Geology and Water Resources of the Bluewater Springs Area Carbon County, Montana

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1779-J

Prepared in cooperation with the U.S. Bureau of Sport Fisheries and Wildlife as part of a program of the Department of the Interior for the development of the Missouri River basin

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By EVERETT A. ZIMMERMAN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGY AND WATER RESOURCES OF THE BLUEWATER SPRINGS AREA, CARBON COUNTY, MONTANA

By Everett A. Zimmerman

ABSTRACT

The Bluewater Springs area in Carbon County, Mont., is drained by spring-fed Bluewater Creek. Water from springs feeding this creek and from a flowing well is used by a fish-rearing station operated by the State of Montana. Water is also used for irrigation, stock, and domestic needs. The U.S. Bureau of Sport Fisheries and Wildlife proposes to install a larger fish-rearing station and requested this study to determine the availability of water.

Rocks underlying the area include the following units: the Madison, Amsden, Tensleep, Park City, Dinwoody, Chugwater, Ellis, Morrison, Cloverly, and Colorado. Of these, the Madison Limestone, Tensleep Sandstone, and Chugwater Formation offer potentially large yields of water by natural flow. Well depths required at the present rearing station site or at a site 1 mile upstream are: 1,250 feet into the Madison, 800 feet through the Tensleep, or 700 feet through the Chugwater. The yield of a well through these formations should be about 5,000 gpm. Westward dip of the beds favors artesian conditions in the aquifers, and faulting contributes to the permeability of the beds. The presence of extensive spring deposits indicates that spring flow has continued over a long period and no evidence was found to indicate depletion.

The water is fairly highly mineralized but is of good quality for fish rearing as is indicated by the rapid growth rate of trout raised at the present station. Calcium and sulfate ions are the principal dissolved constituents. The groundwater temperature ranges from 44°F to 58°F, but much of the water is near 56°F, reportedly the optimum for trout rearing.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

The Bluewater Springs area, as discussed in this report, constitutes the headwater part of the Bluewater Creek drainage basin in T. 6 S., R. 24 E., eastern Carbon County, Mont. The detailed study includes about 16 square miles. This area is part of a larger area described by R. S. Knappen and G. F. Moulton (1930), who undertook the investigation primarily to procure data for classifying public lands.

SCOPE AND PURPOSE

In the spring of 1960 the U.S. Geological Survey was asked by representatives of the U.S. Bureau of Sport Fisheries and Wildlife for information regarding the availability of about 30 cfs (cubic feet per second) of water for the establishment of a large fish hatchery and rearing station in the Bluewater Springs area. There is a State fish-rearing station in the area at present using water from Blue Spring, one of a number of springs whose combined yield originally provided the perennial part of the flow in Bluewater Creek. A test well for oil drilled in the vicinity in 1950 was completed as a water well with an abundant flow of water, and this suggested the possibility of obtaining additional supplies of water for a Federal fish-rearing station by drilling wells. The success of the State rearing station in effecting the rapid growth of fish stimulated interest in the establishment of a Federal station near the site. The Geological Survey undertook this study to determine the feasibility of obtaining enough additional ground water to support the Federal fish-rearing station. The study is a part of the Interior Department's investigational program for development of the Missouri River Basin.

METHOD

During the course of this investigation 1 well and 20 springs were inventoried and their positions noted on aerial photographs on a scale of 1:20,000. A reconnaissance of the geology was made and data recorded and referred to the aerial photographs. These data were transferred to a base map prepared from a topographic map at a scale of 1:24,000 that was prepared by Fairchild Aerial Surveys Inc. for the U.S. Bureau of Reclamation. The Surface Water Branch of the Geological Survey gaged flows of the well and nine springs in October 1960. The Geological Survey Quality of Water Branch has maintained a gaging station on Bluewater Creek near the State fish-rearing station since April 1960 and has analyzed samples of water from several sources in the area. In addition, the Conservation Division of the Geological Survey provided data on oil tests in the area as did F. W. Woodard, a consulting geologist of Billings, Mont. This report was prepared with data obtained from these sources.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the cooperation of the personnel of the Montana State Fish-Rearing Station and of local ranchers in providing access to their lands and furnishing information that would otherwise have been difficult or impossible to obtain. Thanks are also expressed to F. W. Woodard, a geological consultant of Billings, Mont., for making available data on oil tests drilled in the area. The office of the Bureau of Land Management in Bridger, Mont., provided data on location of landlines in the area.

The investigation was under the direct supervision of Frank A. Swenson, district geologist, Ground Water Branch of the Geological Survey.

SITE-NUMBERING SYSTEM

Well, spring, and sampling sites referred to in this report have been assigned numbers indicating their location within the land subdivisions surveyed by the U.S. Bureau of Land Management. The first digit refers to the township, numbered southward from the Montana Base Line in this area. The second refers to the range, which is numered eastward from the Montana Principal Meridian. The third is the section number, which is followed by two letters. The first letter refers to the quarter section lettered counterclockwise from the northeast quarter. The second letter refers to the quarter of a quarter section similarly lettered starting in the northeast quarter of the quarter section. If two or more well, spring, or sampling sites are in the same quarter of a quarter section, consecutive numbers are suffixed in the order in which they were inventoried. The numbering system is illustrated in figure 1.

