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PART V.

THE WATER RESOURCES OF WASHINGTON.

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THE WATER RESOURCES OF WASHINGTON.

POTABLE AND MINERAL WATER.

BY H. G. BYERS.

CITY WATER SUPPLIES.

Water surveys have been or are being made in many of the states. These surveys are for the purpose of determining the sanitary condition of present supplies, of the formulation of standards of purity of unpolluted waters, and of enabling citizens to gain immediate and authoritative information in regard to the potability of any source of supply. These surveys are made at the expense of the state and are in some cases of great extent and corresponding value.

That an abundant supply of pure drinking water is very important for the preservation of health, and that impure water is a most potent factor in the development and spread of disease, are propositions the truth of which is unquestioned by physicians, scientists or the general public. It is not a matter of general information, however, that local conditions greatly modify the deductions to be made from a given analysis, and that such results as would in certain circumstances indicate unsanitary water would in other cases indicate no such condition. For example results which if obtained from the water of deep wells would indicate certainty of contamination would carry no such significance if the water were from surface drainage.

The water supplies of the state are from three sources—rain, deep wells, and surface drainage; this last includes shallow wells and springs. Of these surface drainage waters are by far the most important since but few people use rain water directly and but few deep wells have been sunk. The report in this case therefore deals only with surface waters.

We were led into this investigation by the fact that, when recently arrived in the state, we were called upon to pronounce upon the purity of the water of the city of Chehalis. It was then learned that there were no records of analyses upon which to rest a comparison, and therefore no local data upon which to base a decision. No funds were at our disposal yet we nevertheless started to accumulate such data and deeming that the most valuable imformation was to be gleaned from the investigation of the city supplies, our work was almost exclusively upon them.

In making these analyses we omitted no reasonable precaution to secure results which are accurate and conclusive. The waters, where possible, were collected by ourselves, and in all other cases careful instructions were given to persons who collected the samples for us. As soon as possible after the receipt of a sample the analysis was begun and was usually completed upon the same day. The methods of analysis were those employed by the Massachusetts Board of Health or by the Illinois State Survey. Nearly all the samples were collected between November 15, 1900 and May 1, 1901, and so represent winter conditions. The results of similar analyses of summer waters would add greatly to the value of the report.

The results were surprising in many cases because of the great purity of the waters, and hence it seemed interesting to compare our results with similar analyses of the water supplies of eastern cities. These were obtained from New York, Chicago, St. Paul, Minneapolis, New Orleans, Boston and other places. No results could be obtained from San Francisco and Portland because no analyses have been made. St. Louis failed to send any results. The value of such work is shown by the fact that the city of Chehalis now secures its supply from a purer source and the city of Ballard will probably secure an extension of the Cedar river system which furnishes the supply of Seattle. It is clear also from our analyses that the limits of potability as laid down by the Illinois survey for the waters of that state do not hold here. The results of our analyses are given in the accompanying table.

The results which are given in parts per million are in terms which, for the most part, are unintelligible to the general public, therefore a discussion of them is necessary.

It is well known that water in nature is never pure, but contains in solution various substances upon the character and quan-

TABLE OF SANITARY ANALYSIS OF POTABLE WATERS, IN PARTS PER MILLION.

LOCALITY.	Date.	Sediment.	Color.	Taste.	SOLIDS ON EVAPORATION.			NITROGEN AS—		NITROGEN AS AMMONIA.		Oxygen consumed	Chlorine	HARDNESS.			Remarks.
					Volatile.	Non-volatile.	Total.	Nitrites	Nitrates	Free.	Albuminoid			Temporary	Permanent	Total.	
University of Washington	Feb. 18, 1901	None.	Very clear	None	27.12	29.86	87.08	None	.030	.010	.055	4.40	2.60	2.35	49.82	52.17	Supply from surface springs.
University of Washington	Mar. 15, 1901	None.	Slightly brown	None	30.34	70.28	100.62	None	.384	.012	.036	4.74	5.40	4.40	42.24	46.64	Residue blackened upon heating.
Seattle, city	Feb. 8, 1901	None	Very clear	None	23.00	110.00	133.00	None	None.	.070	.023	1.40	4.40	5.00	65.00	70.00	Cedar river water. Had not washed out pipes. System in short time.
Seattle, city	Mar. 13, 1901	None	Very clear	None	12.50	23.60	36.10	None	.032	.048	.011	1.31	2.50	1.22	15.90	17.12	Cedar river water.
Seattle, city	April 27, 1901	None	Very clear	None	10.50	25.99	36.49	None	0.000	.008	Trace.	1.26	1.50	1.49	12.32	13.81	Cedar river water.
Tacoma, city	Feb. 23, 1901	None	Slightly brown	Little flat	22.00	25.20	47.20	None	0.000	.035	.080	6.34	4.40	0.00	50.00	50.00	Clover creek and springs.
Tacoma, city	April 4, 1901	None	Slightly brown	None	30.78	31.39	62.17	None	.080	.026	.0827	7.63	3.25	3.44	9.77	13.21	Residue blackened upon heating.
Mineral Spring (Ravena Park)	Feb. 28, 1901	None	Very clear	Not pleasant.	33.55	105.83	139.38	None	.380	.400	.045	2.71	4.40	0.00	80.07	80.07	Smells of hydrogen sulphide. Contains trace of sulphur.
Lake Washington	Mar. 9, 1901	Some	Brown	None	24.85	32.70	57.55	None	.130	.010	.095	7.25	4.00	1.18	34.64	35.82	Brown from suspended matter. Residue blackened on heating.
Chehalis, city	Nov. 15, 1900				109.50	130.90	240.40	.098	7.190	.090	.088	2.88	24.80	20.00	75.00	95.00	Residue blackened on heating. Supply condemned.
Newaukum river	Nov. 25, 1900	Considerable	Clear	None	50.00	33.00	83.00	None	0.000	.030	.055	8.57	4.80	1.00	2.50	3.00	—
Everett Water company	Jan. 10, 1901	Some	Turbid	None	48.00	252.80	300.80	None	0.000	.020	.050	7.27	4.80	5.00	150.00	155.00	—
Snohomish, city	Feb. 23, 1901	None	Clear	None	18.28	23.22	41.50	None	.400	.010	.093	3.75	4.00	0.00	40.00	40.00	—
Whatcom, city	Mar. 16, 1901	None	Very clear	None	42.34	116.52	158.86	None	0.000	.004	.033	2.03	3.80	0.00	68.78	68.78	—
Elder's well, Fremont	Mar. 22, 1901	Considerable	Cloudy	None	41.20	150.02	191.22	None	.260	.003	.092	1.35	4.00	4.80	68.61	73.41	Deep artesian well.
Ballard, city	Mar. 25, 1901	Considerable	Very clear	None	43.75	121.91	165.66	None	.320	.874	.100	2.89	5 50	44.68	26.10	70.78	Residue blackened upon heating.
University Heights, Seattle	Mar. 10, 1901	Considerable	Cloudy	None	26.75	75.00	101.75	None	.840	.013	.0063	.559	5.25	13.77	40.71	84.48	From a deep artesian well.
Mineral Spring (Bremerton)	April 3, 1901	Considerable	Clear		45.37	311.79	257.16	None	.290	.066	.1407	6.28	31.00	1.72	1.18	2.90	Residue blackened on heating. Gave an odor of burning garbage, probably due to sulphur.
North Yakima, city	April 8, 1901	Slight	Slightly roily	None	54.68	114.85	169.53	None	0.000	.008	.0177	1.79	2.75	11.19	80.23	97.42	—
Walla Walla, city	April 12, 1901	None	Clear	None	18.81	62.86	81.67	None	.452	.008	.0267	2.89	1.50	0.00	22.68	22.68	Residue blackened on heating.
Aberdeen, city	April 14, 1901	None	Clear	None	12.50	63.19	75.69	None	.090	0.000	.021	.966	6.50	0.00	13.81	13.81	—
Olympia, city	April 20, 1901	None	Clear	None	26.64	80.86	107.50	None	.050	Trace.	.0323	3.38	4.20	11.83	28.59	40.42	—
Spokane, city	April 23, 1901	None	Slightly whitish	None	15.81	34.43	50.24	None	.018	.004	.0363	2.13	1.50	0.00	12.33	12 38	Residue blackened upon heating.
Port Townsend, city	Feb. 16, 1901	Very little	Very clear	Brackish	343.00	830.10	1,173.10	None	2.544	.010	.063	1.52	462.40	67.57	101.92	169.49	Residue blackened upon heating. Solids—sea salt.
Brooklyn (Miss Hansee's well)	Jan. 10, 1901	None	Clear	None	82.50	111.00	192.50	None	6.80	.030	.047	1.90	14.40	85.00	25.00	110.00	Residue blackened upon heating.
Brooklyn (Meredith's well)	Mar. 16, 1901	Some	Cloudy	Flat	47.07	123.17	170.24	None	None.	.371	.095	2.80	14.00	7.02	85.15	92.17	Water smells foul. Residue blackens upon heating.
Fremont (S. A. Graham's well)	Mar. 22, 1901		Clear		119.06	149.91	268.97		8.51	.005	.047	0,27	48.00	None.	93.67	93.67	Well under house. Suspicious.
Ballard (Paul Hopkins' well)	April 8, 1901		Clear		30.95	71.95	102.90	None	4.90	.007	.068	2.03	9.50	1.72	21.80	23.52	—
Seattle (Denny-Fuhrman school)	Sept. 25, 1901		Clear		61.00	132.50	193.50	None	0.00	.050	.030	1.50	8.00				—
Port Townsend (Glendale dairy)	Sept. 28, 1901	None	Clear	None	85.36	153.64	239.00	None	6.94	.200	.187	22.12	46.75	93.05	53.32	146.37	Residue blackened upon heating.
Brooklyn (Mr. Cudworth's well)	May 11, 1901		Clear	None	36.68	102.04	135.72			.1728	.0266	1.40	7.75	4.43	64.08	68.51	—
Everett (private well)	Jan. 22, 1901	None	Clear	None	50.00	42.50	92.50	None	None.	.070	.055	4.50	13.6	0.00	40.00	40.00	—
New York, city (Croton R.)	April 11, 1901		Slightly turbid		21.00	43.00	64.00	None	.424	.035	.160		2.35	0.00	27.40	27.40	—
New York (Ridgewood water)	April 10, 1901		Slightly turbid		35.00	64.00	99.00	None	2.014	.005	.057		22.00	0.00	37.80	37.80	—
Chicago (Lake Michigan)	Feb. 8-11, 1901									.018	.020	1.62	3.31				Daily analysis of Chicago water.
Chicago	Dec. 26, 1896	Very little			6.00	134.40	140.40	.001	.150	.003	.080	2.50	3.00				—
Boston	April 4, 1898	Slight	Slightly turbid		17.50	15.50	33.00	None	.070	.016	.178	5.70	3.00				—
Minneapolis	Dec. 25, 1900	Moderate			53.00	186.00	239.00	None	Trace.	.100	.225	8.45	2.10				—
St. Paul (Lake Vadnais)	Sept. 2, 1899				71.00	102.00	173.00	None	.030	.064	.176	6.00	.50				—
St. Paul (Artesian wells)	Sept. 2, 1899				58.00	214.00	272.00	None	Trace.	.252	.005	1.00	1.25				—
St. Paul (Lake Peltier)	Sept. 5, 1899				120.00	91.00	211.00	None	.040	.062	.595	16.20	1.425				—
New Orleans	April 2, 1901	Considerable	Turbid				956.00	.003	.180	.001	.347	12.70	7.70				—

