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The Quality and Character of
Pacific Northwest Waters
by
Herbert A. Swenson

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THE QUALITY AND CHARACTER OF PACIFIC NORTHWEST WATERS

By Herbert A. Swenson

[Presented at a ground-water symposium,
Pacific Northwest Metals and Minerals Conference,
American Mining and Metallurgical Engineers,
Portland, Oregon, April 30, 1954.]

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The Quality and Character of Pacific Northwest Waters[a]

By

Herbert A. Swenson

INTRODUCTION

This paper is a general discussion of the quality and chemical character of surface and ground waters in the Pacific Northwest as shown by the available data. Previous quality of water studies reported in the literature are reviewed. The composition of natural waters is considered as to the source and significance of the different mineral constituents. Analytical data are presented showing mineral constituents and physical properties of selected surface and ground waters in the region.

PREVIOUS STUDIES

For an area as large as the Pacific Northwest, including Washington, Oregon, and Idaho, few comprehensive studies have been made of water quality. The early work of Van Winkle (1,2) covers investigations of the quality of selected surface waters of Washington and Oregon during the period 1910 to 1912. No recent reports of a similar nature are available for these states. A systematic study of the quality of 27 major water sources in Idaho for the period 1948 to 1949 was made by the University of Idaho Agricultural Experiment Station in connection with correlation of irrigation water with soil characteristics (3). Waring and Meinzer (4) in "Bibliography and index of publications relating to ground water prepared by the Geological Survey and cooperating agencies" list 22 reports in which quality of ground water data appear for Washington, Oregon or Idaho. Most of these 22 reports cover limited areas and contain brief discussions of the chemical characteristics of the ground waters.

Information and chemical analyses for the larger public water supplies have been published by the Geological Survey (5,6,7,8); similar data for individual community supplies in each of three Northwest states have been released by State agencies.

The above review on quality of water in the Pacific Northwest is not complete, but does cover most of the readily-available references and summarizes the sketchy information on file for this important section of the country.

CHEMICAL CHARACTER OF NATURAL WATERS

All natural water whether of surface or ground origin contains dissolved mineral solids. These dissolved solids consist of metals and

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non-metals, dissociated as ions. The metals or cations commonly occuring in water are calcium, magnesium, sodium, and potassium. The non-metals or anions are mainly carbonate, bicarbonate, chloride, sulfate, nitrate, and fluoride. Other ions, including iron, manganese, aluminum, sulfide, and phosphate may be present, usually in minute amounts. These metals and non-metals are in a state of equilibrium with each other and form a balanced system of bases and acids. In contrast to constituents in true solution are mineral solids, principally silica, which occur in natural waters as colloidal suspensions.

The nature of the environment of a natural water influences its chemical and physical properties. The quantity of dissolved mineral substance in a natural water depends primarily on the type of rocks or soils through which the water has passed and the length of time it has been in contact with rocks or soils. Likewise, the quantity of suspended sediment is influenced by climatic conditions, vegetal cover, topography, and land use. The mineral content and physical properties may be modified by drainage from mines or oil fields, by the addition of industrial or municipal wastes, or by drainage from irrigated land.

The quality of surface water at a fixed sampling point will vary from one season to another in response to runoff. In small streams variation in quality may be considerable because of diurnal fluctuation. As a result of variation in dissolved solids and suspended sediment, treatment of the water may be necessary to obtain a satisfactory supply for specific uses. Also, differences in temperature between summer and winter may be sufficient to cause a notable range in the efficiency of condensers and other heat exchangers through which the water is circulated. As an illustration of range in water temperature Columbia River water at Bonneville, Oregon, measured from 32° to 71° F during the period 1947 to 1953, from records of the Portland District, Corps of Engineers. Variation in water quality with stream runoff is shown by a Geological Survey analysis of a sample from the Okanogan River near Tonasket, Washington. In the following table the high runoff in June 1950 is the result of snow-melt which would be expected to reduce concentrations of dissolved solids.