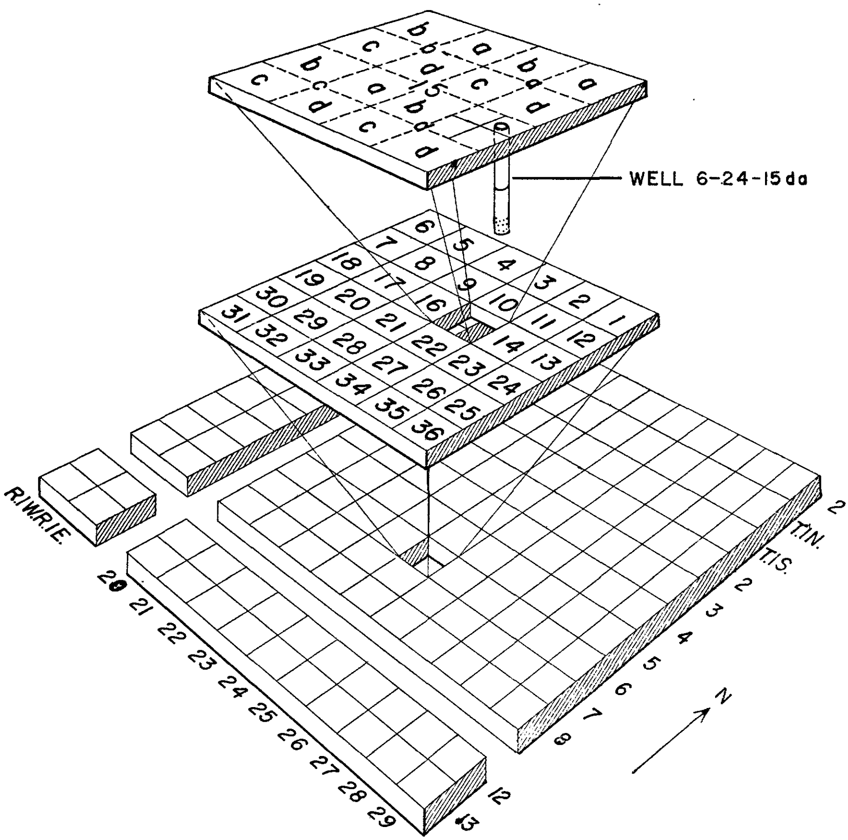

FIGURE 1.—System used in numbering wells, springs, and sampling sites.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The area investigated is drained by Bluewater Creek, a tributary of the Clarks Fork of the Yellowstone River. The topography is moderately rough. The general land surface rises to the east on the west flank of the Pryor Mountains. This rise is broken by many cuestas formed by resistant rocks that generally dip away from the mountains. Altitudes within the area range from 3,700 to 5,000 feet above sea level.

CLIMATE

The Bluewater Springs area has an arid to semiarid climate and an average annual rainfall of about 10 inches. The average mean annual temperature is 45°F. The average temperature during the April through September growing season is 59°F, and about three quarters of the annual precipitation falls during this half of the year. During the coldest winter months, January and February, the average temperature is about 29°F. The frost-free season generally lasts from May 19 to September 17. Marked temperature extremes are common and temperatures as high as 108°F or as low as −35°F have been reported.

POPULATION AND CULTURE

The report area is rather sparsely populated. Houses are situated only in the valley of Bluewater Creek because the land there is most suitable for cultivation and the springs provide water. About 25 people live in the area, at three ranches and the State hatchery. Agriculture, the sole industry, consists largely of livestock raising. Cattle, sheep, and horses graze the dryland parts of the study area, which are generally too rough for cultivation. The irrigated parts are mainly devoted to growing forage crops. In addition to the State fish-rearing station several ranchers have recently begun preparations for rearing fish on a commercial scale.

USE OF WATER IN THE BLUEWATER SPRINGS AREA

The principal uses of water in the Bluewater Springs area are irrigation, fish rearing, watering livestock, and domestic use. Of these, all but fish rearing deplete the water supplies. Virtually all the perennial streamflow is now appropriated for the above purposes either within the area or downstream. However, as fish rearing is not a consumptive use and does not appreciably impair the quality of water for irrigation or livestock use, greater use of presently available water could be considered. Additionally, the use of water for irrigation (the largest single use) is subject to very wide seasonal fluctuation, and thus arrangements may be feasible to consumptively use presently appropriated water during seasons of low demand.

SURFACE WATER

Bluewater Creek is the only perennial stream in the study area. Its flow is sustained by ground water and is relatively steady for a stream in a semiarid region. The Quality of Water Branch of the U.S. Geological Survey since April 1960 has maintained a stream-gaging station on the creek immediately downstream from the fish-rearing station. During the period of record from April 1, 1960, to September 30, 1961, the maximum flow was 104 cfs (cubic feet per second) and the minimum 19 cfs. The annual mean flow was 25.9 cfs in 1960 and 27.5 cfs in 1961. The graph of the streamflow in figure 2 shows the magnitude and distribution of the fluctuations. The fluctuations display no clear-cut pattern except that the lower streamflows were generally in the warmer months when irrigation and consumptive use by vegetation were greatest.

GROUND WATER

GENERAL PRINCIPLES

Ground water in the Bluewater Springs area is obtainable from openings in consolidated rocks of Mississippian, Pennsylvanian, Triassic, Jurassic, and Cretaceous ages and from poorly or irregularly consolidated sediments of Quaternary age. Any formation or other rock unit that yields water to wells is called an aquifer. The openings in an aquifer may be in the form of solution cavities, joints, and bedding planes, or in the form of pore spaces between grains of silt, sand, or gravel. Voids in limestone, dolomite, and gypsum are chiefly solution cavities—enlarged joints and openings along bedding planes. Sandstone, siltstone, and conglomerate contains intergranular openings as well as openings along cracks or joints and bedding planes. In addition to these more common types, tufa contains cavities formed by the decay of vegetation around which the rock material was deposited. In this area many cavities are fractures caused by deformation of the rocks.

The proportion of pore-space volume to volume of solid rock is called porosity. In order to transmit water to a well or other point of discharge the pore spaces must be interconnected. Generally, the larger the connected openings the greater the rate at which water can be transmitted. The capacity of a material to transmit water is called permeability.

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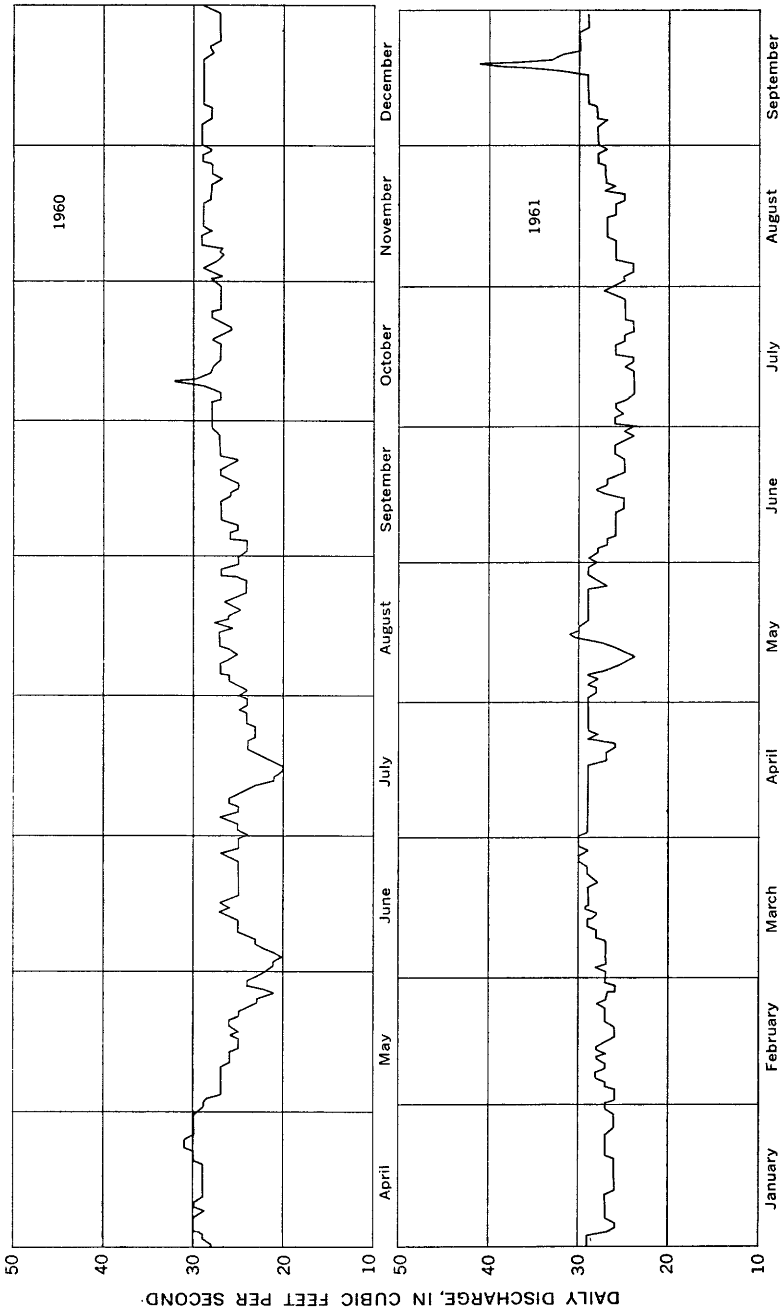