tity of which depends the potability of water. Rain water as it falls from the clouds is probably the purest obtainable without distillation, but even this contains dust particles and gases washed out of the air. As soon as water reaches the earth it begins to dissolve more or less of all the substances with which it comes in contact, becoming impure with harmless, harmful or beneficial ingredients. In well peopled regions the water courses are often simply sewers which convey away or assist in the destruction of the refuse organic matter of the surface. Springs many times contain besides the mineral matters over which they pass, some of the vegetable or mineral matters through which the water has percolated in reaching their sources. In the case of wells contamination is usually due to the nature of the soil in which they are sunk, but may be added to by the infiltration of sewage from cesspools or privy vaults which not infrequently are situated in close proximity to the wells. In such cases the purifying influence of the earth is relied upon, but which, while undoubtedly great, is very frequently over estimated.

The fact that the water of a given source of supply is clear, is as is well known, no certificate of its purity; though lack of clearness, while not a certain indication of *dangerous* contamination, is certainly not a desirable condition. It is true also that clear sparkling water contaminated by sewage may sometimes be used for a long time without harm to the users. No one, however, would knowingly use such water simply as a matter of taste, yet there is the additional fact of the constant danger of the introduction of germs of contagious diseases where the contamination is of animal nature. Such being the case water which is impure with, or subject to contamination from, matter of animal origin is more dangerous than water rendered foul with decaying vegetable matter. In the latter case, however, an excessive amount of impurities is not considered healthful and is to be considered as rendering a water unfit for use. From all these facts it is clear that it is necessary for an analyst, in order to form the most useful conclusion from the result of his analysis to know as much as possible about the history of the water involved, the nature of the soil through which it passes, and the location of surrounding sources of infection.

All waters, except in special cases, contain the same substances and it is upon the varying quantities of these that a judgment is based. The substances usually sought in a chemical analysis, *i. e.*, those which bear relation to sanitary conditions and the amount which it is possible for a water to contain and remain fit for drinking purposes are given in the subjoined table, which is taken from the report of the Illinois Survey:

	Parts per million.
Total solids	500.
Loss on ignition (no blacking should occur and no offensive odor develop)	....
Oxygen consumed	2.
Chlorine	15.
Nitrogen as free or saline ammonia	0.02
Nitrogen as albumenoid ammonia	0.05
Nitrogen as nitrites	0.001
Nitrogen as nitrates	15.

These figures are of course only approximate, even for Illinois, and are but a good general guide. It is to be noted that judging by our analyses the limit for chlorine and nitrates is several points too high, while the limit for ammonia content is too low.

The total solids of a water are not of very great importance unless they are in such quantity as to be detrimental because of that fact or because of their nature as determined by subsequent analysis. The loss on ignition is of water, which may have been chemically combined with the salts present, of carbon dioxide from the carbonates or ammonia salts, or of animal or vegetable matter. The last item is the one of prime importance, and blackening of what is otherwise a white residue is indicative of organic matter, which if of animal origin is likely to develop an offensive odor and give the analyst a clue to the nature of the contamination. The fixed residue consists of harmless or beneficial salts. A sample analysis is given below. The nature and quantity of the organic content of a water is of much greater importance. This consists of living or dead organisms of animal or vegetable nature, of fœcal matter and the products of decomposition of animal matter. There is no direct means of determining their nature and amount because in the process of determination they undergo change. But all organic matter may be burned; that is, made to unite with oxygen, and consequently the amount of oxygen consumed when water is treated with oxidizing agents is, if always determined in the same way, a guide to the relative amount of organic matter present.

More important is the fact that nitrogen is a constituent of all living matter, and its determination in the four forms in which it may exist in water offers the best and most accurate means of study of those substances which render water unsanitary.

Nitrogen as albumenoid ammonia represents the amount of nitrogen present in the form of undecomposed organic matter. This may consist of animal tissues, urea, fœcal matter, etc., substances which serve as food for micro-organisms of vegetable or animal nature and which includes the disease bacteria. The presence of much nitrogen in this form in usually indicative of sewage pollution or drainage from refuse animal matters. The quantity is likely to be normally larger than the limits given in the preceding table where the water passes over such quantites of nitrogen bearing vegetable matter as in this region.

Nitrogen as free ammonia represents the nitrogen either as free ammonia or in combination with acid residues and which usually proceeds from nitrogenous organic matter which has decayed without the presence of considerable quantities of inorganic substances. It may be looked upon as proof of the existence of organic matter in the first stages of decay.

Nitrogen as nitrites represents the decomposition products of organic matter under the influence of living organisms, so that its presence is evidence not only of organic matter but of living germs as well.

Nitrogen as nitrates represents the complete oxidation of the nitrogenous materials, and its presence in large amount signifies that the water if not now dangerous has been so and is still open to suspicion. Indeed our work seems to show that a much smaller amount than fifteen parts per million would in this region indicate contamination.

The chlorides present in water serve for determining the purity of the water only if the location of the supply is known.

Water may contain large quantities of salt and still be free from organic contamination, though whether still good for constant consumption is a doubtful question. This is the case with water of Port Townsend. The source of the chlorine there, as is evident from the location of the pumping station, is seepage from Puget sound which of course contains large quanties of chlorides. Chlorine is however a constant constituent of urine and excrement and, other things being equal, the presence of an unusual amount of it in water is proof positive of sewage contamination.

The hardness of water is of no special sanitary importance; but since, generally speaking, the harder a water the less fit it is for domestic purposes, the relative hardness, expressed as if it were all due to calcium carbonate is a guide to the culinary and cleansing qualities of water.

The inorganic or fixed residue is never analyzed for sanitary purpose, unless the presence of some poisonous substance, as lead, is suspected. Its analysis is a guide to the usefulness of water for boiler purposes. For practical purposes the scale forming portions may be considered as made up of items 4, 5, 6, and 7 of residue analysis given below. Sometimes quantities more or less considerable of magnesium and other chlorides are present, and these are undesirable because of their corrosive action on boilers. Occasionally residue analyses will reveal the presence of ingredients of medicinal value. These will be referred to under the head of mineral springs.

RESIDUE ANALYSIS OF CEDAR RIVER WATER.

	Grams per liter (parts per thousand)
Total solids	.03117
Volatile solids	.00786
Non-volatile solids	.02331
Silica	.00178
Alumina and oxide of iron	.00492
Calcium sulphate	.00514
Calcium carbonate	.01666
Magnesium chloride	.00149
Sodium chloride	.00063

A comparison of the analyses given above reveals the fact that our cities have exceptionally pure water supplies. This is particularly true of Seattle, Tacoma, Everett, Spokane; our largest towns. They have their supplies from mountain streams and lakes which drain water sheds free from injurious contamination and to this they owe their purity.

In a country of such rank vegetable growth and heavy rainfall we would naturally expect the water to be somewhat impure. Indeed, the few analyses of surface waters made by us accord with that expection. See the analyses of wells and springs given in foregoing table.

The character of our city supplies will be sufficiently outlined by a brief description of those of Seattle, Tacoma and Spokane. Seattle obtains its supply from Cedar river at a point twenty-eight miles from the city. The river which flows into Black river is the outlet of Cedar lake, which drains an area of two hundred square miles, all of which is under the control of the city, so that its purity is assured. The water is conveyed to the city from the intake, by gravity alone, to the high service reservoir, whence a portion is pumped by means of the surplus water to the stand pipe on Queen Anne hill, which supplies the highest parts of the city. The amount of water now conveyed to the city is about twenty-five million gallons per day, while the maximum available supply is approximately three hundred millions, a quantity sufficient to supply a population of one and a half million on the basis of one hundred and fifty gallons per capita. The reservoirs at present in use in the city have a capacity of approximately fifty million gallons.

The city of Tacoma obtains its supply from Clover creek, a small mountain stream, and from springs. These are gravel bed springs and, as is true also of Clover creek, are not affected by local rainfall. They together can furnish a maximum daily supply of twelve million gallons per day of exceptionally pure water.

Spokane obtains its supply from the Spokane river, which drains all the north and west slope of the Coeur d'Alene mountains. The supply is pumped to the city from a point about five miles above the city, and now supplies to the city about eight million gallons per day.

