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REPORT ON AN INVESTIGATION OF WATER LOSSES IN STREAMS FLOWING EAST OUT OF THE BLACK HILLS, SOUTH DAKOTA

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TABLE OF CONTENTS

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The principal water losses in streams flowing eastward out of the Black Hills occur across the outcrop belt of the Englewood limestone, Pahasapa limestone and Minnelusa formation. These losses can be prevented by sealing operations.

2. Additional losses occur by percolation into the channel bed and valley alluvium, but much of this water returns to the surface where streams cross shallow rock ledges, or can be recovered in shallow wells. Prevention of such seepage losses is not practicable or desirable.

3. Net water losses through the belt of limestones have been reported or estimated at specific dates as follows: Rapid Creek 2-10 second-feet; Spring Creek before sealing 6-100 second-feet; Spring Creek after sealing up to 6 second-feet; Squaw Creek 7-8 second-feet; Boxelder Creek 20+ second-feet; Elk Creek 5+ second-feet; Little Elk Creek 1+ second-feet and French Creek 5+ second-feet.

4. Water loss into any particular sink, or in reaches up to 100 yards were found to be too small to be detected when the flow exceeded 5 second-feet. Losses at particular places appear to be generally less than 1 second-foot, but loss of 2.75 second-feet at one sink on Spring Creek, prior to sealing, has been reported.

5. The approximate length of the zone of loss on the several creeks is as follows: Spring Creek 24,300 feet; Battle Creek 18,900 feet; Squaw Creek 24,000 feet; French Creek 11,450 feet; Boxelder Creek 62,500 feet; Little Elk Creek 9600 feet; Elk Creek 64,800 feet.

6. The average water yield of Rapid Creek above the zone of loss during the irrigation season, May through September, is 96.4 ac.ft./sq.mi. During periods of simultaneous measurement the average water yield per square mile of other creeks was 52.4 per cent of Rapid Creek or 50.5 ac.ft./sq.mi. This would indicate an average water yield, in acre-feet, during the irrigation season as follows: Elk Creek 1160, Little Elk Creek 810, Boxelder Creek 5500, Spring Creek 8740, Battle Creek 3430, Squaw Creek 1360, and French Creek 5300.

7. From a study of precipitation and runoff records it is estimated that during a 56-year period (1888-1943) the water supply would have been insufficient for irrigation in the Plains or for fish life below the crystalline area in 25 per cent of the years, even if none had been lost into the limestone sinks. In 40 per cent of the years water would have been sufficient to supply all probable irrigation demands and an adequate supply for stockwater and fishing, even allowing for losses in the limestone. In the remaining 35 per cent of the years stream sealing would have been beneficial in sustaining stream flow.

8. Floods on these streams have been comparatively small and infrequent in the last 25 years, but much larger floods have been reported. Flood flows sufficient to cause extensive damage to dry riprap may be expected, on an average, at least once in 10 years.

9. Reservoir storage in the Hills as now utilized has a large recreational value and a small flood-control value, but causes a net loss of water to the Plains due to evaporation. This loss is agriculturally important in only 35 per cent of the years. Release of water at the expense of recreational values, to the extent that it would be lost in limestone sinks, would be unjustified.

10. The Spring Creek sealing work consisted of covering sinks and lining stretches of the channel with sand or loam interlayed with bentonite and clay and protected by riprap, plus several diversions around sinks, effected by low dikes. The works have not suffered much deterioration, although leakage through the riprap was found at two points. No floods of 5 to 10-year recurrence interval have been experienced, however. The cost of the project is reported to have been $40,000.

11. Sealing sinks in the Englewood, Pahasapa and Minnelusa formations, would cause no decrease in water supply from existing artesian wells. The general effect of sealing would be to improve shallow groundwater supply in the alluvium, with possibly some additional intake to the Dakota sandstones, the principal aquifers of the state.

12. The benefits claimed for stream sealing are: (1) increase in fishing and resulting revenue from tourist trade (2) increase in stockwater and irrigation water supply for agriculture. Fishing would probably be the most important beneficiary of stream sealing. Alternative sources of livestock water preclude claiming important benefits for this use. The estimated maximum acreages irrigated in the past are: Elk Creek, 3000; Boxelder Creek, 2000; Spring Creek, 5000; Squaw Creek, 250; Battle Creek, 1000; French Creek, 2,000.

13. The maximum value for irrigation of the water that could be saved by stream sealing in 35 per cent of the years is estimated to be $0.29 per acre-foot annually, or capitalized at 4 per cent, $7.25 per acre-foot.

14. The minimum initial cost of stream-sealing projects is estimated to be $7300 per mile, and the annual maintenance cost $670 per mile, which capitalized at 4 per cent is $16,750. The overall cost per mile is $24,050.

15. The maximum amount of water that could be saved by sealing would not be greater than the average yield of the crystalline area. For this amount of water the agricultural benefits show an unfavorable ratio to costs for all streams. Added fishing and stockwater benefits, which cannot now be evaluated in monetary terms, make it appear that sealing projects might show a favorable ratio for French and Battle Creeks and for maintenance of previous work on Spring Creek.