FIGURE 2.—Hydrograph for Bluewater Creek, Carbon County, Mont., 1960–61.

The water in an aquifer is said to be under water-table conditions if it is under atmospheric pressure. If water in an aquifer is confined by less permeable beds so that it rises in a well penetrating the aquifer, it is said to be under artesian conditions. Ground water is commonly under water-table conditions in one part of an aquifer and under artesian conditions in another part. In the Bluewater Springs area the ground water of most economic importance is under artesian conditions.

MOVEMENT

All ground water of economic importance is constantly moving from the points at which it enters the rocks to points of discharge. The rate of movement varies widely but is generally very slow. The principal factors governing the rate of flow are the permeability of rock and the force inducing flow. This force is due to differences in altitude (head). As most of the ground water considered in this report is confined under artesian head, differences in head inducing flow from areas of high head to areas of low head are of great importance in this study. These head differences are due, in part, to the difference in altitude between areas of recharge and points of discharge.

RECHARGE

Recharge of the ground water is by precipitation, either directly by infiltration from the land surface or indirectly by streamflow seeping into the ground. Many of the aquifers crop out on the summit and flanks of the Pryor Mountains to the east, where precipitation is heavier than in the Bluewater Springs area. The aquifers are recharged by precipitation over hundreds of square miles of outcrop and by the generally ephemeral streams that drain the mountains. As there is little surface-water runoff from the Pryor Mountains, much of the precipitation on the mountains probably recharges these aquifers. However, inasmuch as these formations also persist at depth throughout thousands of square miles and crop out around other mountain ranges, the Pryor Mountains obviously are not the sole area of recharge.

DISCHARGE

Ground-water discharge is the exit of water from a ground-water body. It may be accomplished by natural means as flow from springs, seepage onto the ground surface or into streams, and transpiration by vegetation; or it may be accomplished artificially by pumping a well or allowing it to flow.

In the Bluewater Springs area ground water is discharged principally through springs, although one flowing well is discharging a relatively large amount of water and plants are discharging an indeterminable amount by transpiration. The discharge of individual springs is as much as 8.2 cfs, and the flowing well discharges 8.3 cfs or about 3,700 gpm (gallons per minute). The combined discharge of all the springs and the well, less the amount lost to evapotranspiration, comprises the flow of Bluewater Creek below the fish-rearing station. As noted in the section on "Surface water," this flow averages 25.9 cfs.

HYDRAULICS OF WELLS AND SPRINGS

When a well begins discharging, the water level in the well (or potential level to which it might rise) drops. The level to which it drops is such that the water movement induced in the surrounding aquifer is equal to the rate of discharge. An increase in discharge necessitates additional lowering of the pumping level. The difference between the static water level and the pumping water level is termed drawdown.

Under water-table conditions the zone of water-level lowering around a well being pumped takes the form of an inverted cone with the well at the apex and is called the cone of depression. The size and shape of the cone of depression depend upon the permeability of the aquifer and the rate at which the water is discharged. To supply equal amounts of water to a well, water-bearing materials that have a high permeability require less drawdown (flatter cone of depression) than do materials having a low permeability. The areal extent of the cone of depression is termed the area of influence. Water levels will be lowered in wells within the area of influence of a well that is being pumped.

The hydraulic factors discussed above also apply to artesian wells and springs, except that the drawdown will be from the potential water level which may be elevated well above ground surface, and the cone of depression will be represented by a lowering of the pressure head or piezometric surface around the well. The area of influence of a flowing artesian well characteristically extends very rapidly so that the pressure in artesian wells around a flowing well will be almost immediately reduced when the well begins to flow. This reduction of pressure in other wells is called interference and can be minimized by drilling wells as far apart as feasible. Because most of the springs in the Bluewater Springs area occur under artesian conditions, new artesian wells should be drilled as far from them as is feasible to minimize interference.

The specific capacity of a well is measured in gallons per minute per foot of drawdown. In the case of a flowing well this drawdown must be measured from the piezometric surface under shut-in conditions. Thus, for a flowing well discharging 100 gpm at land surface in which the shut-in pressure could raise the water 100 feet above land surface, the drawdown is 100 feet and the specific capacity is 1 gpm per foot of drawdown. The specific capacity of a well depends on the permeability and extent of the aquifer and the effective diameter of the well. The effective diameter may be either larger than the actual diameter, as where the openings in the well casing are efficient and the well has been thoroughly developed, or smaller where the well openings are too small and inefficient.

Springs behave in much the same manner as wells except that the hydraulic characteristics are more difficult to determine. The effective diameter of a spring rarely can be determined, and as the potential head of an artesian spring is usually unknown, the drawdown and specific capacity are difficult to determine. Springs, like wells, may be under either water-table or artesian conditions. They are under water-table conditions if they exist because the water table intercepts the land surface. Artesian springs are those in which the water comes to the surface from confined aquifers through natural conduits. The larger springs in the Bluewater Springs area are thought to be under artesian conditions.

GEOLOGY

THE ROCKS AND THEIR WATER-BEARING PROPERTIES

OLDER PALEOZOIC ROCKS

Beneath the Bluewater Springs area lies about 2,400 feet of sediments not exposed in the study area. These rocks range in age from Cambrian to Pennsylvanian. Those older than Mississippian are composed principally of limestone and shale of probably rather low permeability. The areal distribution of the rocks exposed in the study area is shown on plate 1.

MISSISSIPPIAN ROCKS

MADISON LIMESTONE

The Madison Limestone of Early and Late Mississippian age underlies the Bluewater Springs area at a depth of about 1,000 feet. The limestone is gray or dark blue, dense, very hard, fine grained to cryptocrystalline, thick bedded, and relatively uniform in character, both horizontally and vertically. It weathers to a light-gray or dirty-white color and contains chert in amounts as large as 5 percent of the total. Quartzite, in beds 3 feet thick or less, constitutes about 15 percent of the upper 100 feet of the formation. The sand content decreases greatly below this upper zone. The limestone is largely nonmagnesian and is quarried for industrial use in some places. The thickness of the Madison is about 900 feet.