These supplies, because of their purity and the ease with which they are conveyed to the users, compare very favorably with that of even Chicago, which pumps its enormous supply of 160 gallons per capita per day from Lake Michigan, the purity of which in the neighborhood of the intake is improved by the sewage canal connecting the lake with the Illinois river. The local supplies are very much of an improvement over those of St. Paul, Minneapolis, New Orleans and other cities.

MINERAL SPRINGS.

The mineral springs of the state are numerous but have not been developed to any very great extent. There are hot springs at Madison on the Great Northern Railway, and at Green River Hot Springs on the line of the Northern Pacific. At both of these places sanitariums have been built and have become considerably frequented by seekers after health and pleasure. The

Madison hot springs were visited by Mr. H. G. Knight, in concection with this work, and some data in regard to them were obtained. Similar data in regard to the Green River springs were requested, but were not furnished by the owners. The Madison springs are on the mountain side just west of the tunnel on the Great Northern. The water comes out of fissures in the mountain side some six hundred feet above and a mile and a half back of the location of the sanitarium. The supply is sufficient to fill a two-inch pipe, and is at the spring at a temperature of about 112° F. The following analysis was made by Mr. C. Osseward, chemist for Stewart & Holmes Drug Company, Seattle:

RESULTS EXPRESSED IN GRAINS PER GALLON.

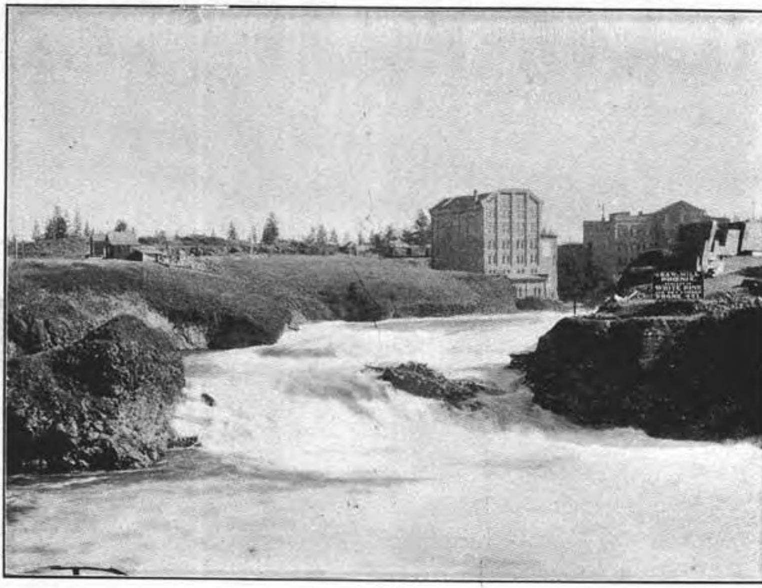
Total solids	9.9	Silica	1.34
Chlorine	0.87	Sodium	1.63
Iron	0.76	Potassium	0.34
Lime	2.33	Sulphuric anhydride	0.52
Magnesia	1.1	Ammonia	0.00058

There are also mineral springs at Cascades in Skamania county, which have a daily flow of thirty thousand gallons. During 1901 7,000 gallons were sold for medicinal use, and about 120,000 gallons were used for bathing purposes. A sample of the water could not be obtained for analysis in time for this report.

The waters of Medical lake in Spokane county are acquiring a reputation for curative properties, and an analysis of the water made by G. A. Mariner, of Chicago, is appended.

	Parts per thousand.
Silica	0.1825
Alumina and iron oxide	0.0120
Calcium carbonate	0.0031
Magnesium carbonate	0.0040
Sodium chloride	0.2869
Potassium chloride	0.1616
Sodium carbonate	0.1089
Potassium carbonate	Trace.
Lithium carbonate	Trace.
Borax	Trace.

Near Skykomish on the bank of the river about a half mile from the little town of Berlin, are some very interesting springs. They are saturated with carbon dioxide, and when the nearly ice-cold water is allowed to stand in vessels it effervesces vigorously. The flow from the larger of the two springs is estimated at from two to three gallons per minute. Both are chalybeate



FALLS OF THE SPOKANE RIVER. SPOKANE.

FALLS OF THE YAKIMA RIVER, PROSSER.

springs and have made considerable deposits of iron around their mouths. The analysis of the water is given.

	Parts per thousand.
Solids, non-volatile	0.5473
Silica	0.0078
Alumina and iron oxide	0.0150
Calcium sulphate	0.0529
Calcium carbonate	0.5627
Magnesium chloride	0.1693
Magnesium sulphate	0.0935
Sodium sulphate	0.9331
Potassium chloride	0.0267
Carbon dioxide	1.4720

There are also mineral springs, warm and cold, in the Yakima Indian Reservation on Simcoe creek about fifteen miles from Fort Simcoe, but at the season of the year when this report was compiled it was impossible to get full information in regard to them.

By the kindness of Mr. Joseph Parrott, of Glenwood, we have considerable information regarding a rather large number of hot springs and cold mineral springs along the Klickitat river, south of Mount Adams. These seem of such interest that an effort will be made to carefully investigate them and include the report upon them in a future report of the survey.

Near Bremerton there is a mineral spring which was formerly a favorite resort of the Indians who not infrequently camped near it to obtain renewed health and vigor. Its analysis shows ingredients which render probable its medicinal value. Analysis by H. G. Knight:

	Parts per thousand.
Non-volatile solids	0.45194
Silica	0.01334
Alumina and iron oxides	0.04764
Calcium sulphate	0.046385
Magnesium chloride	0.04008
Magnesium sulphate	0.07790
Sodium sulphate	0.23686
Lithium sulphate	0.02128

ALKALI LAKES.

The alkali lakes of the state are neither numerous nor large. Among the largest are Moses lake, Blue lake and Sanitarium or Soap lake. These together with numerous temporary ponds and a chain of fresh water lakes occupy the former bed of the Columbia — the Grand Coulee.

Moses lake, which lies about twelve miles southeast of

Ephrata on the Great Northern Railway, is about eighteen miles long and a mile wide, and is very shallow. The average depth is approximately twenty feet. It lies in a shallow basin with low banks, so that a rise of but a few feet would inundate a large section of country. The water is unfit for drinking purposes, but is not strongly alkaline and could probably be used in irrigation. The section of country in which these lakes are located is, of course, very dry and supports only a scanty vegetation. Where there is water, however, the soil is very fertile. The lake drains a large area through upper Crab creek. It has no outlet but across its foot lies a low range of sand hills through which the water seeps into the sources of lower Crab creek, which occupies the bed of the canyon below. Along this canyon lie numerous shallow ponds which dry up in summer. The deposits left by these are not of any considerable value, though they contain an appreciable quantity of borax.

An interesting feature of Moses lake is the fact that it is gradually rising, having risen about ten feet in the last seven years. If it continues to rise through a few more feet it will break through a clear course into lower Crab creek and empty into the Columbia.

The analysis of the water of Moses lake is as follows. The analysis is by H. G. Knight:

	Parts per thousand.
Total solids	0.32357
Volatile solids	0.10095
Non-volatile solids	0.22262
Silica	0.01502
Alumina and iron oxide	0.00331
Calcium carbonate	0.06235
Magnesium carbonate	0.07525
Sodium sulphate	0.01258
Sodium chloride	0.01895
Sodium carbonate	0.10914

More interesting is the so-called Soap lake, or Sanitarium lake, situated about six miles north of Ephrata. This lake is so-called because it is so strongly alkaline as to be soapy to the touch, and when a strong wind blows across it the water along the shore is beaten into great rolls of foam. Fish can not live in the water, nor is there any vegetation in this as in Moses lake. The water is used for bathing, but to those unaccustomed to its use the water has a slightly caustic or irritating effect. It is also claimed that it is useful medicinally. There is much of peculiar interest about the lake. It is about two and a quarter by threequarters miles in extent and is very deep in places and probably averages about forty feet. It drains only a very small area of country and has neither inlet nor outlet in the form of streams. It is located in a deep basin walled to the height of one hundred feet or more on the east and west by cliffs of black basalt. The land to the north and south rises slowly; on the south to nearly the height of the cliffs, but on the north the rise is so slight that should the lake rise fifteen feet it would empty in the next of the chain of lakes to the north. The source of the water of the lake is said to be a spring in the center. The Indians of the neighborhood assert that only a few years since the lake was very small and was fed by this strongly alkaline spring. Fresh water is however continually seeping in from the shores, as is shown by the fact that fresh water wells may be sunk even but a few feet from the shore, and that the cattle disliking the strongly alkaline water face the shore to obtain the sweeter seepage. The water of the lake contains calcareous matter to such an extent that the stones and debris at the bottom are incrusted with a frost-like coating of calcium carbonate.

The analysis of the water is as follows:

	Parts per thousand.
Total solids	28.2669
Volatile solids	0.62503
Non-volatile solids	27.64186
Silica	0.12816
Alumina and iron oxide	Trace
Calcium sulphate	Trace
Calcium carbonate	Trace
Magnesium sulphate	0.39099
Sodium sulphate	6.34872
Sodium chloride	5.81384
Sodium carbonate	14.08901
Potassium carbonate	0.51177
Lithium sulphate	Trace
Phoshorus pentoxide	0.12018
Carbon dioxide (semicombined)	1.37034
Borax	None
Iodine	None
Free ammonia	.03400
Albumenoid ammonia	1.1060
The specific gravity	1.0260

A more extended investigation of the waters of the state would be of value. This is especially true of the mineral waters, which have indeed received but scant attention.

The greater part of the work and most of the analyses represented in this report are due to Mr. H. G. Knight.

ARTESIAN WATER.

BY C. A. RUDDY.

INTRODUCTION.

The fundamental principles governing the flow of artesian water are simple and readily grasped by anyone. It is only an illustration of the well known fact that "water seeks its own level." The prime requisite is to have a water-bearing stratum overlaid and underlaid by impervious strata, and to have its surface outcropping at a higher elevation than the surface of the ground where the proposed well is to be sunk. Although so simple theoretically, yet practically the problem has many factors by no means easy of solution.