Constituent (parts per million)	Discharge in second-feet 1,200	18,500
Calcium	35	15
Magnesium	9.4	2.1
Sodium	8.8	2.6
Potassium	1.4	3.8
Bicarbonate	137	59
Sulfate	30	8.4
Dissolved solids	166	75
Hardness	126	46
Date (1950)	Sept. 4	June 7

As previously stated the mineral content and physical properties of a natural water may be modified by drainage from irrigated land or from wastes. The alteration is usually apparent from increased concentrations of dissolved solids. Where two or more stations are maintained on a river the concentration of dissolved solids at the downstream station is normally higher than the concentration upstream. Howard (9) reports an exception to this general rule by referring to the records of the Snake River at Weiser, Idaho, (drainage area 74,000 sq. mi.) and at Burbank, Washington, (drainage area 109,000 sq. mi.). The average concentration at Weiser was 220 parts per million, and at Burbank, downstream, only 131 parts per million.

Ground water from a particular well or spring does not as a rule vary greatly in chemical character or in temperature, and because of this uniformity, industrial use of ground water has many advantages. The relative constancy in composition of ground water from a given source is shown by the following analyses of water samples collected in 1922 and 1953 from a well 611 feet deep, in Owyhee County, Idaho:

Date sample collected	1922	1953
Calcium (ppm)	7.2	7.9
Magnesium (ppm)	1.0	1.4
Bicarbonate (ppm)	100	114
Sulfate (ppm)	20	21
Chloride (ppm)	13	10
Dissolved solids (ppm)	238	236
Hardness (ppm)	22	25

Some aquifers or water-bearing materials, however, notably the marine sedimentary rocks in places in the Willamette Valley, Oregon, yield brackish waters that are unfit for all ordinary uses.

Mineral constituents in solution

Practically all minerals that compose the earth's crust are soluble in water to some extent, particularly in water containing dissolved carbon dioxide. These minerals are disintegrated and dissolved in part by water at the land surface or in the zone of saturation. In the following discussion individual constituents in water are considered briefly as to source and as to significance in Northwest waters.

Silica

Silica is dissolved from practically all rocks and is an important constituent in many waters of the Northwest. For instance a well in

Owyhee County, Idaho, yields water that has a silica content of 86 parts per million, which represents almost 40 percent of the dissolved solids. The exact physical state in which silica exists in water under all conditions of pH, alkalinity, and ionic concentration is not definitely known. Silica occurs in higher concentrations in ground waters of the Northwest, as a general rule, than in surface supplies. The Willamette River at Salem, Oregon, contains mineral solids of which about one-third is silica; the concentration of silica in the water, however, is relatively low, and averages 16 ppm. Silica affects the usefulness of a water because it contributes to the formation of boiler scales and is usually removed from feed water for high-pressure boilers. Silica also forms troublesome deposits on the blades of steam turbines.

Iron

Iron is dissolved from many rocks and soils. On exposure to the air, normal basic waters that contain more than 1 part per million of iron soon become turbid with the insoluble reddish ferric oxide produced by oxidation. Surface waters, unless acid, seldom contain as much as 1 ppm of dissolved iron. Some ground waters in the Northwest contain iron in concentrations above 1 ppm. Iron is troublesome above 0.3 ppm and causes reddish-brown stains on porcelain or enameled ware and fixtures, and on fabrics washed in the water.

Calcium and magnesium

Calcium compounds are dissolved from practically all rocks, particularly limestones, dolomites, and gypsum. Magnesium salts are leached from many rocks and occur in significant amounts in waters that have been in contact with dolomitic deposits. Calcium and magnesium make water hard and are largely responsible for the formation of boiler scale. Many surface and ground water supplies, particularly those west of the Cascade Mountains in Washington and Oregon are soft (hardness less than about 60 ppm), or moderately hard. Ground water east of the mountains may have hardness of 200 to 300 parts per million, but many supplies in this area on the other hand have low hardness. Some deep-seated wells in volcanic complexes in southwestern Idaho yield very soft, alkaline waters.

Sodium and potassium

Sodium, and to a less extent, potassium are common in rocks and soil, and salts of both metals are readily dissolved by water. Sodium and potassium are not present as a rule in Northwest waters in concentrations that would cause high salinity. Two exceptions are noted in Oregon -- the salt waters in marine sedimentary rocks that occur in places beneath the Willamette Valley, the Coast Range, and the Klamath Mountains, and the strongly-mineralized water that occurs along fault lines in the southeastern plateau. Moderate quantities of sodium and potassium have little effect on the usefulness of a water for most purposes, but waters that carry more than 50 or 100 ppm of the two may require careful operation of steam boilers to prevent foaming. More highly mineralized waters that contain a large proportion of sodium salts may be unsatisfactory for irrigation.