Recommendations

1. No further consideration should be given to sealing projects on Elk, Little Elk, Boxelder and Squaw Creeks.

2. An economic study should be made, through cooperation of local, State and Federal agricultural agencies, of the monetary benefits of supplemental water to farmers and ranchers in the valleys of French and Battle Creeks, and a survey should be made of their willingness to accept charges for partial payment of the initial cost and maintenance of sealing works.

3. An economic evaluation should be made, through cooperation of local, State and Federal fish and wildlife organizations, of the monetary benefits to recreation from maintenance of stream flow.

4. If the evaluations made under items 2 and 3 above indicate the possibilities of favorable ratios of costs to benefits on Battle and French Creeks, detailed surveys of the zone of loss on these streams should be made. The surveys should include determination of the specific points or zones of loss and preparation of plans and specifications for sealing operations.

5. If, after completion of work recommended under items 2, 3 and 4, a favorable ratio of costs to benefits is apparent, local, State and Federal organizations should cooperate in developing plans for financing and maintenance of sealing works.

6. Local organizations interested in stream sealing and development of the water resources of the Black Hills should initiate action for State and Federal cooperation in the establishment of stream gaging stations above, and preferably also below, the zone of loss on French, Battle and Spring Creeks.

REPORT ON AN INVESTIGATION OF WATER LOSSES IN STREAMS FLOWING EAST OUT OF THE BLACK HILLS, SOUTH DAKOTA

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INTRODUCTION

This report gives the results of an investigation of water losses in streams flowing northeast, east and southeast out of the Black Hills of South Dakota. The investigation was made at the request of Representative Francis Case of South Dakota in a letter to Dr. H. H. Bennett, Chief, Soil Conservation Service, dated March 29, 1944.

Since the days of earliest settlement, residents of the Black Hills region have observed that major streams on the east side of the Hills lost a large volume of water in passing through the steep gorges leading from the intermountain valleys to the Plains beyond. The water was observed to disappear into cavities, caves and sinkholes in the massive limestone cliffs bordering the streams and by percolation into the boulder and gravel beds of the streams. This condition was recognized and reported by Government exploration parties in the 1870's (8 p.312)

During the prolonged drought of the 1930's local interest was aroused in the possibilities of sealing obvious "sink holes" along the major streams in order to maintain flow out to the Plains. Through local efforts a W.P.A. project was secured to undertake sealing work on Spring Creek under the technical supervision of the United States Forest Service. This project was carried out mainly in 1939-40, although a small amount of plugging was done by the Forest Service in 1937.

Early in 1944 local organizations and individuals requested an investigation of the feasibility of additional sealing projects as part of a post-war public works program. The State Agricultural Post-War Planning Report of February 1944 contains recommendations for sealing projects on the following streams: Elk Creek, Boxelder Creek, Rapid Creek, Spring Creek, Battle Creek, Squaw Creek and French Creek. The report recommends the expenditure of $15,000 on each stream for sealing an average length of 3 miles, or a total of $90,000.

According to statements of local residents the flow of Spring Creek has been materially increased by the work done in 1939-40, and the benefits of similar projects on other streams were said to be: (1) increased water for livestock, (2) additional irrigation for winter feed crops and (3) increase in extent of fishing water resulting in additional benefits from tourist trade.

This investigation included (1) a field examination during the period May 12-25, 1944 of those streams mentioned in the State Post-War Planning Report, (2) two sets of stream gagings on Spring, Battle and French Creeks in August and September, (3) analysis of results of a questionnaire sent to landowners along these streams by the local Soil Conservation Districts, and (4) analysis of pertinent geologic and hydrologic data. The objectives of the investigation were:

1. To determine the general locations of areas of water loss on each stream, and the geological formations into which the water is lost.

2. To determine whether sealing of the sinks and other places of water loss would affect springs, shallow wells or deep artesian water supplies.

3. To examine and appraise the sealing work done on Spring Creek between 1937 and 1940.

4. To estimate the quantity of water that might be saved for beneficial use through sealing operations.

5. To make a preliminary evaluation of the benefits that might be expected through stream-sealing projects.

6. To determine and recommend the types of investigations and surveys that might be necessary before stream-sealing operations could be started.

7. To determine the types of sealing work or alternative methods of conserving water that might be feasible and practicable and to make some preliminary estimates of costs of such work.

The investigation did not include Rapid Creek, as the development of the water resources of this stream is being undertaken by the United States Bureau of Reclamation as part of the Rapid Valley Irrigation Project. The Deerfield Reservoir now under construction on Castle Creek, a headwater tributary, is designed to meet the water requirements of the land now under irrigation and will assure a continuous flow over the entire length of Rapid Creek, thereby fulfilling the wishes of the fish and wildlife interests.

