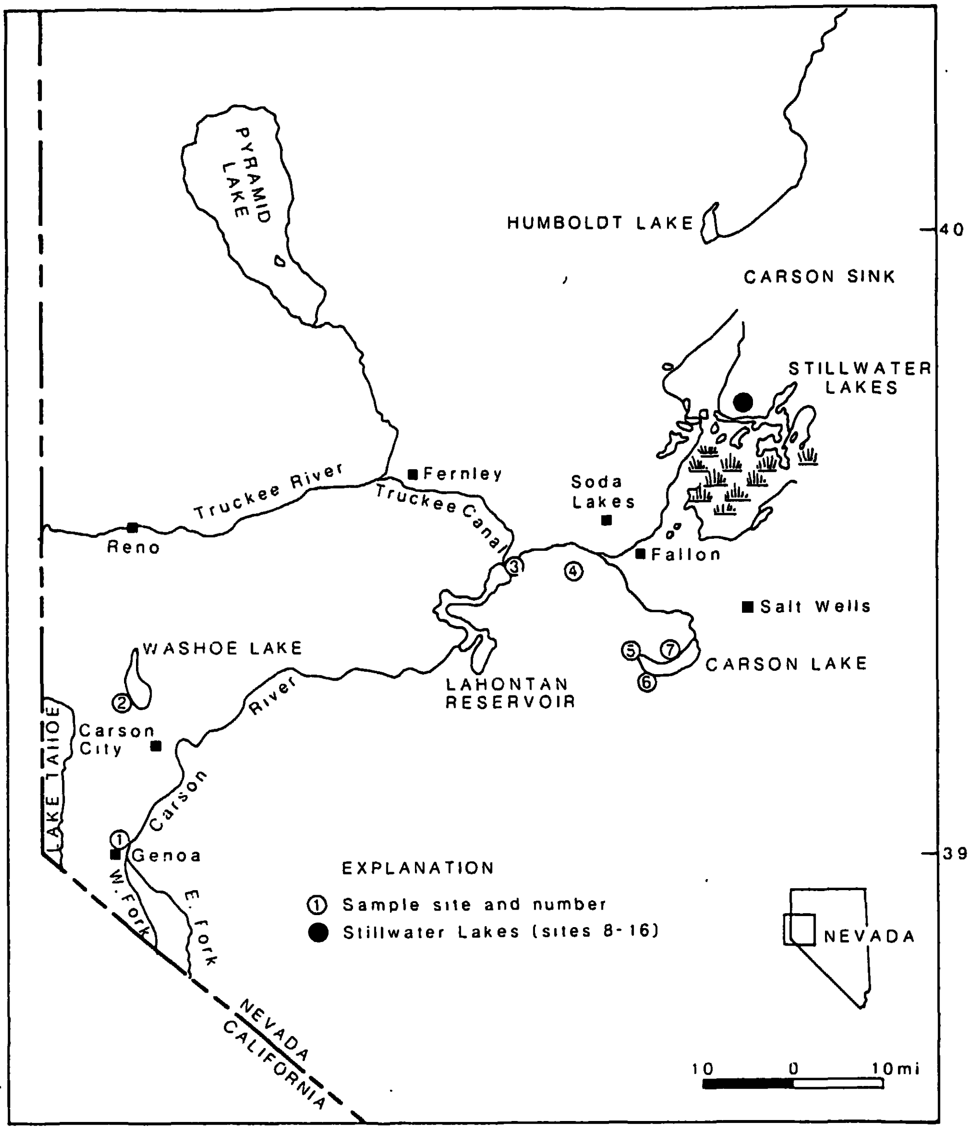

Fig. 1. Map of a portion of northwestern Nevada showing the geographic region bordering Stillwater Lakes. Sites at which water samples were collected, as referenced in Oleson and Carr (1990), are shown by number in this figure.