Our knowledge of the conditions underlying the surface of the earth is very imperfect at best. Usually the surface outcropping of the strata are more or less obscured by a mantle of soil, so that it is often difficult to determine accurately the dip of the rocks or their exact physical structure. The ideal conditions of a synclinal valley with clearly defined strata outcropping on its elevated edges as usually figured in the text-books seldom occurs in nature; the actual conditions are not necessarily more complex, but they are more obscure.

In studying the formation of the rocks in any locality with a view to the possiblity of obtaining artesian water it is well to know just how much dependence can be placed on surface indications. Strata which at their outcrop may have all the appearances of being good water-bearers may at a short distance below the surface of the ground change into perfectly impervious strata, without in any way breaking the continuity of the beds. This change in structure may be either favorable or unfavorable, according to the other conditions of the basin. Likewise the strata above or below the water-bearer may at their outcrop be perfectly impervious and yet change in their nature so much that at the locality where the well is to be sunk they will not hold water at all.

Strata are not usually continuous over wide areas. They are more or less lenticular in shape, being usually thickest towards the center and gradually thinning out as the edges are approached. The same bed may change from coarse to fine, from conglomerate to sandstone, and even to shale.

When the rocks of a region have been greatly folded and faulted there is not much use trying to find artesian water in them. This does not apply to long, open folds unaccompanied by fracturing, but to close folding and crushing, caused by great lateral pressure. The fact that the rocks are in such a distorted condition shows that they have been subjected to enormous pressure, which would have the tendency to compress them so much that they would lose most of their water-carrying properties. Their position, too, would usually preclude the possibility of water being carried any distance under ground. Where rocks in this condition occur it is impossible from surface indications to determine where water would likely be found.

It is useless to look for water in the older crystalline rocks, such as granite, gneiss or schist, so that when in drilling a well rocks of this nature are encountered, there is no use going any deeper.

When the drilling of a well for artesian water is contemplated, the geological structure should of course be carefully worked out as far as surface indications will permit. Very often the pervious stratum, on account of its unconsolidated or friable condition, is more easily eroded than the enclosing beds, so that it is more likely to be found in the bottom of a valley than forming the hill tops. When such a valley floor is at a greater elevation than the surface of the ground where the proposed well is to be sunk, this position of the outcrop is more favorable than otherwise, because it permits of the water being held over the surface of the outcrop for a greater length of time, and thus gives more of it a chance to soak into the rocks. The area of surface exposed of the water-bearing bed should also be taken into considration when estimating the probable quantity of water taken into the rock. The area multiplied by the annual rainfall will give the total amount of water which falls on the outcrop, but it must be borne in mind that not all the water which falls as rain soaks into the rock. A part of it runs off in the streams or is taken into the air again by evaporation. The drier the region the less the amount carried off by streams and the greater the amount lost by evaporation. Sometimes the outcrop, as in the case of the valley mentioned above, receives the drainage of surrounding areas, and thus its available supply is augmented. The porosity of the rock at its surface will of course also have its share in determining what proportion of the rainfall is absorbed by the rocks and what escapes by other means. These considerations are of most importance in arid regions where the wells, even if succcessful, are liable to fail in time, owing to the inadequate supply.

An ordinary red brick will absorb its own weight of water. Coarse grained sandstones absorb water very readily, except where the spaces between the grains have been filled in by material carried there in solution. The finer the grains the less readily will water pass through. Fine shales and clays are almost entirely impervious, so that in an artesian basin they make a good upper and lower layer to keep the water from escaping.

The water may escape either upward or downward by means of fissures in the enclosing beds. Surface outcroppings give little indications of the existence of such defects, but in a general way it may be said that the less the beds are consolidated and the less they have been upturned from their original horizontal position, the less likely they are to be fissured. Limestones, when not fissured, are usually quite impervious, but they are more likely than any other rocks to contain underground channels, so if they form either of the enclosing beds of the supposed water-bearing stratum, they should be viewed with considerable suspicion.

Theoretically, the water should rise in the wells as high as its own head, but as a matter of fact it never does. The frictional resistance offered by the rock through which the water passes, and to a lesser extent, that offered by the walls of the well itself, has the effect of reducing the height of the column of water. The difference in height between the water in the well and at its source in the rock is greater or less depending upon the texture of the rocks, the amount of leakage, the distance the water has to come, and to a much lesser extent, the diameter of the well. Rocks of fine texture offer a very much greater resistance to the passage of water than those of coarse texture. The larger the dıameter of the well the less the resistance offered to the ascending column of water. The discrepancy between the theoretical height of the water and its actual height can not be accurately determined beforehand, but allowance should always be made for it. This is particularly necessary where the head is not very great.

In some of the older geological formations of the eastern states the strata are often continuous over thousands of square miles, but in this state none of the geological formations have strata continuous over wide areas. The sedimentary beds change from coarse to fine and thin out rapidly. This goes to show that it is hazardous to assume what the conditions are below the surface from the appearance of the outcrops, even a few miles away. To the practical man looking for artesian water in this state we would say, pay less attention to the character of the rock at its outcrop than to its dip. By a careful study of the dips and elevations good artesian conditions can often be discovered. Whether the rocks are pervious or impervious is largely a matter of guess work until a well has been actually sunk and the facts ascertained.

In a large number of places in the arid regions of central Washington it is not possible to obtain water for irrigation purposes by means of canals, owing to insufficient water in the streams. In these localities the only salvation lies in finding artesian water. It is perhaps too much to hope that it will be found over very wide areas, but by careful investigation new localities may be found where the position of the rocks would justify the attempt.

By referring to the chart issued annually by the United States Weather Bureau, showing the annual precipitation in different parts of the state, it will be seen that there is a large area in central Washington between the Cascade mountains and the Columbia river, and for some distance east of that stream, where the annual rainfall is less than eighteen inches. While eighteen inches per annum is usually considered the minimum amount with which agriculture can profitably be carried on, yet there are a number of conditions of soil and climate which vary this amount for different regions. Soil which is made up largely of sand or gravel or has either of them for a subsoil quickly loses its moisture and dries up. In certain parts of western Washington south of Puget sound where the annual precipitation is very heavy, there are soils of this nature on which the scanty vegetation withers up during the first few hot days of summer.

On the contrary, within the big bend of the Columbia, known as the "Big Bend Country," the soil is a deep, rich loam formed by the decomposition of the underlying basalt. The rain and snow of winter and early spring soak through the soil and fill up all the crevices of the rocks. Then when the dry weather comes these act as reservoirs and the water is gradually brought to the surface by capillary attraction and made available for the crops. In the country about Waterville, where these conditions occur, good crops are produced with an annual rainfall of about thirteen inches.

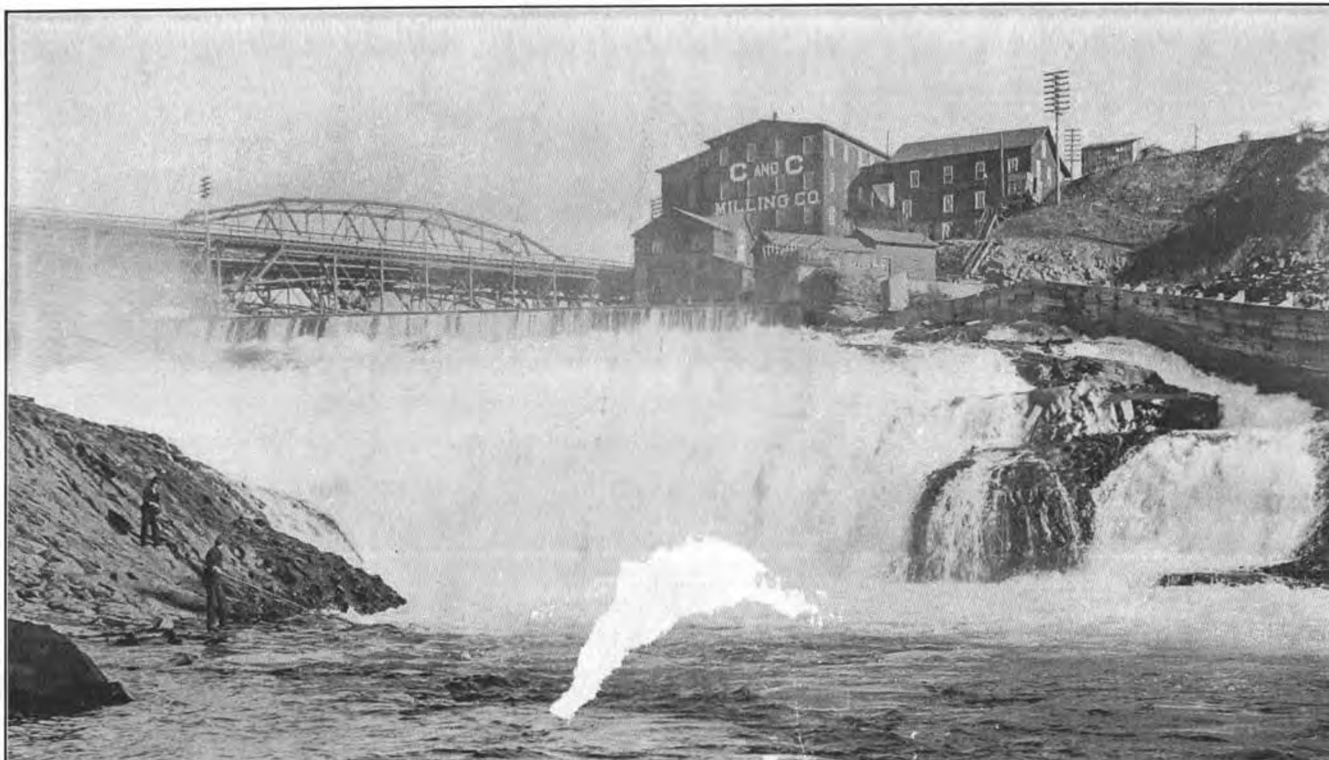
Where the rainfall is scanty it makes considerable difference how it is distributed throughout the year. To be of most use for crops the rain should come during the growing season. Where this is the case comparatively little rain will suffice.