The generous assistance and cooperation of the following persons in the conduct of this investigation is acknowledged: Mr. Clarence Hughes, President Isaac Walton League, Rapid City; Mr. Vergil Johnson, State Game Warden, Custer; Mr. Richard Mansfield, Rapid City; Dr. G. C. Redfield, Rapid City; the Directors of the Pennington, Custer County and Elk Creek Soil Conservation Districts; and field personnel of the Soil Conservation Service, especially Mr. Vergil L. Weiser, District Conservationist, Rapid City; Mr. Herbert O. Simonson, Work Unit Leader, Hot Springs; Mr. J. Arthur Martin, Work Unit Leader, Rapid City and Mr. L. A. Eberlein, Work Unit Leader, Rapid City.

RELATION OF GEOLOGY TO STREAM FLOW LOSSES AND GAINS

Figure 1 is a map of the geologic formations of the Central Black Hills Area that are important in the problem of water losses. Figure 2 is a columnar section showing the geologic formation on the eastern flank of the Black Hills. Figure 3 is a cross-section showing the dip of the formations away from the Hills along a line just south of Boxelder Creek and passing through the deep Well No. 2 at the Rapid City Airport in sec. 13, T. 2 N., R. 8 E. The vertical scale of the cross-section is exaggerated 10 times over the horizontal scale, which results in exaggerated dips. Actually the dip of the formations at their outcrop averages about 5 per cent or 250 feet per mile and rarely exceeds 20 per cent except in a few sharp local flexures. The average dip flattens rapidly away from the Hills. Between the two wells at the Rapid City Airport the dip is only 35 feet per mile.

Geologically, the Black Hills is an irregular, elongated structural dome about 125 miles long by 60 miles wide. The dome was formed, beginning probably in late Cretaceous time, in a wide expanse of almost horizontal strata that underlie the Northern Great Plains. The uplift, which has continued by stages into Quaternary time, raised above the general level of the surrounding Plains a basement complex of ancient crystalline rocks, including schists, conglomerates, quartzites, limestones, granites and other igneous rocks. Subsequent erosion stripped off the Paleozoic and Mesozoic sediments that once overlay these ancient rocks, so that there is now exposed around the margins of a central crystalline area the tilted outcrop belts of a nearly complete sequence of the sedimentary formation of this region. These formations underlie the Plains for long distances to the east, north and south as shown by records from deep wells.

The oldest Paleozoic beds form an escarpment that faces the central area of crystalline rocks, and each formation passes beneath a younger one in regular succession outward toward the margins of the uplift, or into the Plains.

The streams under consideration all originate in the central crystalline area of the Hills and flow more or less at right angles across all of these formations to their junction with the Cheyenne River some 15 to 50 miles distant. In the Hills and through the upturned sedimentary formations the streams have narrow valleys and steep gradients. After leaving the Hills they are bordered by wide floodplains of fertile alluvial soil.

In the central crystalline area the rocks are for the most part dense, and practically impermeable to water. This is the main catchment area for stream flow both because of the higher precipitation, and because the generally excellent forest cover of spruce and pine, or the thick grass sod and highly organic soils are condusive to maintenance of return flow from groundwater even during dry seasons. Springs and seeps, where soil water comes to the surface, are common, and sustained flow has been aided by numerous beaver dams and artificial ponds and reservoirs. There is no reported water loss on any of the streams in the crystalline area, other than by natural evaporation or reservoir storage.

Deadwood formation

The first formation which the streams cross after leaving the central crystalline area is the Deadwood formation of Upper Cambrian age. It has a thickness ranging from 90 feet to the south to 250 feet or more to the north (2). The formation consists of sandstones and shales (See Figure 2).

▧ Dakota group

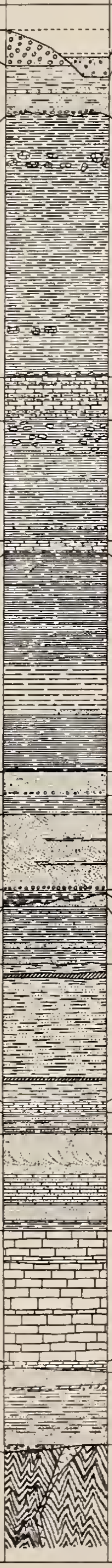
▨ Englewood - Pahasapa - Minnelusa zone of water loss

░ Valley alluvium

Figure 1. - Geologic formations significant in water losses in Central Black Hills, South Dakota.