The Madison Limestone was exposed to prolonged erosion before the overlying Amsden Formation (Mississippian and Pennsylvanian) was deposited. Chemical weathering of the limestone created extensive systems of caverns and sinkholes and an irregular, pitted surface on top of the formation. When the Amsden was deposited over the irregular surface, it filled the sinkholes with red and purple shale, and the collapse of many caverns resulted in their being filled with a breccia of limestone blocks in a matrix of red and purple clay. The sinkholes and caverns provided conduits for percolation of mineralized ground water, and local concentrations of uranium minerals have been found associated with the sinkhole and breccia deposits in the Pryor Mountains.

The upper part of the Madison is highly permeable owing to the presence of caverns and smaller voids caused by solution of limestone and extensive jointing and shattering of the rock by structural deformation. The formation is the source of a number of large springs in Montana and Wyoming, and several oil tests have produced large flows of water from the Madison. However, because the limestone is rather impermeable except where voids have been formed by solution or fracturing, and because these voids occupy only a small percent of the total rock volume, the chance of finding water in the Madison Limestone is difficult to judge. In the Bluewater Springs area the likelihood of finding permeable zones in the upper part of the Madison is somewhat increased by the presence of several faults which probably have shattered the rock to some extent.

MISSISSIPPIAN AND PENNSYLVANIAN ROCKS

AMSDEN FORMATION

The Amsden Formation unconformably overlies the Madison Limestone in the Bluewater Springs area. The formation, of Mississippian and Pennsylvania age, consists of beds of red and purple shale in the lower part and soft and sandy limestone and some discontinuous, thin beds of pink quartzite in the upper part. The Amsden is about 140 feet thick.

The following section was measured by Knappen and Moulton (1930, p. 12) in a canyon in the SE¼ sec. 7, T. 6 S., R. 25 E.:

Tensleep sandstone.

Evident erosional unconformity; beds above and below are parallel.

Amsden formation:	*Feet*
Limestone, soft, or chalky mud, cream-colored, porous, soft, fine-grained, thin-bedded, uniform in composition, weathering to yellow clay; the rock is decidedly argillaceous, but contains little separate clay or shale	103

Amsden formation—Continued	Feet
Limestone, very soft, like unit above, with minor amounts of red, purple, and green shale interbedded; deep-red shale reaches a thickness of 15 in. in two beds	22
Clay shale, red to purple, sandy, very soft; some buff to cream-colored chalky limestone interbedded; bedding poor, and material would be considered Mississippian residual soil if thin cream-colored or buff limestone were not present	18
Covered	4
Conglomerate; limestone, chert, and quartzite pebbles in red clay matrix; all material is characteristic of underlying Madison and is a residual soil product, only slightly sorted	1
Total thickness of Amsden formation	148

Erosional unconformity, with relief of 2 in 10 ft, horizontally.
Madison limestone.

The material comprising the Amsden Formation is too fine grained and well cemented to transmit water freely except where cracks and fissures have formed. Thus, the Amsden could be expected to contribute little water to wells, but fractures can transmit water between the underlying Madison Limestone and the overlying Tensleep Sandstone.

PENNSYLVANIAN ROCKS

TENSLEEP SANDSTONE

Overlying the Amsden Formation is the Tensleep Sandstone of Pennsylvanian age. Tan to white sandstone, slightly calcareous and argillaceous at some places, comprises the formation. Some beds are very friable, nearly pure, white sandstone. The steeply inclined cross-bedding and uniform grain size of the lower part of the formation suggest eolian deposition.

Where the Tensleep Sandstone is exposed on the east edge of the study area, its resistance to erosion causes it to weather into hogbacks and to form box canyons. Knappen and Moulton (1930, p. 13) measured the following section overlying the previously described Amsden section:

Embar(?) limestone.

Tensleep sandstone:	Feet
Sandstone, cream-colored to buff, argillaceous, slightly calcareous, easily eroded	21
Sandstone, buff, 1 to 2 mm grains, beds 2 to 6 ft thick, straight cross beds dipping 25° or more, resistant to erosion and weathering; makes main Tensleep hogback and forms narrow box canyons	84
Total thickness of Tensleep sandstone	105

Erosional unconformity.
Amsden formation.

The uniform grain size and lack of cementing material make the Tensleep Sandstone relatively porous and permeable, but the small size of the pore spaces slows the movement of water. As in the underlying formation, the Tensleep is more permeable where fractured.

The flowing well, 6–24–4dd1, reportedly obtains its flow from the combined Amsden and Tensleep interval. When this well was drilled in February 1950 the flow was gaged by several means. The results ranged from a high of 5,200 gpm to a low of 3,600 gpm. The discharge in October 1960 was about 3,700 gpm. Thus, the maximum decline during approximately 11 years was 1,500 gpm, but as the 5,200 gpm discharge is a maximum, it is probably more reasonable to use a median figure of 4,400 gpm as the initial flow. This indicates a decline in flow of 700 gpm. The discharge of this well is now probably in equilibrium with recharge and little or no water is being withdrawn from storage.

When this well was completed, water discharged through a 3-inch nipple in an open stream to a height of over 100 feet. Data obtained regarding pressure required to force a firehose stream to this height indicate that a pressure head of at least 200 feet would be necessary. Thus, the effective drawdown was at least 200 feet from the potential level to which the water would rise if it were confined in casing. Using the maximum reported discharge of 5,200 gallons, this would mean that the specific capacity of this well was 26 gpm per ft of drawdown. This is a rather high specific capacity for a well in sandstone but is not unreasonable if fracturing is taken into account.

Blue Spring at the State fish-rearing station is probably obtaining part of its water from the Tensleep Sandstone. No decline in flow was noted when the flowing well was drilled but, as no accurate record of the spring discharge was kept, it is not certain that there was no interference. Wells drilled in the area in the future should be situated as far as practicable from existing wells and springs to minimize interference.

PERMIAN ROCKS

ERVAY TONGUE OF PARK CITY FORMATION

Overlying the Tensleep Sandstone at three exposures is a limestone which Knappen and Moulton tentatively referred to as the Embar Formation. The name Embar was abandoned (McKelvey and others, 1959) and the names Park City and Dinwoody Formations are used in this area. The Ervay Tongue of the Park City consists of about 12 feet of gray-white, very porous limestone with irregular, wavy beds up to 1 inch thick. In many ways it resembles tufa.

The Embar (Permian and Triassic age) of former usage is the intertongued, thinning, discontinuous remnant of beds which, farther to the south, have been subdivided into the Park City Formation of Permian age and the Dinwoody Formation of Early Triassic age.

Because of its relative thinness, the Park City Formation is not considered an important aquifer. Its porous character suggests that it can transmit water, but its discontinuity may isolate it from recharge.