Artesian water is of course of most value in arid regions, especially if the quantity is sufficient for irrigation. For this reason more attention ought to be paid to its exploitation in regions where the rainfall is light than where it is sufficient for agriculture. Nevertheless a good flowing well is of value almost anywhere.

YAKIMA VALLEY.

In this state the greatest progress in developing the artesian water supply has been made in the Yakima valley.

The oldest rock which outcrops in this valley is the Columbia lava, of Miocene age. It forms part of the great lava field which covers southeastern Washington and Oregon and extends southward and eastward into Idaho, Nevada and California. In Yakima county it is made up of a succession of flows varying in thickness from a few feet to a hundred or more, the line of contact between the layers being usually very well marked. Some layers show a marked difference in jointing from those above and below. The rock is a very dark basalt, usually quite compact, but often more or less vesicular. In many places beds of volcanic tuff are found between the basalt flows. Basalt, in its molten state, is one of the least viscous of lavas. When in its liquid state it is poured forth from a vent, instead of building up



FALLS OF THE SPOKANE RIVER, SPOKANE.

a cone it spreads far out as a nearly horizontal sheet. For this reason we find no volcanic cones in the Columbia lava field. Each flow found its way to the surface through a fissure which was afterwards covered up by succeeding flows. The interval of time between successive flows in this region must have been in some cases many years, and even centuries. Sufficient time elapsed for soil to form and forests to grow thereon before being overwhelmed by the next overflow. This is shown by the presence of charred wood between the flows of lava.

During the long ages in which the older rocks were becoming more and more deeply submerged by the molten flood, there was little folding or tilting of the rocks in this region. The Cascade mountains were very much lower than at present, especially in the southern part of the state. When the outflows of basaltic lava had almost ceased, there came a change, so that the region now forming the valley of the Yakima formed part of the bed of a great fresh-water lake. This lake existed so long that sediments more than a thousand feet in thickness were deposited on its bed. It was a time of great volcanic activity, as shown by the character of the sediments. These are largely volcanic ash and broken fragments of pumice. The eruptions which furnished this material were largely of the explosive type, rather than the quiet outflows which characterized the formation of the Columbia lava plain. Along the ancient shore line conglomerate beds occur, made up of boulders of light-colored andesite and other volcanic rocks. The great variations of the beds show that the oscillations of the land were comparatively rapid and irregular. Sometimes the water of the lake would recede and the streams would cut rapidly into their soft sediments; then the waters would encroach again and new sediments would be spread out, leveling off the old irregularities.

At intervals throughout the period in which the lake sediments were accumulating, there came belated outbreaks of basaltic lava which spread out over the soft sediments. These were the last convulsive signs of life of those great volcanic forces which were active throughout a great part of the Miocene period and which caused the formation of the Columbia lava fields, the greatest body of lava in the known world.

After the lake was finally drained the greater part of the sediments were carried away by erosion, but remnants still remain. They form the light-colored sedimentary beds outcropping in places in the Yakima valley and about its borders. These are the rocks in which artesian water has been found. They form what is known as the Ellensburg formation, and are of Miocene age, as shown by the fossil leaves preserved in them. The most extensive outcrops are seen along the Natches river and at White Bluffs, on the Columbia.

At the close of the period just described, the region to the westward was gradually uplifted so as to form the Cascade mountains. At the same time or later, a series of low east and west folds were formed between the Columbia river and the Cascades, nearly at right angles to the axis of the mountain range. The ridges are not due to faults, as formerly supposed; they are all anticlines, while the valleys between them are synclines. Atanum creek occupies one of these synclines, and the Natches river another. The crests of the ridges have been almost entirely denuded of the Ellensburg beds, so that only the basalt is left. One of these, known as the Selah ridge, borders the Yakima valley on the north, and another, the Yakima ridge, borders it on the south. The Yakima river has cut gaps through the ridges and crosses them at right angles. It evidently had its course established before the folding began; then as the folds arose slowly the river kept pace with them, cutting down its channel.

At some period later than the Miocene, a great stream of lava came flowing down from somewhere between the headwaters of the Nachez and Tieton rivers, covering the hills and obliterating the valleys. It reached as far east as the mouth of the Cowiche creek and then stopped. The rock is a very dark andesite. It forms a conspicuous landmark, standing as bold cliffs on the lower Tieton and at the junction of Cowiche creek with the Naches river. It is safe to say that nowhere on the surface of this lava can artesian water be found. It stands at too high an elevation, and any water contained in the beds below would find a readier outlet by means of springs along the base of the cliffs where the andesite meets the underlying rocks.

As shown by the geological map, the Ellensburg beds extend westward a mile or two beyond Tampico postoffice and occupy practically all of the valley below that point. The city of North Yakima stands at an elevation of about 1,067 feet above sea level. Ellensburg beds have been traced twenty miles west of that point to an elevation of 2,350 feet. On the hills north of Tampico postoffice they outcrop as beds of conglomerate, sandstone and volcanic ash, dipping slightly to the eastward.

North Yakima had a total precipitation in 1900 of 7.22 inches. To the westward as the mountains are approached the precipitation increases. It seems probable that most of the water which finds its way into the strata falls upon the western border of the Ellensburg, and gradually finds its way down into the the lower part of the valley.

The two synclines occupied respectively by the Naches river and Atanum creek in their upper valleys gradually merge into one as they approach the Yakima river. Where the Yakima has cut its way across the valley there is only one syncline. On both the north and south sides, parallel to the longer sides of the valley, the beds dip towards the valley at a steep angle. On the eastern and western sides they dip more gradually. The valley is underlaid by Ellensburg beds to a depth of over a thousand feet, while along the elevated edges it has all been eroded away, leaving the bare basalt ridges.

A large part of the rain which falls on the ridges is absorbed by the rocks as soon as it reaches the porous beds at the base of the hills. Along the western border of the basin the tops of the hills are at such an elevation as materially to increase the rainfall. Atanum creek flows over the Ellensburg beds for a number of miles, and from measurements made of its volume at different places along its course, it is evident that a considerable part of it is absorbed by the rocks.

The part of the valley east of the Yakima river is known as the Moxee valley. It is here that nearly all of the artesian wells are located. There are now more than thirty wells within an area of six square miles. The following table, taken from the report of Mr. George Otis Smith on the Geology and Water Resources of a Portion of Yakima County, Water Supply and Irrigation Papers of the United States Geological Survey, No. 55, gives most of the important information concerning these wells:

LIST OF WELLS IN ATANUM-MOXEE BASIN.

Number....	NAME OF WELL.	Location. Section...	Township	Range....	Approximate elevation ..	Depth......	Flow......	Depth to principal flows.				Temperature of water....
					Feet.	*Feet.*	*Sec. ft.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Deg. F.*
1	Clark No. 1.......	6	12	20	1,110	940	1.34	700	(?)	(?)	(?)	73.2
2	Clark No. 2.......	31	13	20	1,130	1,026	.15	800	(?)	(?)	1,000	76.2
3	Clark No. 3.......	31	13	20	1,120	1,000	.52	......	......	......	......	75.6
4	Longevin No. 1...	8	12	20	1,070	637	.40	637	......	......	......	72.2
5	Haines............	8	12	20	1,145	902	.984	702	760	790	902	72.2
6	Bradford	9	12	20	1,155	623	.904	386	......	623	......	73.2
7	Dickson	8	12	20	1,095	525	*.......	515	......	......	......	70.7
8	Gano..............	8	12	20	1,075	851	*.......	649	......	851	......	76.0
9	Sauve.............	8	12	20	1,155	1,020	.475	832	(?)	(?)	1,020	75.2
10	Ellens. No. 1......	7	12	20	1,065	835	.13	835	......	......	......	73.2
11	Holland No. 1	5	12	20	1,100	736	†2.00	588	688	736	......	76.0
12	Regimbal.........	5	12	20	1,105	689	1.09	525	640	686	......	73.2
13	Buwalda..........	32	13	20	1,150	653	.05	424	508	550	600	67.2
14	Ellens. No. 2......	8	12	20	1,100	676	*.......	424	504	657	......	....
15	Buwalda and Haines..........	5	12	20	1,140	636	†.566	475	575	636	......	69.2
16	Holland No. 2.....	5	12	20	1,115	686	.35	520	620	686	......	74.7
17	Clark No. 4.......	31	13	20	1,140	960	.197	660	770	820	......	73.2
18	Allwardt..........	9	12	20	1,185	809	.64	......	{615 ‡to 718	}752	......	72.2
19	Deeringhoff.......	4	12	20	1,165	625	....	390	......	625	......	73.2
20	Rein..............	10	12	20	1,195	631	.485	+630	......	......	......	66.3
21	Hill...............	4	12	20	1,170	225	....	206	......	......	......	....
22	Longevin No. 2...	8	12	20	1,080	836	.807	530	(?)	820	......	72.7
23	Peck..............	6	12	20	1,105	818	†1.10	620	(?)	818	......	....
24	Wilson	29	13	18	1,165	1,267	§.75	800	1,000	1,050	......	80.0

* Well closed April, 1901. ‡ Six flows.
† Approximate measurement with current meter. § Estimated.

It is estimated that the total area irrigated by these wells amounts to about 1,650 acres. Some of them are said to be decreasing in volume, and in some instances even to have ceased flowing altogether. This may be due to caving of the wells due to improper construction. It is quite possible, of course, that the basin may now be developed to its full capacity, so that the drilling of more wells would not increase the total flow. If such were the case, the water which would flow from new wells would simply decrease by that much the amount which flowed from the other wells. Heretofore the wells have been allowed to flow freely throughout the year, but at the last session of the State Legislature a law was passed compelling owners of wells to keep them closed from the 1st day of October in any year until the 1st day of the following April. This does not prevent the use of water for stock or for domestic purposes. The effect of this law will be salutary in preventing the waste of water during the season when it is not necessary for irrigation, and will greatly increase the capacity of the basin. The amount of land in this part of valley which can be brought under cultivation is limited only by the supply of water.