COLUMNAR SECTION

GENERALIZED SECTION OF THE SEDIMENTARY ROCKS OF THE EASTERN FLANK OF THE BLACK HILLS, SOUTH DAKOTA
SCALE: 1 INCH = 500 FEET

SYSTEM	SERIES OR GROUP	FORMATION	SYMBOL	SECTION	THICKNESS IN FEET	CHARACTER OF ROCKS	CHARACTER OF TOPOGRAPHY AND SOIL
QUATERNARY		Alluvium.	Qal		0-30	Gravel, sand, clay, and loam.	
		Terraces	Qt		0-30	Boulders, gravel, and sand.	
TERTIARY	OLIGOCENE WHITE RIVER GROUP	Brule clay and Chadron formation	Tw		0-250	Sand, gravel, clay, fuller's earth, sandstone, and limestone.	Valleys and saddles among the ridges and plateaus, with badlands.
		UNCONFORMITY					
CRETACEOUS	MONTANA GROUP	Pierre shale	Kp		1,000-1,200	Dark-grey shale with widely scattered limestone masses.	Wide, rolling plains with shallow valleys. Clay soil, in greater part sodded.
	UPPER CRETACEOUS COLORADO GROUP	Niobrara formation	Kn		175-225	Impure chalky limestone or calcareous clay.	Valleys or flat areas with fertile soil.
		Carlile shale	Kcr		500-750	Light-grey to dark-gray shale containing numerous large concretions and sandy layers.	Rolling plains and valleys. Clay soil.
		Greenhorn limestone	Kg		50-65	Impure slabby limestone.	Low ridges with thin soil.
		Graneros shale	Kgs		900-1,150	Dark-grey shale.	Wide rolling plains. Clay soil.
		(Mowry shale member)	(Kmr)		(225-250)	Shale that weathers light-grey.	Wooded ridges.
						Dark fissile shale.	Rolling plains and valleys. Clay soil.
	LOWER CRETACEOUS DAKOTA GROUP	Fall River sandstone	Kfr		25-200	Massive sandstone, weathering brown, thinner-bedded at top.	Rocky slopes and cliffs. Sandy soil.
		Fuson shale	Kf		30-188	Massive grey to purple shale or clay.	Slopes with clay soil, partly bare.
		OVERLAP					
		Lakota sandstone	Klk		70-485	Coarse hard cross-bedded sandstone, mostly buff to grey.	Hogback ridges, sloping plateaus, cliffs, and canyons Thin sandy soil.
		OVERLAP SOUTHWARD					
JURASSIC	UPPER JURASSIC	Morrison shale	Km		0-220	Greenish to maroon shale and thin limestone.	Inner slope of hogback ridges. Clay soil.
		UNCONFORMITY					
		Unkpapa sandstone	Ju		0-225	Soft massive fine-grained sandstone.	Steep slopes, mostly covered by talus.
		Sundance formation	Jsd		70-300	Sandstone, shale and thin fossiliferous limestone.	Inner slopes of hogback ridges, mostly covered by talus.
		UNCONFORMITY					
TRIASSIC?		Spearfish formation,	TRs		500-700	Gypsum overlain by red shale. Red sandy shale, soft red sandstone, and gypsum beds. Gypsum locally near base.	Wide valley with thin barren red soil except where covered by alluvium.
CARBONIFEROUS	PERMIAN	Minnekahta limestone	Cmk		30-50	Massive grey, thinly laminated limestone.	Rocky slopes and canyon walls. Thin soil.
		Opeche formation	Co		75-115	Red shale and red slabby sandstone.	Slopes of limestone ridges, mostly covered by talus.
	PENNSYLVANIAN	Minnelusa formation	Cml		400-600	Massive granular sandstone, slabby sandstone, and limestone of reddish, buff, and white colors. Red shale and concretionary limestone at base.	Rocky ridges, mountain slopes, and canyon walls. Sandy Soil.
		UNCONFORMITY					
	MISSISSIPPIAN	Pahasapa limestone	Cp		300-630	Mostly massive light-colored limestone weathering dove-colored.	High ridges, plateaus, and cliffs. Thin fertile soil.
		Englewood limestone	Ce		30-60	Pale-pink to buff slabby limestone, with shale locally at base.	Slopes mostly covered by talus.
CAMBRIAN	UPPER CAMBRIAN	Deadwood formation	€d		40-500	Massive buff to brown sandstone, green shale, flaggy dolomite, and locally quartz conglomerate at base.	Wide high plateaus, ridges, slopes, and canyon walls. Sandy Soil.
		UNCONFORMITY					
PRE-CAMBRIAN		Various formations				Schist, slate, grit, granite, and other igneous rocks.	High rocky ridges and valleys. Fertile soil in parts of intervening valleys.

After Darton
U.S.G.S. Folio 219

Figure 2 — Columnar section of geologic formations on the eastern side of the Black Hills, South Dakota.