chlorides, sulfates, carbonates, and borates, are formed when evaporation causes saturation of such compounds. Brines often occur within a few feet of the surface at many playas including the Carson Sink. Chemical analyses of dissolved solids of brines indicate that halite is most abundant and magnesium, sulfate and carbonate are generally abundant but vary from playa to playa. Less common elements present in small amounts (one to several hundred ppm) include boron, cesium, fluorine, iodine, lithium, phosphorus, potassium, strontium, tungsten, uranium, and rubidium. Papke (1976) noted that a local source, such as hot springs or volcanic rock, would most likely be responsible for the concentration of a particular element in a restricted area (e.g. the presence of borate in closely spaced playas in Mineral and Esmeralda Counties). Papke (1976) also suggests three possible sources of soluble matter brought into a playa and precipitated through evaporation: leaching of constituents present in small quantities in the rocks within the drainage system, leaching of constituents present in excessive amounts in a particular rock type, and magmatic contributions of a constituent from hot springs in the vicinity.

With the extreme low relief of the Carson Sink, constantly fluctuating water levels cause evaporite deposits to be interbedded with Pleistocene Lake Lahontan sediments and Quaternary alluvial deposits. Eolian sand deposits, present at Stillwater, often co-exist with evaporite deposits. This may be due to the capture of eolian material by salt cementation as saline water is carried to these areas by capillary action and evaporated. Large eolian sand ridges in the area are generally aligned along a north to northeast strike and may indicate buried fault scarps.

Stillwater Lakes lies within an area of recurrent Quaternary faulting and partially within the boundary of a thermal ground-water anomaly covering approximately 25 square miles (Fig. 2 and Fig. 3). Numerous faults intersect the anomaly. Several geothermal wells have been drilled in the Stillwater area to depths around 4,000 feet with temperatures ranging from 77^{o} to 277^{o}F (Garside and Schilling, 1979). The high temperatures may be caused by flow from much greater depths along faults and into shallow aquifers (Morrison, 1964). The thermal anomaly coincides with the extension of the Rainbow Mountain fault which was responsible for the Fallon-Stillwater earthquakes of July 6 and August 23, 1954. The fault extends northward from Rainbow Mountain to the southern rim of the Carson Sink (Fig. 3). The earthquake of July 6, 1954 resulted in severe cracking and a vertical scarp ranging from 1 to 12 inches in height originating at the base of Rainbow Mountain and continuing northward towards the Stillwater Wildlife Refuge. The earthquake of August 23, 1954 increased displacements along the July 6, 1954 breakage and continued northward for an additional fourteen miles with a relative movement of 30 inches. The combined faulting episodes resulted in 25 miles of surface faulting evidence (Slemmons, 1956) . The general alignment of the geothermal anomaly and Stillwater Lakes along a north-northeast trend suggest faults at depth.

PREVIOUS WORK

In a previous study (Oleson and Carr, 1990) a multivariate transformation procedure known as correspondence analysis (Greenacre, 1984) was applied to perform a cluster analysis on two water quality data sets collected at Stillwater Lakes and other background sites. The data, obtained from the U.S. Geological Survey, Carson City, Nevada, were collected for June and September, 1986 from 16 localities assigned numerical values of 1 through 16 (Fig. 1). Sites 1 through 4 are background sites not associated with wildlife deformity and death. Sites 5 through 16 are located within the Stillwater area. In total, the two data sets contained 43 attributes and included specific conductance, temperature, dissolved oxygen, pH,nitrogen ammonia, phosphorus, arsenic, boron, cadmium, barium, chromium, selenium, uranium, copper, lead, zinc, mercury, gross beta as strontium-90 and yttrium-90, alkalinity, and dissolved solids.

Quantitative analysis of the data along with results obtained from using correspondence analysis were used to determine the correlation between sampling locations (individuals) and chemical constituents (attributes). Correspondence analysis software (Carr, 1990) conveniently displays a relatively large amount of data as visual plots of attributes and individuals which are used to identify associations. Results from the analysis showed that the control sites were found to be different from the Stillwater sites indicating that the Stillwater sites are unique. Boron, specific conductance and dissolved solids were found to be most closely associated with the Stillwater sites followed by arsenic, lead and mercury; specific conductance is an indication of a high saline content attributed to boron and other constituents. Sites 9 through 12, associated with TJ Drain (Fig. 2), consistently had the highest levels of these constituents.