TRIASSIC ROCKS

DINWOODY AND CHUGWATER FORMATIONS

The Chugwater Formation crops out in the eastern part of the study area and consists of bright-red sandstone, siltstone, clay, and gypsum beds. The bright-red color is a conspicuous feature of the formation. The following section was measured by Knappen and Moulton (1930, p. 15–16) in the SW¼ sec. 36, T. 6 S., R. 24 E.:

Sundance formation (clays).	
Erosional unconformity of very slight relief.	
Chugwater formation:	*Feet*
Clay, red, shading to pink and rose color, with much gypsum, disseminated or in veinlets and interlaminated in beds as much as half an inch thick	34
Gypsum, massive, pure white in upper 20 ft; basal part contains some red clay; this bed has been quarried for a plaster of Paris plant in sec. 18, T. 7 S., R. 24 E	30
Sandstone, 0.5 to 1 mm grains, in regular beds, cemented, veined, and interlaminated with gypsum; color varies from dark to bright red; this is the upper sandstone and forms the Chugwater cuesta or hogback	55
Clay and sandstone, interbedded regularly, brown to olive-green but normally appear red because of staining by slope wash; contain no gypsum	20
Sandstone, gypsiferous, red-brown, thin-bedded and not resistant to erosion, showing shallow-water wave ripples and cross beds	17
Clay, sandy, bright-red, poorly laminated except for numerous well-bedded thin sandstones; not resistant to erosion and makes a gentle slope above the scarp of the underlying middle sandstone	71
Sandstone, bright-red, well-laminated or bedded in strata ½–8 in. thick, containing much red clay in sandstone and a smaller quantity interlaminated; gypsum present in veinlets and to less extent in $\frac{1}{16}$-in. laminations; sandstone shows wave ripples and short, curved crossbeds, not over 1 ft long; this is the prominent middle sandstone	50
Clay, gypsiferous, and sandstone, olive-brown	½
Sandstone, gray to brown, argillaceous, nonresistant and makes reentrant in cliff face; appears red because of slope wash	12
Clay, red, massive; not laminated and not at all indurated	23

Chugwater formation—Continued	*Feet*
Sandstone, brick-red, 0.05 to 0.3 mm grains; well laminated and containing a few gypsum laminae; combines with underlying 29 ft to form the resistant cliff-forming lower sandstone	5
Clay, red, unindurated, nonresistant; well laminated, an unusual characteristic in clays of this formation	11
Sandstone, brick-red, fine-grained	2
Clay, bright-red, laminated and containing a few ¼-in. beds of green shale	3
Sandstone, dark brick-red, fine-grained, wave-rippled	13
Clay, bright-red to brick-red, poorly laminated to massive; gypsum disseminated in lower part and in veinlets throughout; irregular vertical or steeply inclined joints, slickensided by settling movements; green spots half an inch or less in diameter with rare black material at center, probably an organic remnant that has reduced iron in the surrounding clay	64
Gypsum, white, marble-like, coarse-grained	¼
Clay, brick-red	4
Clay, green, with gypsum interlaminated, perhaps as much as 10 percent, in beds 5 in. or less in thickness; this zone has been considerably crumpled, apparently by compacting or possibly flowing under the load of the escarpment above	13
Gypsum, granular, white	⅔
Clay, green, with gypsum lamination as much as half an inch thick	8
Total thickness of Chugwater formation	436

Unconformity with wavy, irregular surface; relief amounts to 3 in 25 ft horizontally.

Tensleep sandstone (calcareous).

The upper 64 feet of the measured section has been included with the overlying Piper Formation of the Ellis Group by some workers but, as it is lithologically similar to the underlying beds, the usage of Knappen and Moulton (1930) is followed in this report. The basal 26 feet is the Dinwoody Formation of current workers.

The sandstone beds of the Chugwater are too fine grained and well cemented to transmit water freely through the rock itself but the formation is extensively jointed and in some places faulted. The system of fractures gives rise to a fairly high permeability. During the drilling of the well, 6–24–4dd1, a flow of water estimated at about 1,500 gpm was obtained from the Chugwater but was cased out to permit deeper drilling. Many of the springs in the area apparently flow from the Chugwater. The largest of these, 6–24–15db, flows as much as 3,700 gpm, and the combined flow of three springs in sec. 15 provides the perennial flow of Bluewater Creek.

Some evidence indicates there may be somewhat poor hydraulic connection between fracture systems furnishing water to springs in the Chugwater. The spring behind the Tom Lester home in the

NE¼SW¼ sec. 15, T. 6 S., R. 24 E., is fully 75 feet higher and only 1,500 feet from the springs that rise in the hay meadow in the NW¼SE¼ sec. 15, T. 6 S., R. 24 E. It was reported that a large spring in the SW¼SW¼ sec. 14, T. 6 S., R. 24 E., ceased to flow following the 1935 earthquake at Helena, Mont. It may be that new fractures opened and permitted the water that formerly issued at this location to escape at other springs lower down the valley.

The Chugwater Formation probably could provide as much as 1,500 gpm to a well drilled about 750 feet deep anywhere along Bluewater Creek from the State fish-rearing station to the confluence of Bluewater and Frosty Jack Creeks. The highest yields, however, might be expected near the faults crossing Bluewater Creek in the NE¼NW¼ sec. 16, T. 6 S., R. 24 E., and at the fish-rearing station. A well drilled at the fish-rearing station would probably interfere with the flow from Blue Spring.

JURASSIC ROCKS

ELLIS GROUP

Knappen and Moulton (1930) mapped beds of Middle and Late Jurassic age in this area as the Sundance Formation (Upper Jurassic). More recent workers have designated these beds the Ellis Group following terminology used in central Montana. The Ellis Group is divided into three formations: Piper (Middle Jurassic), Rierdon (Upper Jurassic), and Swift (Upper Jurassic). These divisions were not made in mapping for this report as the three formations comprise a lithologic unit almost uniformly unfavorable as a source of water.

The total thickness of the Ellis Group in the study area is about 500 feet, but wells drilled along Bluewater Creek above the fish-rearing station would penetrate less than 400 feet of the group. The permeability of the Ellis is low as compared to other formations and the quality of the water is inferior. A number of good springs emerge in the Ellis outcrop area, but most of these probably yield water conducted through the Ellis along faults from more permeable beds below. The beds of the Ellis Group do not constitute an important aquifer in this area.

MORRISON FORMATION

The Morrison Formation (Upper Jurassic) consists of a series of fresh-water and continental sandstone, shale, and clay beds. It is distinguished by its light-colored but not bright clay, shale, and yellow sandstone. Pastel tints of red, yellow, green, and purple characterize the formation which, in general, consists of two beds of soft yellow or white sandstone separating three beds of shale or clay. The upper and lower beds of clay are normally light yellow to yellowish tan; the middle clay is varicolored, light green, purple, salmon, and light red. The Morrison attains a thickness of about 240 feet but is present only in the western part of the study area.