Carbonate and bicarbonate

Bicarbonate occurs in waters largely through the action of carbon dioxide which enables the water to dissolve carbonates of calcium and magnesium. Carbonate is usually not present in appreciable quantities in natural waters. Most of the natural waters in the Northwest are the calcium bicarbonate type, and bicarbonate is the principal anion. A few exceptions occur, especially in ground waters from marine deposits where the water contains more chloride than bicarbonate. Bicarbonate in moderate amounts has no effect on its value for most uses.

Sulfate

Sulfate is dissolved from many rocks and soils, and in large quantities from gypsum and beds of shale. Sulfate is present in low to moderate amounts in many waters in the Pacific Northwest. An objection to considerable sulfate in water that contains much calcium and magnesium is the formation of hard scale in steam boilers and increased costs in softening the supply.

Chloride

Chloride is dissolved from many rock materials and composes a very small amount of the mineral solids in waters of the region, the exception being the saline waters from marine sediments previously discussed. Large quantities of chloride may affect the industrial use of water by increasing the corrosiveness of waters that contain considerable calcium and magnesium. Large amounts of chloride also impart a salty taste to drinking waters.

Fluoride

Fluoride has been reported as being present in some rocks to about the same extent as chloride. However, the quantity of fluoride in natural surface waters is ordinarily very small compared to that of chloride. In the Pacific Northwest fluoride does not occur in significant amounts in most waters, on the basis of existing information. Two examples are given of areas where significant concentrations of fluoride occur--certain sedimentary formations in the Rogue River Valley, Oregon, and volcanic complexes in southwestern Idaho. In the latter area the Geological Survey measured fluoride in concentrations as high as 24 parts per million in waters from deep wells. Earlier results obtained by the Idaho Department of Public Health confirm data reported by the Geological Survey. Recent investigations indicate that the incidence of dental caries is less when small amounts of fluoride are present in the water. However, fluoride in excessive concentrations in water is associated with the dental defect known as mottled enamel if the water is used for drinking by young children during calcification or formation of the teeth. This condition becomes noticeable as the quantity of fluoride in water increases above 1 part per million (10).

Nitrate

Nitrate in water is considered a final oxidation product of nitrogenous material and in some instances may indicate previous contamination by sewage or other organic matter. Of data examined, nitrate does not appear to be present in concentrations that would restrict the water for ordinary use. Some exceptions would occur in shallow wells where surface runoff has become contaminated and enters the well. The primary concern of high concentrations of nitrate in water is associated with the incidence of methemoglobinemia ("blue babies") in infants (11).

Boron

Boron is a minor constituent in most natural waters, and probably does not occur in significant amounts in Northwest waters, although data are lacking. Ground water in the Tule Lake area south of Klamath Falls, Oregon, is reported to contain boron, but exact concentrations are unknown. Ground water in certain deep wells in Baker Valley and in the Rogue River Valley, Oregon, are reported to contain boron. Minute quantities of boron are essential for plant growth, but in larger quantities the element is detrimental to citrus and other crops. Borax has been produced in the past from the Alvord Lake region in Harney County, Oregon.

Dissolved solids

The reported quantity of dissolved solids consists mainly of the dissolved mineral constituents in the water. It may also contain some organic matter and water of crystallization. Waters with less than 500 parts per million of dissolved solids are usually satisfactory for domestic and some industrial uses. Of data available for the Northwest the majority of surface and ground water supplies contain less than 500 ppm of dissolved solids.

Properties of natural waters

Some properties or characteristics of water are considered, and include color, hydrogen-ion concentration (pH), specific conductance, hardness, and percent sodium.

Color

Color refers to the appearance of water that is free from suspended sediment. The yellow-to-brown color of some waters is usually caused by organic matter extracted from leaves, roots, and other organic substances in the ground. Data on color of Northwest waters are not abundant, but most water supplies have little color.