NEW HYPOTHESES

The origin of boron, occurring in large amounts and most correlated with Stillwater Lakes, is linked to hot springs associated with volcanism and plutonism (Papke, 1985; Watanabe, 1975). Other constituents that correlated well with Stillwater Lakes such as arsenic, lead and mercury are also known to be associated with thermal waters. There are several avenues in which geothermal activity may have both indirectly and directly contributed to the high levels of chemical constituents present at Stillwater. Over thousands of years, such constituents were introduced to the area by hot springs associated with volcanism and then concentrated within sediments by evaporation. Today, excess water from flood irrigation practices prevalent throughout the Fallon-Stillwater area are channeled through these sediments and eventually flow into Stillwater Lakes.

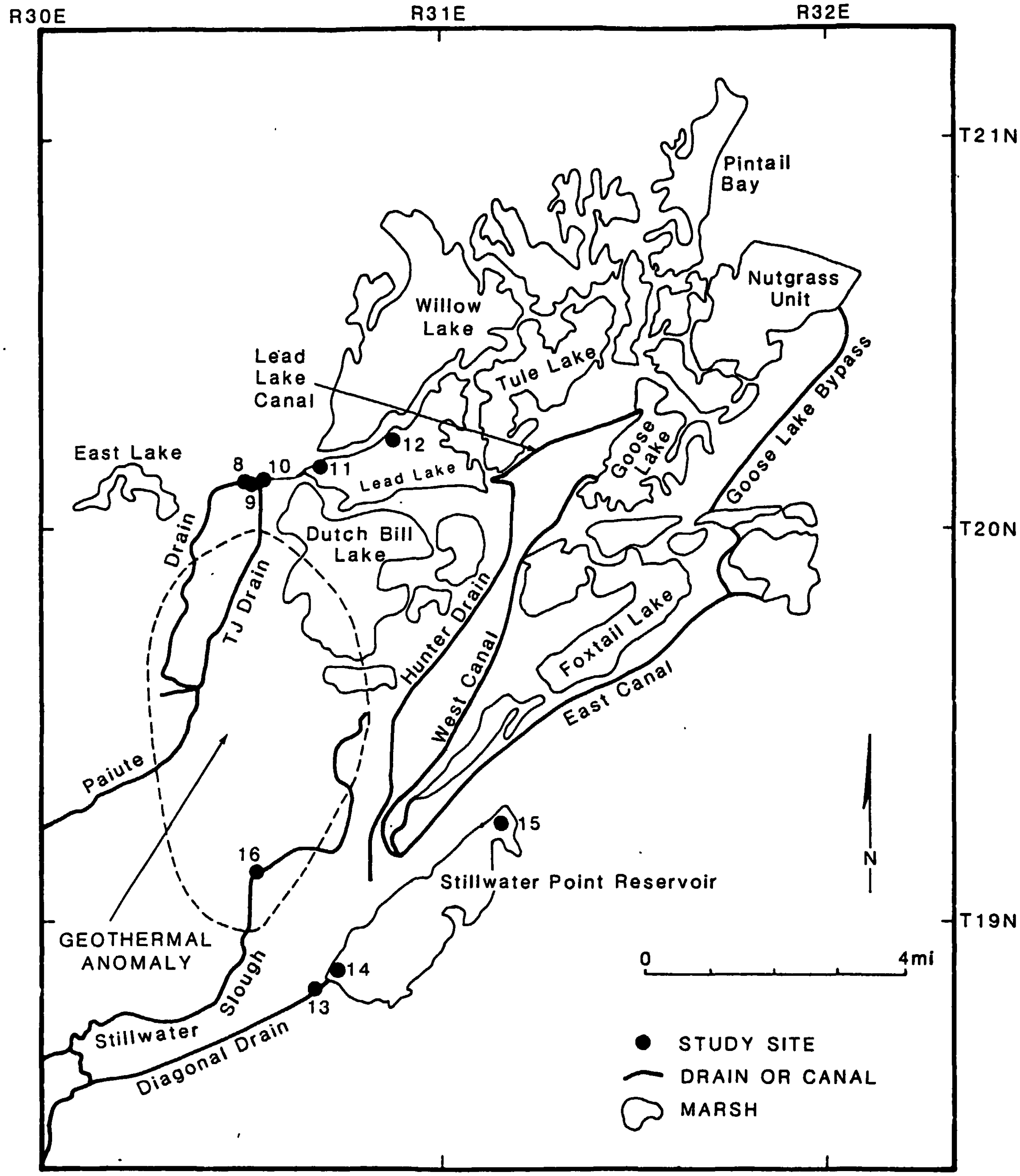

Fig. 2. Detailed plot of the Stillwater Lakes system. The geothermal anomaly is outlined.

Dissolved matter is leached from the soils by irrigation runoff (Stillwater Lakes primary source of water) and enters the Stillwater Lakes system through a network of unlined canals. Current drought conditions may have concentrated these elements to toxic levels.

Another hypothesis is that Stillwater Lakes and canals, especially TJ drain may be directly intercepting thermal waters. Since the early 1900's, irrigation practices have raised the water table in the Fallon-Stillwater area. Thermal waters from depth have been mixing with