The Morrison Formation is not an important aquifer for the purposes of this report largely because it does not underlie the most feasible sites for a fish-rearing station. If a site downstream from the State installation is selected, the Morrison would be penetrated but would not yield great amounts of water.

CRETACEOUS ROCKS

CLOVERLY FORMATION

The Cloverly Formation (Lower Cretaceous), overlying the Morrison, consists of a basal conglomerate or sandstone member, a middle variegated shale member, and an upper shale, siltstone, and sandstone member. These members are so distinctive in their lithology that the lower and upper members have been named the Pryor Conglomerate Member and the Greybull Sandstone Member, respectively.

The Pryor Conglomerate Member consists of fluvial conglomerate and yellow sandstone. The conglomerate part is composed of pebbles, predominantly black chert, in a matrix of medium- to coarse-grained, yellow to gray sandstone.

Bright-red, green, purple, blue, yellow, and dull-black clay beds deposited above the Pryor Conglomerate Member constitute the middle members of the Cloverly. The clay beds are normally sandy, rarely laminated, repeatedly channeled, massive, and easily eroded.

The Greybull Sandstone Member consists of interlaminated brown quartz sandstone, siltstone, and sandy shale. The sandstone is thin bedded and shaly but fairly well cemented with limonite so that it is somewhat resistant to erosion and makes a distinct escarpment. The porosity of the member is rather low.

The Cloverly Formation has a total thickness of about 300 feet. Like the Morrison, it does not constitute an important aquifer for the purposes of this report because it does not underlie the most likely sites for a fish-rearing station. The Pryor Conglomerate Member can supply small to moderate amounts of water for stock or domestic purposes, but the water in it is under insufficient pressure to induce large flows.

COLORADO GROUP

Overlying the Cloverly Formation is a series of beds about 2,400 feet thick. These are composed predominantly of marine shale with some sandstone beds. They are commonly differentiated into the

Thermopolis, Mowry, Frontier, Carlile, and Niobrara Formations; but as only the lowermost 500 feet or so is present in the report area, and as the beds do not constitute a source of water for the proposed fish-rearing station, they are not considered separately here and are shown on the geologic map as the lower part of the Colorado Group (Lower Cretaceous).

QUATERNARY DEPOSITS

TUFA

The water from the springs in the Bluewater Springs area contains calcium bicarbonate in solution. When the water reaches the ground surface, the reduced pressure permits evolution of dissolved carbon dioxide as a gas. This lessens the acidity of the water and under less acid conditions calcium bicarbonate changes to the less soluble calcium carbonate (lime), which precipitates to form a rock known as tufa. Fairly extensive deposits of tufa underlie much of the valley and smaller deposits occur on some hillsides. The deposits are generally intermixed with alluvial or colluvial deposits.

When the tufa was deposited much vegetative matter growing in the water around the springs was covered and incorporated in the deposits. The subsequent decay of the vegetative matter left voids in the molds thus formed. The presence of these and other voids caused by re-solution of the tufa gives the deposits a high porosity. Thus, in places, the tufa has a hollow sound when walked upon and many excavations made in the material have developed rather copious flows of water.

The deposition of tufa around springs tends to build up cones until the pressure of the water either breaks through confining deposits or permits their re-solution. Thus, the general surface of the deposits is broken by small mounds or hills marking the sites of former spring activity. The large volume of the tufa deposits suggests that spring flow and tufa deposition have continued over many centuries.

An intricate system of conduits in the tufa allows water to flow easily from one part of the deposit to another. Most of the recharge to the tufa is believed to be conducted up fault zones from underlying formations. Although wells in the tufa can yield abundant quantities of water if pumped, wells in the underlying formations probably would prove more satisfactory as a water source for fish rearing because of their natural flow.

STRUCTURE AND ITS RELATION TO GROUND WATER

The rocks underlying the Bluewater Springs area generally are tilted toward the west away from the uplifted Pryor Mountains.

In addition, numerous faults cut the beds. The area lies to the north of a system of en echelon faults known as the Nye-Bowler lineament, and the faults in the report area are probably related to this system. The beds in this area are displaced vertically along the faults but the displacement usually is not large. The largest fault crossing the area, called the Bluewater Fault by Knappen and Moulton (1930), extends to the northeast to join the North Pryor fault and its displacement increases in this direction. Where it crosses Bluewater Creek the displacement is about 100 feet but increases to 300 or 400 feet in the northeast part of the area. The entire Nye-Bowler lineament and associated faulting are probably the surface expression of a deep fault of much larger displacement.

The dip of the beds is important to the occurrence of ground water in this area because the beds are thus exposed at substantially higher elevations to receive recharge and thus create favorable artesian conditions. Faulting of the beds is also important because the shattering of the rocks in the vicinity of the faults has increased their permeability and provided conduits for water to escape at the surface as springs. The most favorable sites for large-capacity wells lie along the fault zones, where advantage may be taken of the increased permeability.

QUALITY OF THE WATER

The quality of the water in the Bluewater Springs area is a prime factor in making the area desirable as a site for fish rearing. The rate of growth of fish reared in the State rearing station is reportedly among the highest in the Northwest and is attributed, in part, to the mineral content of the water. The Quality of Water Branch of the U.S. Geological Survey collected and analyzed water samples at several sites in 1960. The results of these analyses are shown in table 1. In addition, a portable instrument for measuring the specific conductance of water was used during the course of this study. The specific conductance of water is a measure of the ability of water to conduct an electrical current and is expressed in micromhos per centimeter at 25°C. Because it is related to the amount of dissolved material, it may be used for approximating the total dissolved-solids content of water. The results are tabulated in table 2. The location of water-quality sampling sites is shown in figure 3.

In general, springs in the northern part of the area produce water with a higher specific conductance, and thus higher mineralization than those in the southern part. Springs in the northern part probably yield water conducted from deep artesian aquifers (Madison Limestone and Tensleep Sandstone) to the surface along fault planes, whereas those in the southern part yield water largely from the Chugwater Formation at shallow depth.