On the western side of the Yakima river the demand for artesian water is not so urgent. A number of canals bring water from the Naches river, and supply all the lower part of the valley. Other canals utilize the waters of Atanum creek. Up to the present time only one artesian well has been drilled west of the Yakima. This is on the farm of Mr. George Wilson, in Wide Hollow, and irrigates about fifty acres. It is important as showing the presence of artesian water in this part of the valley, so that the problem is simplified for any one who in the future wishes to sink a well in the same locality.

KITTITAS VALLEY.

In the Kittitas valley, in which the city of Ellensburg is situated, the same geological formations occur as in the Yakima valley farther south. Its basin-like structure, however, is not so clearly marked. The valley is underlaid by the Ellensburg formation to an unknown depth. On every side of the valley the enclosing hills are of basalt. The Yakima river flows through the valley from northwest to southeast and escapes through a deep notch cut in the enclosing ridge. A well was sunk in the valley a number of years ago and is said to have reached basalt at 700 feet. Water came up within 40 feet of the surface. Mr. Smith, in the report previously referred to, is of the opinion that the chances of obtaining artesian water are sufficiently favorable to justify the drilling of another well.

WHITMAN COUNTY.

About the only other locality in the state where an artesian basin has been developed is in Whitman county. Flowing water has been struck at a number of places in the county, but the most important basin lies within the town of Pullman. This locality is within the limits of the Columbia lava field, but is not more than a dozen miles from its eastern border, where the lava lies against the flanks of the mountains of western Idaho, which are composed of ancient crystalline rocks. At several places north and south of Pullman there are isolated buttes of crystalline rock entirely surrounded by the lava, which represent the highest peaks of the ancient land surface which was submerged by the lava. Steptoe and Kamiack buttes are the most conspicuous. In Snake river canyon, a few miles to the southward, sections of the lava are exposed, which Russell* has estimated to be as much as 5,000 feet in thickness. This goes to show the extreme ruggedness of the old topography. The lava sheets have been upturned only in a very slight degree from their original horizontal position. Between some of the layers of basalt there can be seen the evidence of forest growth, showing that a considerable interval of time must have elapsed, in some cases at least, between the successive flows. In some places beds of sand occur between the sheets. These probably indicate the courses of streams which flowed over the lava during the interval between flows. The sand beds act as reservoirs for the storage of artesian water.

At Pullman there are about a dozen flowing wells in the lower part of town. In putting down these wells the drillers first penetrated a layer of basalt and finally reached sand at a depth of seventy or eighty feet. Flowing water was found in the sand. These wells have now been flowing for a number of years and do not show any diminution in volume. Besides a number of private wells, the city has one from which the whole town is supplied.

At the town of Palouse, Whitman county, there are four flowing wells. The geological conditions are the same as at Pullman. Black basalt was first penetrated and water found in the underlying sand.

It is evident that little can be foretold as to where water is likely to be found in the Palouse country. The rocks are so nearly horizontal that it is difficult to identify a basin. The beds of sand are of limited extent and usually do not outcrop on the surface. The most favorable positions for sinking wells, of course, are the lowest parts of the valleys. There is a wide extent of country where flowing waters are liable to be found. The rainfall in this part of the state is sufficient for agriculture and good non-flowing wells for domestic purposes can be found almost anywhere, so that the finding of artesian water is not of such vital importance to the welfare of the community as it is in the arid region to the westward.

*Russell: Water Supply and Irrigation Papers, No. 4, U. S. Geol. Survey.

The arid and semi-arid region of the state includes all of Douglas, Franklin and Adams counties, the eastern parts of Kittitas, Yakima and Klickitat, the western halves of Lincoln and Walla Walla, and parts of Okanogan and Chelan counties. In certain parts of this region, as in the vicinity of Waterville, farming is carried on with more or less success, but water is used for irrigation wherever it is possible to get it. By far the greater part of this arid region is very sparsely inhabited, and is so dry that it is not fit for grazing purposes, except during a few short weeks in spring. The average annual rainfall for the last ten years varies in different parts of the region from six and a half to sixteen inches. The available water in the streams is sufficient to irrigate only a small proportion of the total area, even when utilized to its fullest possible extent.

In the region west of the Columbia river, it is not unreasonable to expect that the artesian conditions which exist in the Moxee-Atanum valley may be duplicated in other places where the geology is somewhat similar. South of the Moxee-Atanum valley the country between the Cascade mountains and the Columbia is traversed by several east and west ridges similar in appearance to those to the northward whose structure has been shown to be anticlinal. If these southern ridges are also anticlines, which seems probable, the troughs between them ought to form artesian basins. Priest rapids, on the Columbia, marks the point where one of the east and west ridges has been upraised across the course of the Columbia. A careful study of the structure of these southern valleys would be necessary in order to determine whether or not it was worth the while to drill in them for water. East of the Columbia the conditions will probably be found to be somewhat different. The streams are nearly all small and have cut deep trenches in the basalt plateau. They can irrigate only small patches at best, and they usually run dry at the season when they are the most sorely needed. Where not too deeply dissected, artesian water may be found in isolated areas throughout this region in basins similar to those discovered in Whitman county.

WATER POWER.

By R. E. Heine.

INTRODUCTION.

Washington contains the greatest amount of water power of any state west of the Mississippi. The extremely heavy rainfall of the Cascade and Olympic mountains supplies the water for a large number of short, swift rivers which come tumbling down out of the mountains with a fall, in many instances, of several thousand feet in a very few miles. The Cascade mountains have been very appropriately named; everywhere along the upper reaches of the streams which head in these mountains one can see foaming cataracts and cascades alternating with stretches of more quiet water. The aggregate potential power contained in these streams is inconceivably great. The snow accumulates in the mountains to great depths in winter and melts off gradually during the summer, thus insuring a fairly uniform volume of water throughout the year.

In western Washington the greatest floods usually occur in December or the latter part of November. These are due to the heavy autumn rains which come at a season when the temperature in the mountains is not low enough to convert the moisture into snow. Again in the latter part of May, or early part of June, there are floods in all the rivers flowing down from the mountains. The floods are brought about at this time by the rapid melting of the snow during the first few hot days of summer. These floods are especially high in the tributaries of the Columbia and in that river itself. Cloudy weather during April and May, followed by a very dry, hot spell, will send all the rivers booming, and the floods are frequently very destructive. In western Washington the spring floods are not so high as they are along the eastern slope of the Cascades and in the Okanogan highlands. The climate of western Washington is more equable; there are no rapid changes from one extreme to the other, such as we find east of the Cascades, and therefore the snow melts at a more uniform rate. The streams gradually decrease in volume as summer advances until the fall rains come again. In

HEAD-WORKS OF SNOQUALMIE FALLS POWER COMPANY.

August and September they are at their lowest. All of the larger streams which head in the Cascade and Olympic ranges have at least some of their tributaries fed by glaciers. In the late summer after all the snow has disappeared from the exposed mountain sides and even the sheltered ravines, the glaciers on the highest peaks still continue to feed the streams which issue from them.

In estimating the available water power of a stream the calculations are of course based on the volume of water which the stream carries when it is at its lowest. In many cases where the stream gets too low, storage reservoirs could be built.

The Columbia river is the master stream of all eastern Washington. It has a minimum volume of about sixty thousand cubic feet per second, and in its course through the state has a total fall of about thirteen hundred feet. In a number of places along its upper course power could no doubt be taken from it. Many of its larger tributaries are rapid streams with immense undeveloped water power. In some places, as at Spokane falls on the Spokane river, and at Prosser falls on the Yakima, the power is already being utilized.

The western slope of the Cascade mountains is approximately parallel to the axis of the valley of Puget sound and its southern extension to the Columbia. This valley region is the most populous part of the state and is rapidly taking rank as a manufacturing center. Power for street railways, for electric lighting, and for all kinds of manufacturing purposes is necessary, and the problem of the cheapest way of obtaining it is one whose solution has great practical bearing upon the future welfare of the community. The great plant installed by the Snoqualmie Power Company at Snoqualmie falls will serve as an object lesson and an example of what can be done along this line. The number of places in western Washington where plants similar in kind but smaller in size could be installed is very large.

The Blue mountains lie in the extreme southeastern corner of the state. The annual rainfall on these mountains is from twenty-two to twenty-four inches. After the last of the snow melts upon their summits in the spring there is a long dry season, during which the streams get very low. For the greater part of the year, however, they possess an abundant water power which could be utilized for many purposes. Some of the streams have already been harnessed, as in the case of Mill creek from which the city of Walla Walla derives power.

SNOQUALMIE FALLS.

The great falls of the Snoqualmie river are situated in the western foothills of the Cascade mountains, about 25 miles east of Seattle, and 34½ miles northeast of Tacoma. The river proper commences about three miles above the falls, at the junction of three tributaries whose origin is in the snow fields of the Cascades. The flow of the river is about 1,000 cubic feet per second during the driest season, and about ten times as much during the periods of high water. The river has a vertical drop of 270 feet at the falls, giving a minimum available energy of 30,000 horse-power.

The present plant is somewhat unique in its construction, inasmuch as the water wheels and electrical machinery are installed together in a large underground chamber, whose floor is directly above the tail-race tunnel which extends to the river below the falls.

A shaft 10x27 feet has been sunk into the rock about 300 feet above the falls, and at the bottom of this is excavated out of the solid rock a cavity 200 feet long by 50 feet wide and 30 feet high, and from this cavity a tunnel serving as tail-race extends to the foot of the falls.

The water is received from the river through a masonry intake and conducted down the shaft to the water wheels through a steel pipe seven and one-half feet in diameter.