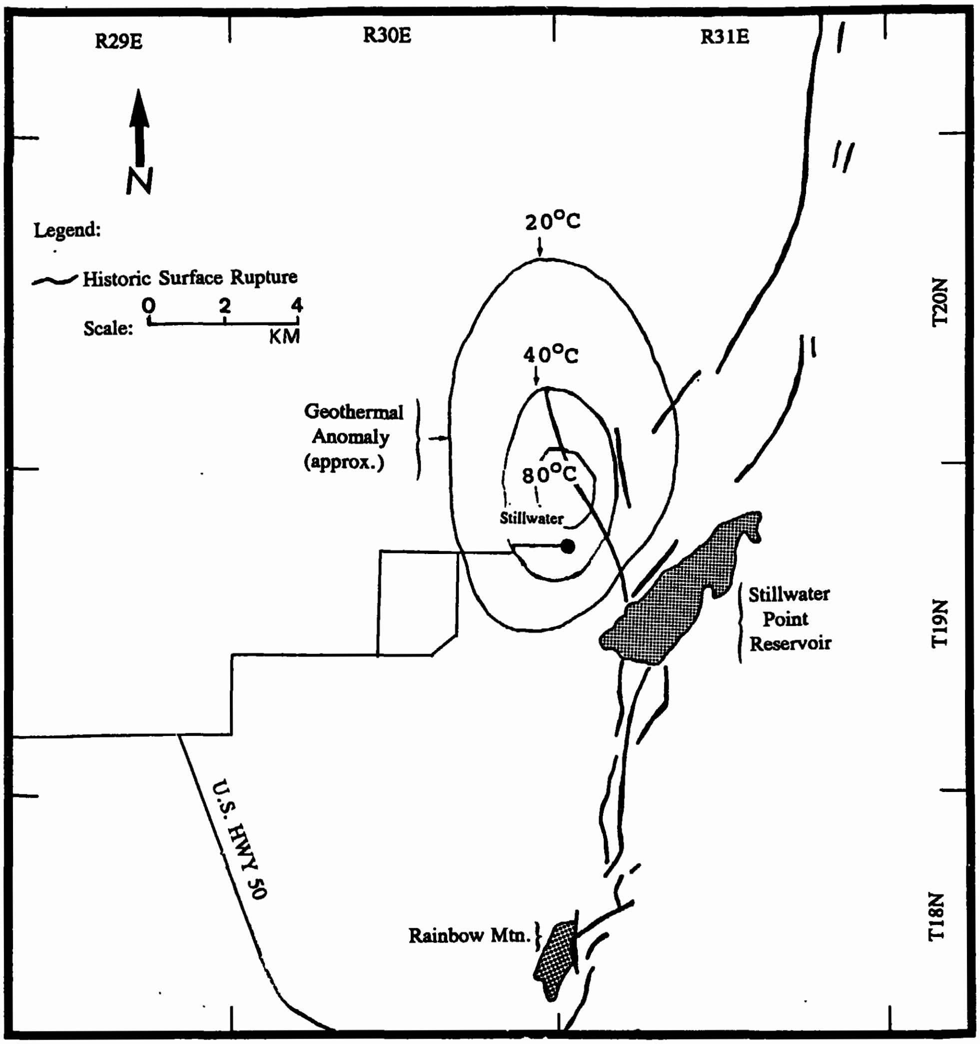

Fig. 3. Outline of geothermal anomaly near Stillwater, Nevada. Faults associated with the Rainbow Mountain system are plotted from Bell (1984). Faults shown inside the anomaly are plotted from Garside and Schilling (1979).

shallow nonthermal waters displaying a north-northeast gradient, flowing toward Stillwater Lakes (Olmsted, 1975). TJ drain, found to be especially high in several constituents, flows over the geothermal anomaly. Constructed in 1982, the drain is known to intercept the water table and coincides with the onset of unexplained massive fish and waterfowl deaths. Analysis of water from a geothermal well adjacent to the confluence of TJ drain is shown in Table 1. Boron and lithium are among the elements present at elevated levels in groundwater associated with the geothermal anomaly beneath TJ drain. Recent faulting activity in the area may have provided additional avenues for migration of thermal waters into the shallow groundwater system or into Stillwater Lakes hydrologic system.

Table 1

Element	Concentration (mg/L)
Na	2754
K	84
Ca	86
SiO_2	169
Cl	4360
B	34
Li	6

Perhaps most important to the understanding of the hydrogeologic aspect of geothermal activity in Nevada is a study by Buchanon (1990). At one time, recharge of Nevada's geothermal springs was attributed to recent meteoric water (precipitation). Through the analysis of isotopes in water from geothermal springs, however, Buchanon (1990) shows that water in these thermal systems is much older, derived from Pleistocene precipation. Moreover, as shown before, this water is heavily mineralized, especially with boron.