TABLE 1.—*Chemical analyses of water from the Bluewater Springs area, Montana*

[Results in parts per million except as indicated. Analyses by U.S. Geol. Survey]

Site	Depth of well (ft) or source	Water-bearing formation	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
6-24-4dd1	787	Tensleep sandstone.	3-31-60	57	11	0.01	262	39	2.5	0.8	233	0	619
9bb	Creek		3-31-60		13	.02	270	55	8.7	1.4	223	0	705
9bd1	Spring	Tensleep(?) sandstone	4-22-60	56	14	.01	576	64	21	2.0	220	0	1,500
16da?	Creek		7-18-60		12	.00	124	42	3.6	1.8	224	0	295

Site	Depth of well (ft) or source	Water-bearing Formation	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids as residue at 180°C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-absorption ratio	Specific conductance (micromhos per cm at 25° C)	pH
6-24-4dd1	787	Tensleep sandstone.	0.5	1.3	1.2	0.02	1,160	813	622	1	0.0	1,350	7.2
9bb	Creek		1.1	1.4	1.8	.06	1,260	898	715	2	.1	1,450	7.8
9bd1	Spring	Tensleep(?) sandstone.	3.9	1.3	.7	.10	2,490	1,700	1,520	3	.2	2,450	7.6
16d?	Creek		1.6	1.0	1.2	.04	628	482	298	2	.1	858	7.5

TABLE 2.—*Temperature and specific conductance of water from selected wells and springs*

Spring or well	Temperature (°F)	Specific conductance (micromhos per cm at 25°C)	Spring or well	Temperature (°F)	Specific conductance (micromhos per cm at 25°C)	Spring or well	Temperature (°F)	Specific conductance (micromhos per cm at 25°C)
6-24-3cc	54	1,750	6-24-9ac3	56	1,700	6-24-15bd	46	800
4dd2	55	2,200	9ad1	55	1,300	15ca	58	900
9aa1	58	2,000	9ad2	53	950	15db	54	900
9aa2	56	2,000	9bd2	56	2,750	16ab	54	910
9ac1	52	2,200	9cd	52	850	16bd	55	
9ac2	54	2,200	9dc	53	850	22ca	50	650
						27ab	44	910

Water from springs in the northern part of the area has a higher concentration of dissolved solids and higher specific conductance than water from the flowing well 6-24-4dd1. This is probably owing to the fact that whereas all the spring water percolates through gypsiferous beds, the well water rises in casing. Thus, the spring water has been in prolonged contact with gypsum. The source of water for most springs is probably the Madison and Tensleep. The water analyses in table 1 show that the principal difference between water from spring 6-24-9bd1 (Blue Spring) and that from well 6-24-4dd1 is that the spring water contains over twice the concentration of calcium and sulfate ions of the well water.

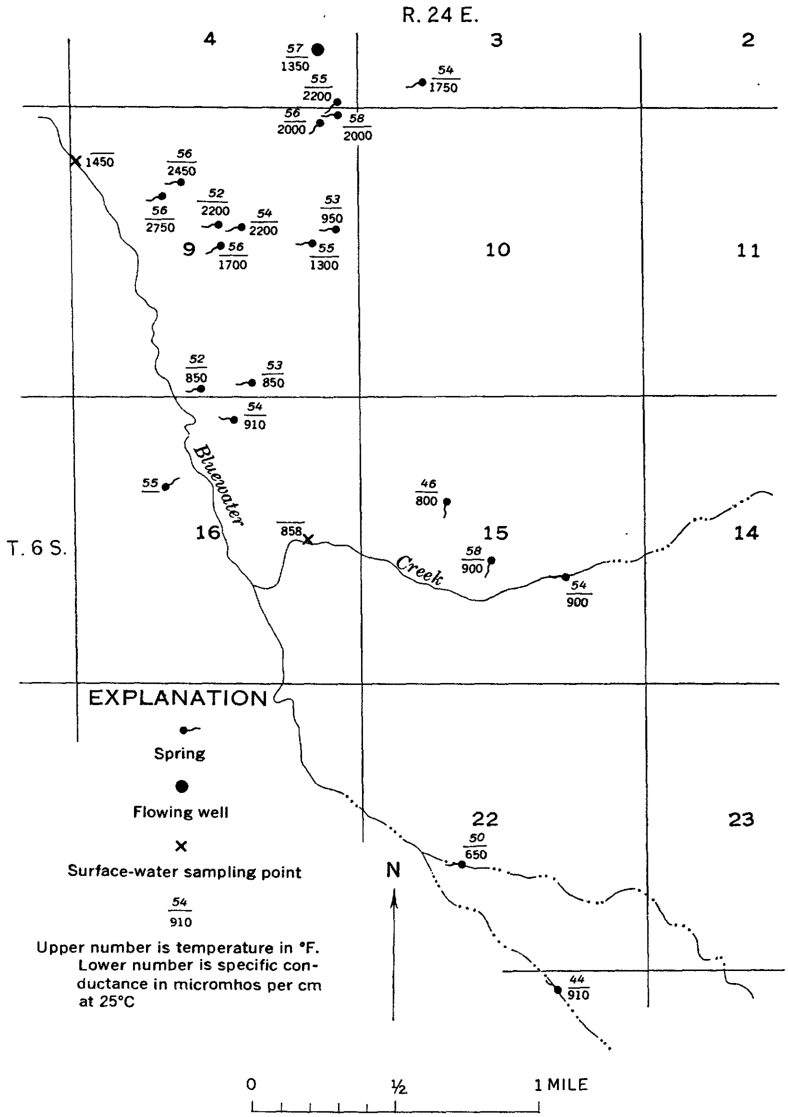

FIGURE 3.—Location of points where water-quality data were collected.

The temperature of the ground water in the Bluewater Springs area ranges from 44°F to 58°F. In general, the water temperature is higher in springs in the northern part, averaging between 54°F and 55°F, than in the southern part where the temperature of the spring water averages 51°F. The optimum water temperature for rearing rainbow trout is reportedly 56°F.

Although the mineral content of the water from Blue Spring (6–24–9bd1) is thought to be an important factor contributing to its value for fish rearing, there is some suggestion that the mineralization is higher than optimum. The laboratory of the Wyoming Game and Fish Commission reported that fish sent from the Bluewater fish-rearing station showed moderate to extreme vacuolation of the liver, probably owing to the high mineralization of the water.

Water from the well and some of the springs has a slight odor of hydrogen sulfied gas (rotten-eggs odor). The gas is largely removed during the aeration necessary for water used for fish rearing and should pose no problem.

Many of the oil tests drilled in south central Montana and the Bighorn Basin in Wyoming have found shows of oil in the Tensleep Sandstone. Oil found in a well drilled for a fish-rearing station would undoubtedly adversely affect the usefulness of the water for fish rearing, but in view of the free artesian circulation it is unlikely that this problem will arise.

SUMMARY AND CONCLUSIONS

From the standpoint of water availability, the most favorable sites for a fish-rearing station are at the present State station or where Bluewater Creek crosses the fault in section 16. (See pl. 1.) These sites are favorable because of their proximity to Bluewater Creek, their low altitude which favors maximum yield from artesian aquifers, the presence of faults that increase rock permeability by fracturing, and their accessibility.

The formations that are most favorable for producing large amounts of water at these sites are the Chugwater, Tensleep, and Madison. The Chugwater is composed principally of jointed red sandstone and shale. The top of the formation is at a depth of about 250 feet at either site, and a well should completely penetrate the formation at a depth of less than 700 feet. A flow of about 1,500 gpm should be obtainable from joints and other fractures in the formation, and the water should be in the 50°F to 55°F temperature range. Specific conductance of the water should be 800 or 900 micromhos per cm with a dissolved solids contents of 600 or 700 ppm (parts per million).