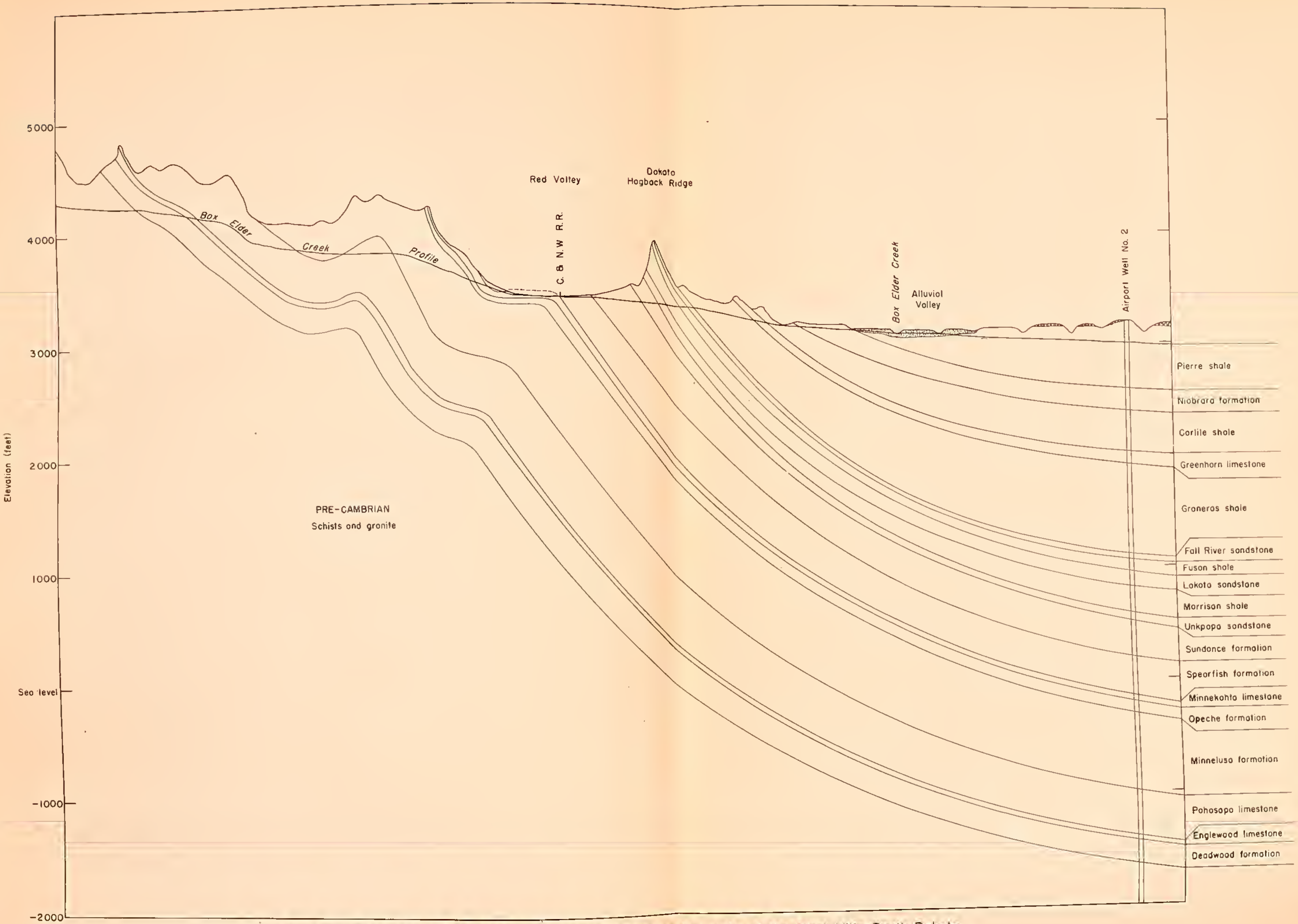


Figure 3.—Cross section of geologic formations on the eastern side of the Black Hills, South Dakota.

The sandstones are generally well cemented and the basal sandstone might be described as quartzitic. The generally "tight" character of these rocks and the short zone of outcrop through which the streams flow indicate that water losses would be insignificant. Inspection of the streams where they cross the Deadwood stata did not reveal any areas in which losses of consequence appeared likely.

Englewood limestone

Overlying the Deadwood formation from Elk Creek south is the Englewood limestone of Mississippian age. This formation is composed of pale pinkish to purplish and buff-colored, slabby limestone and is generally distinguishable with ease by its reddish cast from the overlying Pahasapa limestone. The formation is quite persistant in thicknesses of 30 to 60 feet (2). It shows solution along joints and bedding planes and cavities lined with calcite crystals. On Squaw Creek a large sink is reported where the stream runs into a bluff of Englewood limestone. This formation should be included in the group requiring treatment to prevent water losses.

Pahasapa limestone

The Pahasapa limestone of Mississippian age forms great cliffs along most of the streams and outcrops along their channels for distances up to 6 miles or more. The limestone is mostly fine grained, massive bedded, and light gray to dove colored. It is characterized by very numerous solution cavities, generally lined by calcite crystals and by frequent large and small caverns. All of the commercially exploited caverns of the Black Hills area, including Wind Cave, Crystal Cave, Jewel Cave, Onyx Cave, Rushmore Cave and many others are in this formation. The formation is about 600 feet thick on Elk Creek, 300 feet on Rapid Creek (reported as 204 feet by Rothrock and Robinson (11)) 300 feet on French Creek, 350 feet on Spring Creek (2). In a well in Martin Valley (sec. 20,. T. 6 S., R. 6E.) the formation was 289 feet thick, and in the Rapid City Airport wells 400 feet (3). This limestone is one of the principal sources of water loss on streams flowing out of the Black Hills. Its highly cavernous nature and the widespread solution along joint and bedding planes indicate ample opportunities for water loss from streams both where they impinge on cliffs of the limestone and from the limestone floor under the porous boulder and gravel-filled valleys that cross the outcrop.