Hydrogen-ion concentration

The degree of acidity or alkalinity of water, as indicated by the hydrogen-ion concentration, expressed as pH, is related to the corrosive properties of water and is useful in determining the proper treatment for coagulation that may be necessary at water-treatment plants. A pH value of 7.0 indicates that the water is neither acid or alkaline. Values progressively lower than 7.0 denote increasing acidity, whereas values progressively higher than 7.0 denote increasing alkalinity. The pH of Northwest waters examined show that most of the waters are neutral or slightly alkaline. Some deep wells yield waters of a pH between 8.0 and 9.0.

Specific conductance

The specific conductance of a water is a measure of its capacity to conduct a current of electricity. The conductance varies with the concentration and degree of ionization of the different minerals in solution and with the temperature of the water. Specific conductance, measured as micromhos, is a convenient tool in following changes in concentration of the total quantity of dissolved minerals in natural waters.

Hardness

Hardness is the characteristic of water that receives the most attention in industrial and domestic use. Hardness is the calcium carbonate equivalent of calcium and magnesium and all other divalent cations that have similar soap-consuming and incrusting properties. Hardness is recognized by the increased quantity of soap required to produce lather. Hard water is also objectionable because of the formation of scale in boilers, water heaters, radiators, and pipes, with the resultant decrease in rate of heat transfer, possibility of boiler failure, and loss of flow. Water that has less than 60 parts per million of hardness is usually rated as soft; waters with hardness from 61 to 120 parts per million are rated as moderately hard; waters with hardness from 121 to 200 parts per million are hard; and above 200 parts per million waters are rated as very hard. From available data Northwest waters are rated as soft to moderately hard, with some exceptions.

Percent sodium

Percent sodium is reported in analyses for waters that are used or have potential use for irrigation. The proportion of sodium to all the basic constituents in the water has a bearing on the suitability of a water for irrigation. Waters in which the percent sodium is more than 60 may be injurious when applied to certain types of soil, particularly when adequate drainage is not provided.

Representative analyses of waters of the Northwest

Analyses of representative natural waters of the Northwest are given in tables 1 to 4. Table 5 is included to show the chemical character of municipal water supplies of several cities in the area.

SUMMARY

Natural waters contain dissolved solids which dissociate as ions into a balanced system of bases and acids. Silica, an exception, normally occurs in colloidal suspension. Regardless of place of origin, water has chemical and physical properties that are determined by the nature of its environment. Surface waters, as a rule, are more susceptible to changes in quality and in temperature than are ground waters.

On the basis of existing information the quality of Northwest waters is generally good. Some exceptions occur in waters from deep-seated wells or in surface sources that have received agricultural or industrial wastes.

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APPENDIX

Tables 1 - 5

Table 1: Average analyses of water from Columbia River

[Parts per million except pH, color or as indicated]

Constituent	Sampling Stations			
	[a]Revelstoke B.C.	[b]Northport Wash.	[c]Grand Coulee Wash.	[c]Maryhill Ferry, Oregon
Silica	5.5	8.7	8.6	12
Iron (Fe)	.08	.02	-	.06
Calcium (Ca)	22.1	18	21	20
Magnesium (Mg)	5.7	4.7	4.9	5.8
Sodium (Na)	1.4	4.7	2.3	7.4
Potassium (K)	0.9		2.3	2.3
Carbonate (CO_3)	.1	0.	0.	0.
Bicarbonate (HCO_3)	79.4	73	77	85
Sulfate (SO_4)	15.5	12	13	15
Chloride (Cl)	.3	.6	1.1	3.7
Fluoride (F)	.04	-	.2	.3
Nitrate (NO_3)	1.4	.23	.6	.9
Dissolved solids	93	84	89	111
Total hardness as $CaCO_3$	78.6	64	72	74
Noncarbonate hardness as $CaCO_3$	11.5	4	9	4
Percent sodium	3.6	14	6	17
Specific conductance, micromhos at 25°C.	166	-	147	176
pH (range)	7.6-8.4	-	7.2-7.8	6.9-8.0
Color	7	3	-	4-35
Period Sampled	1949	1910-11	1950-51	1950-53
Number of analyses distributed over period	12	37	30	91
Drainage area in square miles	10,400	60,500	74,100	237,000

Source of data:

a. Thomas, J. F. J., Industrial water resources of Canada: Canada Dept. of Mines and Tech. Surveys Water Survey Rept. 4, pp. 22-23, 1953.

b. Van Winkle, Walton, Quality of the surface waters of Washington: U. S. Geological Survey Water-Supply Paper 339, p. 82, 1914.