The top of the Tensleep Sandstone is about 700 feet below land surface and complete penetration would require a well depth of about 800 feet. This formation yields 3,700 gpm to well 6–24–4dd1. The proposed sites are about 200 feet lower in altitude than the well and a larger yield should be available. The water contains 1,160 ppm of dissolved solids, has a specific conductance of 1,350 micromhos per cm, and a temperature of 57°F.

The Madison Formation, the top of which lies about 1,050 feet below the sites, contains a zone of potentially high permeability in the upper 200 feet. Thus, a well drilled to 1,250 feet should penetrate the part of this formation most favorable for water production. The Madison is inadequately tested as an aquifer in this area but is potentially capable of yielding over 3,000 gpm of water. This water probably contains 1,000–1,500 ppm of dissolved solids and should have a temperature of 57°–60°F.

There is some doubt as to whether the yield from well 6–24–4dd1 is derived entirely from the Tensleep or is partly water from the Madison that has risen along fractures into the Tensleep. For this reason caution should be exercised in arithmetically adding the estimated yields to obtain a combined yield. Such addition would indicate a yield of 7,200 gpm but would probably be unrealistically high, especially if it includes an increment for the poorly tested Madison Formation. A reasonable estimate of the combined yield would be about 5,000 gpm from two wells—one drilled through the Chugwater to a depth of about 700 feet and another drilled about 1,250 feet deep into the Madison and developed in beds in the Tensleep, Amsden, and Madison. Two wells would be required because if only one were drilled and developed in all the formations, water from the deeper formations under higher pressure could enter the shallower Chugwater against the lower pressure of the water in that formation, thus reducing the total possible yield.

Well drillers on the project should be cautioned about the presence of water under high pressure so that they can be prepared to control it. Casing should be securely cemented in the wells. When a well is completed, it should be fitted with a valve to permit control and prevent waste of the water and unnecessary loss of pressure.

The combined yield of 5,000 gpm (about 11 cfs) is much less than half the estimated requirement of 30 cfs (about 13,500 gpm) for the fish-rearing station. Additional wells could undoubtedly furnish more water, but if such wells were dispersed widely enough to minimize interference with one another and with existing wells and springs, the conduits needed to gather the water for use would greatly increase the cost. If additional wells were drilled too close together, the net increase in water yielded would not be proportional to the increased cost (for example, two wells in the same aquifer 100 feet apart would not yield twice as much as one). If 30 cfs of additional water were developed, the flow in Bluewater Creek would be doubled, and this would undoubtedly cause complex flooding and erosion problems in the valley downstream.

The use of surface water for part of the station's requirements would make enough additional water available without causing undue disruption of the stream regimen. As the use of the water for fish rearing is nonconsumptive, it would not impair the rights of downstream users. One objection to the use of surface flow is the possibility of waterborne fish diseases, but as the stream heads only about 3 miles above the present station, this problem should not be difficult to control.

Other possible sources of additional water for a fish-rearing station are the flow from the existing well or increasing the yield from Blue Spring by pumping. Obtaining the flow from the well is primarily a problem of negotiation. The water is now being put to beneficial use and the owner may be reluctant to sell the rights. However, the flow from this well would increase the available supply by only 3,700 gpm (8.3 cfs).

The results of pumping the spring could not be evaluated during this study for technical reasons. If a specific capacity comparable to that of the flowing well is assumed, then an additional 26 gpm could be obtained for each foot of drawdown induced. Thus, if the maximum of 20 feet of drawdown that appears feasible were induced, the yield would be increased by 520 gpm to a total of 2,600 gpm (about 5.8 cfs). Because the specific capacity of the spring could not be determined, the above computation is only an estimate.

The rather large volume of tufa deposits indicates that springs in the Bluewater Springs area have flowed for a long time. The large area of outcrop of the principal aquifers assures adequate recharge to enable them to continue to flow indefinitely, barring interference from other discharge points.

RECORD OF WELLS AND SPRINGS IN THE BLUEWATER SPRINGS AREA

Information pertaining to 1 well and 20 springs in the Bluewater Springs area is tabulated in table 3, which follows. The well-numbering system used in this report is described on page J3.

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TABLE 3.—*Record of wells and springs in Bluewater Springs area, Montana*

Topographic location: C, creek bank; H, hillside; L, level or nearly so; SD, shallow depression; U, undulating topography.
Type of well: Dr, drilled well; S, spring.
Type of casing: P, iron or steel pipe.
Character of material: Clb, blue sandy clay; R, rock undifferentiated; Ss, sandstone.
Method of lift: F, natural flow.
Use of water: D, domestic; I, irrigation; N, not being used; S, stock.

Well or spring	Owner or tenant	Year drilled	Topographic location	Type of well	Depth of well below land surface (ft)	Diameter of well (in)	Type of casing	Character of material	Geologic source	Method of lift	Use of water	Altitude above mean sea level (ft)	Remarks
6-24-3cc	Town & Marks		H	S				R	Tufa	F	S	4,200	20 gpm estimated yield.
4dd1	do	1950	H	Dr	787	12.5	P	Ss	Tensleep Sandstone.	F	I	4,190	3,720 gpm yield, flows.
4dd2	do		L	S				R	do	F	N	4,160	10 gpm estimated yield.
9aa1	do		L	S				R	do	F	N	4,158	Do.
9aa2	do		L	S				R	do	F	N	4,156	
9ac1	do		L	S				R	do	F	N	4,040	
9ac2	do		L	S				R	do	F	N	4,030	1 gpm estimated yield.
9ac3	do		H	S				R	do	F	N	4,035	2 gpm estimated yield.
9ad1	do		H	S				R	do	F	D	4,118	
9ad2	do		H	S				Clb	do	F	D, S	4,120	
9bd1	State of Montana		U	S				R	do	F	D, S	3,980	2,080 gpm yield.
9bd2	do		U	S				R	do	F	D, S	3,982	426 gpm yield.
9cd	Thiel		H	S				Ss	Chugwater Formation (?).	F	S, I	4,005	10 gpm estimated yield.
9dc	Town & Marks		SD	S				Ss	Chugwater Formation.	F	S	4,080	4 gpm estimated yield.
15bd	Lester		C	S				Ss	do	F	S	4,250	79 gpm.
15ca	do		H	S				Ss	do	F	D, S, I	4,300	1,320 gpm.
15db	do		U	S				Ss	do	F	I, S	4,220	3,700 gpm.
16ab	Thiel		H	S				Ss	Chugwater(?)	F	D, S	4,100	
16bd	do		H	S				Ss	Chugwater	F	S	4,050	1/16 gpm estimated.
22ca	Thiel(?)		C	S				Ss	do	F	S	4,320	5 gpm estimated.
27ab	do		C	S				Ss	do	F	S	4,320	2 gpm estimated.