Minnelusa formation

The Minnelusa formation was mapped as the "Minnelusa sandstone" and assigned to Pennsylvania age by Darton (2). More recent and detailed work by Condra, Reed and Scherer (1) on the southern flank of the Black Hills in the vicinities of Hot Springs and Loring Siding show that the upper part of the formation is of Permian age.

It is characterized by massive sandstone beds, but also contains numerous limestone strata. Some of the unweathered sandstone beds contain calcareous cement. The upper part of the formation is mainly rather coarse-grained, massive sandstone that forms high cliffs which are striking features in the walls of many canyons.

Near Hot Springs where the formation has a thickness of 711 feet, more than 150 feet are classified as limestone and dolomite. Many of the sandstone beds are reported to be calcareous. Rothrock and Robinson's (11) section on Rapid Creek indicates that about one-third of the formation is limestone and that much of the sandstone is calcareous. On Bear Butte Creek 89 feet of the 450-foot section are described as limestone beds, and much of the sandstone is described as calcareous (2). In Beaver Canyon near Wind Cave the formation contains 100 feet of limestone out of 497 feet in the section. In the Rapid City Airport Well No. 2 drilled through 675 feet of the Minnelusa into the Pahasapa the well log (3) shows more than 50 feet of anhydrite and more than 282 feet of dolomite and limestone. Most of the sandstone and shale was reported as "dolomitic", "with streaks of anhydrite and dolomite", etc.

Examination of the streams through the outcrop area of the Minnelusa shows clear evidence of important water losses in this formation. Details of evidence of such losses is presented under description of the individual streams. Moreover, the fact that sealing work was carried across the entire outcrop of the Minnelusa on Spring Creek indicates that important losses were recognized during the course of this work. Sealing across the outcrop of the limestone beds of the Minnelusa formation is fully as important as sealing across the Pahasapa.

Opeche formation

The Opeche formation of Permian age consists of 70 to 115 feet of red sandy shales and bright brownish-red sandstones, mainly in beds 1 to 4 inches thick. Because of the large amount of shale in this formation it is relatively impervious. No water has been obtained from it in deep wells. The stream valleys are generally wider and contain thicker alluvium of finer texture where they cross its outcrop. No water losses of consequence appear to occur over this formation.

Minnekahta limestone

The Minnekahta limestone of Permian age is light gray to pinkish, dense, hard and homogeneous. It forms prominent ridges, mesas and stripped dip slopes on the west side of Red Valley north of Rapid City. On most of the streams there is a gate or narrow constriction where they cross its outcrop, particularly on Little Elk, Boxelder, Squaw and Battle Creeks. The formation is 40 feet thick on Elk and Battle Creeks, and 36 feet on Rapid Creek. In the Rapid City Airport Well No. 2 its thickness is 50 feet. There is no evidence of significant water loss where the streams cross the short outcrop zone of this formation.

Spearfish Formation

The Spearfish formation of Triassic (?) age, commonly known as the "Reds Beds", forms the floor of most of the Red Valley which lies between the Dakota Hogback Ridge on the east and the Minnekahta limestone escarpment on the west. The formation consists predominantly of red sandy shale 600 to 700 feet thick, and has an outcrop width of 1 to 2 miles. The streams flow in broad alluvial valleys crossing its outcrop. Some slow water loss may occur from the base of the alluvium, which is 20 to 30 feet or more in thickness, but this type of loss cannot be prevented by sealing and no treatment across this zone would be practicable with respect to benefits gained.

Sundance formation

The Sundance formation of Upper Triassic Age in mostplaces forms part of the slope that rises from the Red Valley to the crest of the Dakota Hogback Ridge. It consists of buff sandstones and shales, and ranges in thickness from 70 to 300 feet. It has the same relation to water losses as the Spearfish formation.

Unkpapa sandstone

This formation of Upper Triassic age occurs on the inner slopes of the Dakota Hogback Ridge, but is generally obscured by talus. The sandstone is characteristically massive, fine grained and remarkably uniform in texture. The formation varies from 30 to 200 feet thick. In the stream valleys it is covered by alluvium. No water has been obtained from it in deep wells, and it is considered too compact to transmit much water. No water loss of consequence, and none that is preventable, is believed to occur over this formation.

Morrison Shale

Immediately underlying the massive Lakota sandstone outcrop on the inner edge of the Hogback Ridge, is the Morrison shale of Upper Jurassic age. This formation consists predominantly of massive shale and clay 100 to 150 feet thick. The formation thins to the south and is absent south of Squaw Creek. It is impervious to water and no losses occur where streams cross it.