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Table 2: Analyses of ground water from unconsolidated deposits in the Pacific Northwest

[Parts per million except pH, color or as indicated]

Silica (SiO_2)	34	47	80	6.7	31
Iron (Fe)	.22	.00	-	-	-
Calcium (Ca)	23	47	10	59	23
Magnesium (Mg)	2.9	16	0.9	6.7	5.2
Sodium (Na)	30	58		14	57
Potassium (K)	.8	5.4	47	1.0	
Carbonate (CO_3)	0.	0.	0.	0.	0.
Bicarbonate (HCO_3)	144	333	117	208	138
Sulfate (SO_4)	2.6	14	20	20	51
Chloride (Cl)	10	9.5	9.0	7.0	23
Fluoride (F)	.2	.5	-	-	-
Nitrate (NO_3)	2.0	11	1.6	3.9	4.8
Boron (B)	.06	.03	-	-	-
Dissolved solids	185	376	222	221	257
Total hardness as $CaCO_3$	69	184	29	175	79
Noncarbonate hardness as $CaCO_3$	0	0	0	4	0
Percent sodium	48	40	78	15	61
Specific conductance, micromhos at 25°C.	269	571	282	377	396
pH	7.6	7.4	7.6	-	7.2
Temperature °F	64	52	-	47	67
Well location	Oregon	Oregon	Idaho	Washington	Idaho
Well depth (feet)	110	24.5	353	52	365
Date sample collected (1953)	9-21	4-28	11-23	2-27	11-17

Source of data: Unpublished records of the U. S. Geological Survey.

Table 3: Analyses of ground water from consolidated deposits in Oregon and Idaho

[Parts per million except pH, color or as indicated]

Constituent	Water-bearing material					
	Conglomerate	Shale	Basalt	Sandstone	Lava	Basalt and tuff
Silica (SiO_2)	61	19	52	59	30	86
Iron (Fe)	0.00	1.75	0.13	-	0.5	-
Calcium (Ca)	18	1,980	37	16	137	17
Magnesium (Mg)	6.8	113	2.7	1.8	45	3.1
Sodium (Na)	20	824	68	66	369	42
Potassium (K)	3.2	12	11		6.0	
Carbonate (CO_3)	0.	0.	0.	0.	0.	0.
Bicarbonate (HCO_3)	130	51	174	123	258	137
Sulfate (SO_4)	5.6	30	6.6	68	161	19
Chloride (Cl)	4.5	5,010	83	12	690	9.0
Fluoride (F)	.6	.2	.2	-	.0	-
Nitrate (NO_3)	.9	-	.1	4.0	1.9	1.9
Boron (B)	.00	2.1	.26	-	2.0	-
Dissolved solids	181	8,010	346	282	1,570	234
Total hardness as $CaCO_3$	73	5,400	104	47	527	55
Noncarbonate hardness as $CaCO_3$	0	5,360	0	0	316	0
Percent Sodium	36	25	56	75	60	62
Specific conductance, micromhos at 25°C.	224	13,300	541	402	2,750	286
pH	7.9	7.0	7.6	7.2	7.4	8.2
Temperature °F	53	-	57	59	57	105
Well location	Oregon	Oregon	Oregon	Idaho	Oregon	Idaho
Well depth (ft.)	28.2	93	480	906	162	1220
Date Sample collected	4-27-53	4-19-51	5-17-51	11-24-53	6-17-51	11-23-53

Source of data: Unpublished records of the U. S. Geological Survey.