It is also mentioned previously that numerous climatic cycles have occurred in the Great Basin since the Pleistocene. During unusually wet periods, as did occur in the period 1980-84, the Carson Sink, normally dry, fills. Fish, carp in particular, suddenly appear in the Sink in large numbers. Once the wet period is over, however, the Carson Sink reverts to its dry condition; in the process of shrinking, large numbers of fish, more than seven million in 1985-86, are stranded. What appears to be a major environmental disaster is actually a naturally occuring phenomenon.

During the unusually wet periods, associated with substantial runoff from snow melting in the Sierra Nevada Mountains, soluble mineral deposits are flushed in quantity into the Carson Sink. Mineral deposits derived from geothermal springs add to the volume of dissolved minerals. Once the wet period is over and evaporation exceeds runoff, the Carson Sink and surrounding regions become associated with heavily mineralized water, with dissolved solids concentrated through evaporation. Boron is the one mineral constituent having the highest concentration in the Stillwater Lakes system adjacent to the Carson Sink. This mineral, especially, indicates that geothermal mineral deposits constitute the major volume of total dissolved solids reaching the Carson Sink.

SUMMARY

It is clear that Stillwater Lakes sites are highly correlated with elements typically associated with thermal waters. The presence of these anomalous concentrations seems to suggest a geothermal source. It is not clear, however, if geothermal waters are directly responsible for the contamination, or indirectly responsible, acting as a source for deposition of elements such as boron, followed by subsequent leaching and transportation of dissolved constituents by irrigation.

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