Dakota Group

The Dakota Group of Lower Cretaceous age forms the prominant Hogback Ridge that extends completely around the Black Hills and separates the Red Valley from the surrounding Great Plains. The Dakota Group consists of three formations in this area. The lower formation is the Lakota sandstone, a moderately hard, massive, coarse-grained, cross-bedded gray sandstone, which includes some greenish-gray shale members. It ranges from 100 to 350 feet thick averaging about 200 feet. Overlying the Lakota is the Fuson Shale, a soft formation whose outcrop zone is generally marked by a topographic depression between a low crest of Fall River sandstone on one side and a long slope of Lakota sandstone on the other. The formation is a mixture of fine sand and clay. Its thickness is from 30 to 188 feet. The Fall River sandstone (formerly called the Dakota sandstone until this name was applied to the Group) outcrops on the outer edge of the Hogback Ridge. It is mainly massive to slabby, gray to buff sandstone, weathering to brown and iron stained. It ranges in thickness from 20 to 163 feet.

Both the Lakota and Fall River sandstones are important aquifers over much of South Dakota and adjacent states. Particular attention was given to the problem of water losses where streams cross these formations. The stream valleys narrow and pass through gaps in the Hogback Ridge. It appears that the alluvium of the valleys becomes much thinner. The effect of this is to force water, which is moving through the alluvium, to the surface. Flow in several streams, notably Elk and Boxelder Creeks reappears where they cross the Dakota outcrop. Considering the relatively short zone of outcrop across these sandstones and the relatively slow rate of water movement through them (possibly on the order of one mile per year), the general absence of large open joints and fissures, and the notable reappearance of increased stream flow where they are crossed, it is concluded that the net water loss is of no consequence. In any event no attempt should be made to seal channel beds across these formations, so that no claim can be laid to possible effects on artesian water supply.

Formations overlying Dakota Group

Overlying the Dakota group in ascending order are the Graneros shale (900-1150 feet), Greenhorn limestone (50-65 feet), Carlile shale (500-750 feet), Niobrara formation (175-225 feet) and Pierre shale (1000-1200 feet). These formations are predominantly impervious. None of them yield important water supplies in wells. The streams flow in wide alluvial valleys across their outcrops. No water loss of consequence into these formations is believed to occur and sealing across their outcrop would be of no value.

Alluvium

Alluvium, consisting of boulders, gravel, sand and clay, forming the stream beds and adjacent floodplains, is one of the most important geological formations with respect to water losses and gains. In the steep canyon sections of the streams, the valleys are narrow, often V - shaped, and rock shoals occur frequently in the channels. The alluvium consists of a poorly sorted mixture of detritus ranging in size up to boulders several feet in diameter. It is concentrated on first one side of the stream and then on the other, for the streams generally swing from one valley wall or cliff to the other every few hundred yards. The alluvium is generally shallow, ranging up to 10 or 15 feet in thickness - rarely more. Because of the large proportion of coarse material, the alluvium is relatively pervious, especially the gravelly stream beds. The alluvium is generally well saturated, and there is doubtless a considerable movement of water downstream through it. The alternating increase and decrease in the discharge of Rapid Creek as shown by measurements of the Bureau of Reclamation indicates the likelihood that at some points where rock ledges cross the narrow valley, water is forced to rise and augment surface flow; at other places part of the flow has percolated into the alluvium, and surface flow is decreased.

Where the streams flow into the Red Valley they have generally deposited an alluvial fan of poorly sorted material similar to that found in the canyons upstream. As is characteristic of fans the texture of the material becomes finer away from the apex. As far out as the Dakota Hogback ridge the bordering alluvium contains little material coarser than sand. A considerable amount of water undoubtedly percolates from the stream bed into the upper part of the fan as well as the extension of the alluvium into the lower sections of the canyons.

Where the streams cross the Hogback Ridge the valleys become much narrower and the alluvium is underlain at shallow depths by ledges of sandstone. This forces to the surface water that is moving down stream through the alluvium. Several of the streams begin to flow again in this reach. East of the Hogback Ridge, the streams have cut into relatively weak shales, and have developed broad valleys 3/4 to 1-1/2 miles wide. These valleys are floored with alluvium consisting of alternating layers of gravel, sand, silt and clay to depths generally of 10 to 40 feet but with limits of 6 to 100 feet. Many shallow wells develop domestic and stock water supplies from the alluvium and it seems certain that a comparatively large amount of water is migrating down valley through the alluvium even when the streams are dry. The stream flow at low stages decreases by a considerable percentage as it passes through relatively more porous zones and gains where the alluvium becomes thinner. "Springs" in the creek beds are reported to be common. These represent places where imperious layers or other conditions force groundwater from the alluvium to the surface. They are in no way related to water losses into bedrock in the mountains.

AREA AND EXTENT OF WATER LOSSES AND GAINS

Very few quantitative data are available on the magnitude of water losses and gains in the several streams. The information given here is based on field examination of the streams, on two sets of discharge measurements on Spring, Battle and French Creeks in August and September 1944 and on such data as could be gleaned from published and unpublished reports. It was not generally possible to locate specific points of loss. The field work in May was conducted during the period of normally greatest flow. Rapid, Spring, Battle and French Creeks were flowing all the way from the crystalline area to the Cheyenne River, although with noticeably decreased flow after passing the principal zone of loss over the Englewood, Pahasapa and Minnelusa formations. Elk, Little Elk, Boxelder, and Squaw Creeks lost their flow in this zone, but a live stream appeared at downstream points.