The generating plant consists of four electric generators, each driven by a Doble water motor of 2,500 horse-power coupled directly to it. Two exciters of 75 kilo-watt each and one elevator operated by a water wheel complete the power equipment. The generators deliver current at 1,000 volts, which is raised to 30,000 at the transformer station above the power house.

The Snoqualmie Falls Power Company furnishes power for both lighting, railway and general power purposes, and it is expected that many of the manufacturing plants of Seattle and Tacoma will soon be operated by Snoqualmie power. At Issaquah, Renton and Auburn, power is used for lighting. In Seattle all the stationary motors, the entire municipal street-lighting system, several large mills and half of the street railways are operated by Snoqualmie power, while at Tacoma all the lighting circuits, street railways and many motors are run from the same source.

The plant now installed develops a total of 10,000 horsepower. A transmission line to Everett, 35 miles distant, is proposed, where a smelter, paper mill and other factories are expected to be operated by electricity. By the erection of a 50-foot dam above the head works, a reservoir having an area of 15 square miles and average depth of 25 feet could be formed. This would almost double the power, should the demand call for it. The shaft will accommodate another penstock of the same capacity as the present one, and both intake and tail-race have been built for double the capacity. Another chamber and additional machinery are the only extensions necessary to double the capacity of the plant, and these have been under consideration by the company.

The Snoqualmie Falls Power Company does not engage in the distribution of power to small customers, but sells power in large quantities to customers at moderate prices. The Seattle Electric Company and Seattle Cataract Company are among the largest consumers, using nearly two-thirds of the total power generated.

SPOKANE FALLS.

Within the city limits of Spokane, and in close proximity to the manufacturing center, a series of falls are encountered by the Spokane river, aggregating a total of about 130 feet. The Washington Water Power Company owns and controls practically all of the available water power at that place, and furnishes power, either in the form of electric energy, or by leasing a part of the water supply to parties wishing to use the same.

A portion of what is called the "lower falls" is at present used for the development of power, and a number of flumes have been built from a dam 200 feet wide, situated at the head of these falls, to a power house located about 600 feet below this dam. The available head of water is 70 feet, which after reduction for height of water in the tailrace, is reduced to an effective head of 68 feet. The flumes are built of steel, of circular cross-section; two of them are each seven feet and one ten feet in diameter. The velocity of the water in the flumes is approximately six and one-half feet per second, and with the present electrical equipment about 5,300 horse-power are carried on the switchboard.

The power generated is used for the operation of the street cars, the lighting of the street lamps, stores and private residences, and furnishing power to the various manufacturers in the city.

During the past year the Washington Water Power Company has installed two 1000-horse-power generators, one for operating the street railway system and the other for lighting and power purposes.

The conditions for development of additional water-power at Spokane are decidedly favorable. The capacity of the falls exceeds the demand. During the driest months of the year the quantity of water discharged at the falls is never less than 2,000 cubic feet per second. The present equipment of the plant utilizes scarcely 1,000 cubic feet per second, or scant fifty per cent. of the available water, which goes to show that the output of the plant can be doubled by additional flumes without increasing the head.

The Washington Water Power Company has already completed plans for the addition of two flumes, each ten feet in diameter, for the operation of a long-distance power-tansmission line to the Coeur d'Alene mining district, about ninety miles [illegible] of Spokane.

[illegible] Coeur d'Alene region is one of the great mining centers [illegible], and the operation of the various types of mining mac[illegible]y calls for a large amount of power, which has been found most suitable and flexible in the form of electricity.

The proposed transmission system is to be three-phase with a step-up transformer station at the power house, the line pressure to be 45,000 volts. Two pole lines are planned for one circuit each, copper conductors, although until the demand for power requires it, but one circuit will be put up.

By the addition of this machinery the total output of the pl[illegible] will be increased to very nearly 13,000 horse-power, and wi[illegible] enable the company to supply light and power to parties in the vicinity of the transmission line.

In spite of the fact that Spokane is subject to considerable extremes of temperature, the Spokane river never freezes up and anchor ice is unknown, nor is the variation of head between the tail-race and head falls very large. These two facts permit a closer regulation of the water-wheels than is the case in many water-power plants.

Should conditions demand it, the great natural reservoir, Coeur d'Alene lake, could be used as a storage reservoir, whereby the output of the plant would be increased by about 25 per cent. The Washington Water Power Company has not found it necessary to develop the power of the upper falls, which would yield an additional head of 60 feet of water. The company, however, will lease portions of these falls to parties desiring to develop their own power, or will furnish them with electric power directly, which might be a more simple proposition for an intending customer.

It is only a question of time when the manufacturing industries of Spokane will have reached a stage when nearly 20,000 horse-power will be required. The total available horse-power has been variously estimated, but in all probabilities does not fall below 30,000.

MILL CREEK, NEAR WALLA WALLA.

In the spring of 1901 the Walla Walla Gas and Electric Company completed a water-power plant for the supply of electric current to Walla Walla. The plant is situated five miles east of the city on Mill Creek, and is operated on the monocyclic system supplemented by a rotary steam engine.

Mill creek has its origin in the Blue mountains and is subject to rapid fluctations. The minimum flow is 2,800 cubic feet per minute during extreme dry weather, but the average is considerable higher.

The water is taken from the creek at a point 5,600 feet above the plant, where a concrete dam is built. The water is conveyed to the plant through a four-foot stave pipe built of redwood, the actual head at the power house being 85 feet. The pipe is buried in the ground for the entire length and has shown but little depreciation during a period of seven years.

A 27-inch Morgan-Smith turbine of 450 horse-power is directly connected at a 300 kilo-watt G. E. generator. A 400 horse-power rotary steam engine, of the Thomas and Brumagin type, is belted to generator shaft, provided with a Hill clutch, so that the generator can be operated either by water, steam or both.

The plant has been run on a 24-hour per day service since May 1, 1901, and has been in continuous operation without a single shut-down or accident.

PROSSER FALLS, YAKIMA RIVER.

The town of Prosser, in the eastern part of Yakima county, is favorably located for the development of water-power for irrigational and manufacturing purposes. Both of these have been attempted, but have not been carried out to the full capacity of the available water-power in the Yakima river. The river has a fall of about twenty feet at Prosser, and during the dry season the discharge is about 2,000 cubic feet per second, from which nearly 5,000 horse-power could be obtained.

At present the Yakima Falls Roller Mills and the Prosser Irrigation Company are the only users of water-power at that place. The former operate a small mill, using about 50 horse-power, while the latter company have already taken steps for the utilization of most of the water. A small electric light plant of 30 horse-power is also in operation, but this will be supplanted by the contemplated improvements of the Prosser Falls Irrigation Company.

This company has now in operation two pumps, each of 4,000 gallons per minute, used for irrigational purposes. Each pump is driven by a Victor turbine, forty-eight inches in diameter, capable of developing 135 horse-power, and the two combined deliver water through a 28-inch steel pipe, 2,900 feet in length, to the canal, 112 feet above the surface of the river. The irrigation canal has two branches, one three miles and the other seven miles long and is capable of irrigating nearly 2,000 acres.

The company is contemplating the addition of another pump for the purpose of supplying the city with an adequate water-works system, and an electric generator to supply the town with light and power. There is also a scheme on foot for the construction of an electric railway from Prosser on toward Yakima, the power to be generated at Prosser falls. In that event it will be necessary to either build a dam to increase the fall, or to go some distance below the falls in order to obtain sufficient head of water, as the present pumping station is worked at a head of only twelve feet.

The prospects for an increased demand of power and water at Prosser and vicinity are very favorable, a larger electric lighting plant being now almost a necessity. The Prosser Falls Irrigation Company controls the entire south side of the river, on which the town is situated, and is prepared to install machinery for parties contemplating the use of power.

CHELAN FALLS.

One of the large and still undeveloped sources of water-power of the state can be found in the Chelan river, which is the outlet of Lake Chelan, and flows into the Columbia river. The river is about three and a half miles long from Lake Chelan to the Columbia river, the total fall being 375 feet, distributed through the whole distance in a series of rapids and low falls. About one-third of the total fall occurs within a distance of half a mile, where the river flows through a box canyon. It is only thirty or forty feet wide in places, rushing down between rocky walls 300 feet high.

The cliff recedes at one point, leaving ample room for a large power station. In the two and a half miles from the lake to the canyon, the fall is quite regular, and power plants could be located at many places. The only existing plant at present is a 40-barrel flour mill at Chelan falls near the mouth of the river.

No accurate measurements of the water supply have been made, except those of some local parties, which show that the minimum flow is from 1,200 to 1,500 cubic feet per second.

The Chelan Transportation and Smelting Company expect to erect an electric plant very soon, the capacity of the plant to be about 500 horse-power. This plant will be used for the operation of their smelter and an electric railroad from the smelter, situated on the Columbia river, to the lake. The company expects to have the cars in operation during the latter part of 1902. The chief use of the railroad will be the transportation of ores from the numerous mines in the vicinity to the smelter, the capacity of which will be about 500 tons per day.

There is a good opportunity for flouring mills to be operated by water-power, the wheat crop of the entire "Big Bend country" being at their very doors.

Irrigation can also be developed to a considerable extent, there being over 3,000 acres of land waiting for water. All that is required is the necessary capital for the operating plant.

As mentioned before, no thorough investigation of the resources of water-power have been made at this place, and one can safely predict an industrial center at Chelan should the same ever be developed to the full capacity.

PURITAN MINES, NEAR LOOMIS.

The Puritan mines are situated on a stream known as Toats coulee, a rushing mountain torrent, which encounters a fall of about 300 feet within the located water right of the mining company. At the lowest stage of water the supply is sufficient to develop fully 1,000 horse power, which would be ample for all necessary mining and milling operations on their property.

At present two Pelton water wheels are installed, one driving a 50-horse-power Ingersoll compressor, and the other operating a saw-mill utilizing about 60 horse-power.