Table 4: Average analyses of water from miscellaneous streams in the Pacific Northwest

[Parts per million except pH, color or as indicated]

Constituent	Kootenai River at Porthill Idaho	Pend Oreille River at Metaline Falls Wash.	Flathead River at Columbia Falls Mont.	Similkameen River at Oroville Wash.	Willamette River at Salem Oreg.
Silica (SiO_2)	8.3	9.4	5.5	12	16
Iron (Fe)	.07	.04	.04	.14	.08
Calcium (Ca)	27	21	23	17	5.0
Magnesium (Mg)	6.7	5.7	6.0	3.7	2.0
Sodium (Na)	1.9	2.5	1.1	3.2	3.4
Potassium (K)	1.5	2.2	1.3	2.5	1.0
Carbonate (CO_3)	0.	0.	0.	0.	0.
Bicarbonate (HCO_3)	103	85	95	66	26
Sulfate (SO_4)	12	9.0	4.5	9.4	3.0
Chloride (Cl)	1.3	1.2	.8	2.0	2.6
Fluoride (F)	.3	.3	.2	.3	.3
Nitrate (NO_3)	.4	.5	.4	.7	.6
Dissolved solids	110	94	90	83	52
Total hardness as $CaCO_3$	92	76	82	58	21
Noncarbonate hardness as $CaCO_3$	8	6	4	4	0
Percent sodium	4	6	3	10	26
Specific conductance, micromhos at 25°C.	186	155	155	127	52.8
pH (range)	7.1--7.9	7.0--7.8	7.2--8.0	6.6--8.1	6.6--7.5
Temperature °F	45	53	43	32-72	35-75
Number of analyses	36	29	36	36	60
Period sampled	Oct.1949-Sept.1950	Oct.1949-Sept.1950	Oct.1949-Sept.1950	Oct.1949-Sept.1950	Oct.1951 Sept.1953

Source of data: Unpublished records of the U. S. Geological Survey.

Table 5: Analyses of some municipal water supplies in the Pacific Northwest
[Parts per million except pH, color or as indicated]

Constituent	Vancouver B.C.	Portland Oregon	Seattle Wash.	Tacoma Wash.	Spokane Wash.	Boise Idaho	Pocatello Idaho	Butte Mont.	Missoula Mont.
Silica (SiO_2)	4.0	7.2	4.0	26	20	25	14	20	5.2
Iron (Fe)	.1	.2	.04	.0	.0	1.0	.12	.16	.03
Calcium (Ca)	1.9	2.3	6.3	6.4	35	29	30	16	4.5
Magnesium (Mg)	1.4	.7	.6	1.3	16	3.1	6.6	4.0	1.1
Sodium (Na)		2.1		6.7	4.0	12	6.0	5.3	.8
Potassium (K)	2.1	.2	.4	-	-	1.8	1.4	2.4	.8
Carbonate (CO_3)	-	0.	0.	0.	0.	0.	0.	0.	0.
Bicarbonate (HCO_3)	4.2	15	22	30	175	91	116	64	15
Sulfate (SO_4)	4.6	.9	2.1	2.1	13	34	6.4	11	1.8
Chloride (Cl)	1.0	2.4	.6	6.3	2.0	3.1	9.1	3.0	1.2
Fluoride (F)	-	.0	.0	.0	.0	.3	.1	.4	.1
Nitrate (NO_3)	.4	.3	.0	.0	2.2	.5	.5	1.3	.1
Dissolved solids	22.5	30	37	[a] 64	184	157	136	98	22
Total hardness as $CaCO_3$	9.7	9	18	21	153	85	102	56	16
Noncarbonate hardness-$CaCO_3$	6.3	0	0	0	10	11	7	4	3
Specific conductance, micromhos at 25°C	-	-	-	-	-	228	219	137	27
pH	7.0	7.0	7.3	7.8	7.9	7.3	7.9	7.4	7.5
Color	-	15	0	0	-	10	12	12	5
Temperature °F	-	59	43	-	-	58	42	-	55
Date sample collected	10-25-46	9-19-47	1-8-51	10-4-48	6-51	6-4-51	3-29-51	11-17-51	6-22-51
Source of public supply[b]	SW	SW	SW	SWandGW	GW	GW	SWandGW	SW	SWandGW
Origin of sample analyzed	Seymour River	Bull Run River and Lake	Cedar River	Green River	Five Wells at Pumping Station	Reservoir No. 4	Gibson Jack Creek	Big Hole R., Basin Crk. Res. and Yankee Doodle Creek	Rattlesnake Creek

a. Sum of determined constituents
b. SW - Surface Water, GW - Ground Water