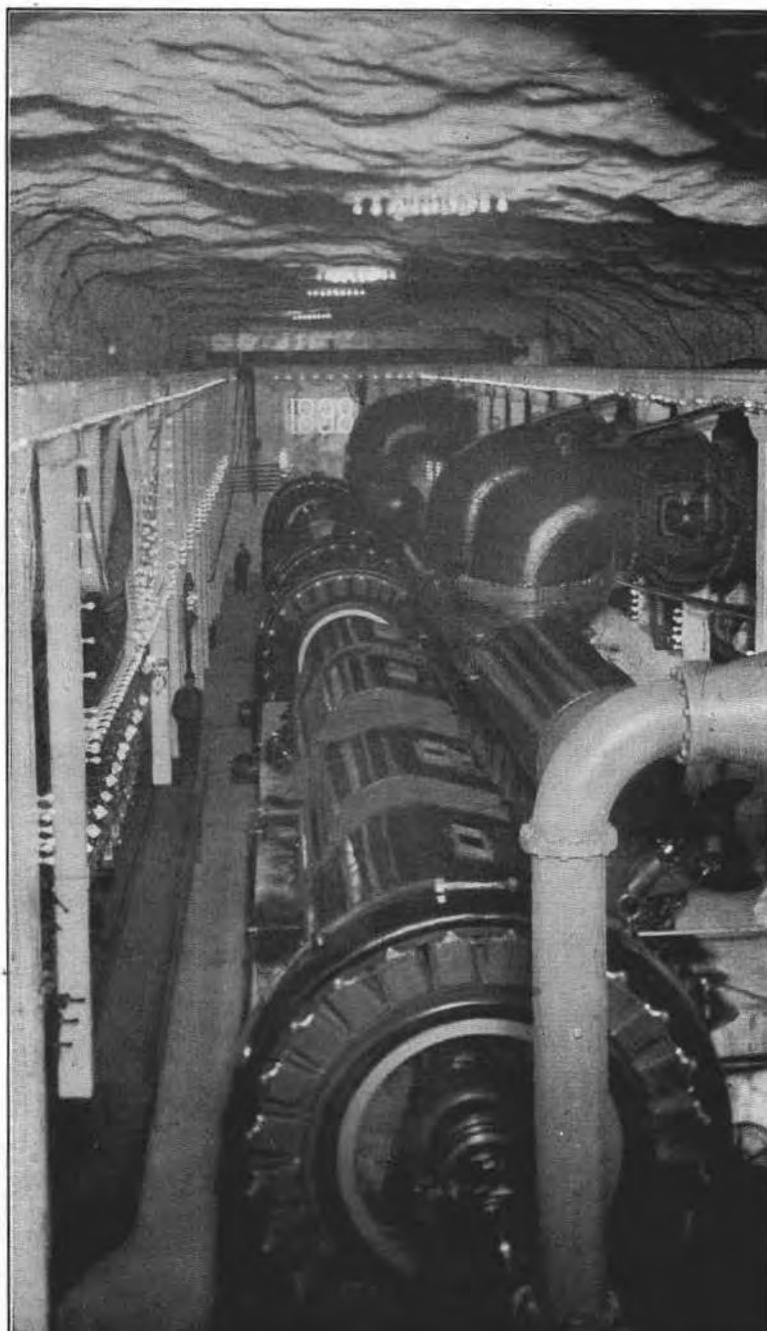
Future developments in the mining and milling industries at this locality might make the development of additional water power necessary, for which, however, there is an abundant supply in the stream mentioned above, the total head of water which might be utilized being nearly 1,000 feet.

WHATCOM FALLS.

Lake Whatcom, having an area of about eight square miles, is situated nearly three miles from Bellingham bay, and its mean elevation is about 318 feet above tidewater. Whatcom creek, the outlet of the lake, empties into the bay in the city of Whatcom. The water-power of this creek consists of three main falls, the first occurring about half a mile from the lake, the next half a mile below this one, and the last just before the stream enters Bellingham bay. This last fall is now developed and is used for the operation of a large lumber mill.

For the first two miles the stream is very rapid, the banks steep and the average width of the stream not over forty feet. The river bed shows in many places to be of solid rock, and ought not to add any difficulties for the foundations of any power plants. The total head of water from the lake to bay is about 315 feet, of which 150 feet occurs in the upper two falls.

No accurate measurements of the amount of water discharged have ever been taken, but rough measurements by various parties show that the minimum flow is about 140 cubic feet per



INTERIOR OF SNOQUALMIE FALLS POWER STATION.

second. The watershed which drains this lake contains no less than sixty square miles. By building a dam at the outlet of the lake, which can be done without great difficulties, the level of the lake might be increased four or five feet, affording an excellent means of storing water during the wet months, to be available during the dry seasons, and amply sufficient to sustain a minimum flow of 150 cubic feet per second.

With an effective fall of 200 feet a total of 2,400 net horse-power can be relied upon at all times, this being more than will be required to meet the demands for a number of years.

At the present time the creek supplies the city of Whatcom with water, and is capable of furnishing a total of 25,000,000 gallons per day.

Various propositions for the development of this power have been made from time to time. Perhaps the simplest scheme would be to develop the power nearest the city first, which would furnish about 1,200 horse-power, and later, when a greater demand for power will exist, develop the rest of the falls.

NOOKSACK FALLS.

The Bellingham Bay & Eastern Railway, operating a steam railroad in the northwestern part of the state, has undertaken to develop the water-power of the falls of the Nooksack river. The falls are situated fifty-two miles, by rail, from the city of Whatcom, and fifteen miles beyond the present terminus of the road. Active work on the construction of a large power station has already begun. The power-house is to be located 1,500 feet below the falls, whose vertical height is 103 feet. The intake will be about 250 feet above the falls, and a large tunnel is being excavated. By so locating the power station an effective head of water of 179 feet is obtained; this with the amount of water being capable of developing a minimum of 10,000 horse-power. On account of the difficulty of handling material, three steel pipes, each thirty inches in diameter, will be run to the power-house instead of one large one; this will also permit the operation of a part of the plant as soon as the machinery is installed. All the power will be converted into electric energy. The transmission line is planned along the right-of-way of the railroad. The company expects to supply the Great Excelsoir Mining Company, located close by, as well as the rest of the mining properties in the vicinity, with power. An electric railway into the mining districts is also to be operated from the falls, and ultimately a line supplying the Bellingham bay cities with light and power, is to be constructed.

TUMWATER FALLS, NEAR OLYMPIA.

About two miles south of Olympia, at what is known as Tumwater, are a series of three falls in the Deschutes river, aggregating a total fall of about 78 feet. The flow of water is somewhat variable, being about eight times greater during February and March than in July and August. There is at present a power station built at that place, utilizing the water of the upper falls, or an effective height of 46 feet. The construction of the plant is in brief as follows: From a retaining wall a flume, 10 feet square on the inside, has been built toward the lower fall. A tap, eight feet square, is taken from this to the power house and operates two pair of 25-inch and one pair of 17-inch turbine wheels, capable of developing about 1,200 horse power. During the dry months, however, the supply of water is not sufficient to operate all of these at full load. The present output of the plant averages about 800 horse power, which is used for lighting, power and street railway purposes.

In order to obtain the most out of the available water power it should be developed all at one fall and in one power house. By building a storage pond at the upper fall, and with proper allowance for low tide, an effective fall of 48 feet could be obtained. This will require a good deal of blasting of rock, especially at the lower falls, inasmuch as the river bed is composed entirely of solid rock. The table below shows the discharge of the falls and horse power obtained at 84 feet fall.

MONTH.	*Cu. ft. per sec.*	*H. P. at 84 ft.*
January	781	5,580
February	1,060	7,550
March	1,040	7,400
April	692	4,900
May	416	3,000
June	251	1,800
July	120	860
August	104	740
September	142	1,010
October	357	2,540
November	634	4,500
December	925	6,600

During the three driest months the available power would be somewhat below 1,000 horse power, but for the rest of the year it is safe to assume it at 3,000. Inasmuch as the lightest load would fall upon the plant during the summer months, the capacity of the plant might be rated at 3,000 for the entire year by the addition of a small supplementary steam plant.

The present plant is the only one operated in that vicinity, and has, up to this time, been able to meet all demands for electrical power.

CARBON RIVER AND EVANS CREEK, FAIRFAX.

In the vicinity of Fairfax, Pierce county, are situated several mines utilizing water power to a great extent, and in a way which might serve as a model to many mines in similar positions.

The Montezuma Mining Company operates several mines and a lumber mill about two miles from Fairfax and utilizes the water power of Evans creek, a small mountain stream, to its full capacity. The water is brought to the entrance of the mines in a wooden flume 3x4 feet, where it has a vertical effective fall of 89 feet through a penstock, operating a 350 horse-power turbine. A two-horse-power blower is also operated from this fall. The power developed is used for the operation of the saw-mill, a small machine-shop and the machinery in the coal-bunkers. A 15-horse-power dynamo furnishes electric light for the mine and shops. An air compressor, used to furnish power for the mine drills, is driven by the same turbine. The water, after it has left the turbine, is diverted into two shallow flumes, used for coal and lumber respectively. The latter are flumed from the bunkers and mill for a distance of three-fourths of a mile, where they can be loaded on railroad cars. The plant has been in operation for some time and been running very satisfactorily; it being unique in the way that the full amount of power being utilized for the operation of the most varied kinds of machinery, electric lighting, saw-mill and coal handling and compressed air machinery, all being run from one small creek.

The Western American Mining Company, very near Fairfax, has partially utilized the water-power of the Carbon river. Owing to the absence of any appreciable fall in this river a flume 8x4 feet has been built, extending up along the river for about one mile. A penstock, giving a vertical fall of 47 feet, is built above a 300-horse-power turbine, operating a 200 kilo-watt generator. This generator furnishes power for ventilating the mine, operating the electric locomotives, the coal bunkers, coal-handling machinery and machine-shop, and also lights the town of Fairfax and the mines proper.

An additional installation of a 250-horse-power turbine will be made shortly, although at present the water supply at its lowest stage is not quite sufficient to operate both turbines at one time.