In reaches reported by local residents to be "sinks" the loss in flow was not sufficient to be detected by eye with discharge ranging from 5 to 20 second-feet. It appeared to the writer at the time of examination unlikely that a loss of as much as 1 second-foot was taking place at any "sink" or in any reach of 100 yards or less. The flows seemed to be disappearing gradually downstream by percolation into the coarse alluvium, and by running into relatively small crevasses and fissures in the limestone. Powell (3) reported a loss of 2.75 second-feet, however, at one sink on Spring Creek in September 1937. The only losses into bedrock observed during this examination were at two points on Spring Creek.

There are two means of determining specific points of loss. One is by careful gaging of the flow with current meter or Parshall flume at many points through the zone of loss. This would be expensive because the nature of the stream bed affords very few naturally favorable sites for accurate measurement with flow meter. The other method, the one used on Spring Creek, is to observe the point of disappearance of the flow every few days during several low flow seasons in late summer and fall.

Rapid Creek

Although no systematic field examination was made on Rapid Creek, the available data on water losses and gains are given in some detail for they are the best available on any stream.

An investigation of water losses and gains on Rapid Creek was made by the U. S. Bureau of Reclamation in 1940-41 (4). The stream flow was gaged at Big Bend approximately 6 miles above the outcrop of the Deadwood formation, just above Jackson Springs, which is within the Minnelusa outcrop and less frequently at several intermediate points. Gagings on specific dates are shown in Table 1. Table 2 gives the calculated losses for several months.

Table 1. Measurements of stream flow in Rapid Creek from records of U. S. Bureau of Reclamation

	1940			1941			
Station	6/27	10/21	10/28	3/19	5/28	8/16	10/4
	sec.ft.	sec.ft.	sec.ft.	sec.ft.	sec.ft.	sec.ft.	sec.ft.
Big Bend	4.0	11.7	12.1	19.7	27.8	19.6	18.4
Jackson Springs	0.7	4.5	4.6	11.6	20.6	17.3	15.5
	1/	2/	2/			3/	3/
Loss	-3.3	-7.2	-7.5	-8.1	-7.2	-2.3	-2.9

1/ The river bed was dry for ½ mile above Jackson Springs. A flow of 0.7 second-foot was apparently forced to the surface by a sandstone ledge under the channel a short distance above the measuring station. As a result of a long period of dry weather the stream flow was not great enough to cause the full possible water loss.

2/ Rapid Creek had been flowing 6 weeks at this date, and for 2 weeks at a comparatively uniform rate.

3/ As a result of heavy precipitation during the summer, especially in July, it is probable that considerable return flow from groundwater made the apparent losses less than actual losses.

Table 2. Water losses on Rapid Creek in 1941 from records of U. S. Bureau of Reclamation.

Station	May	June	July	Aug.	Sept.	Oct.
	ac.ft.	ac.ft.	ac.ft.	ac.ft.	ac.ft.	ac.ft.
Big Bend	2641	8777	3428	1876	1197	1385
Jackson Springs	2325	8224	3293	1641	977	1216
Loss	-316	-553	-135	-235	-220	-169
Average loss,	sec.ft.	sec.ft.	sec.ft.	sec.ft.	sec.ft.	sec.ft.
	-5.1	-9.2	-2.2	-3.8	-3.7	-2.7

From the data presented in Tables 1 and 2 engineers of the Bureau of Reclamation concluded that in dry years the average loss was about 7 second-feet, but with normal rainfall groundwater return flow would reduce the apparent loss to about 4 second-feet.

In Table 2 the losses in May and June were attributed in part to bank storage from the rising river. During July the small loss was attributed to regain of bank storage. In August, September and October the net loss was not much less than 4 second-feet. The losses were reported greatest for a distance of 3 miles upstream from Jackson Springs. The length of outcrop of the Englewood and Pahasapa along the stream is approximately 1.8 miles and of the Minnelusa 1.4 miles. No point of localized loss was found. Moreover, it was thought that part of the loss might be attributable to transpiration from plant growth along the stream and to evaporation. Heavy woods are found along the stream in many places. It has been noted that stream flow increases in the absence of rainfall when frost kills the vegetation and lower temperatures reduce evaporation.

Several large springs of which the most important are Jackson Springs and Cleghorn Springs occur in the valley alluvium just above the head of Canyon Lake, 3 miles west of Rapid City, and just below the mouth of Deadman Gulch. They are within the outcrop area of the Minnelusa formation. Jackson Springs is now the principal source of water supply for Rapid City. Measurement of the flow of these springs was reported by the Bureau of Reclamation as shown in Table 3.

Table 3. Flow of Jackson Springs and Cleghorn Springs

Date	Cleghorn Springs	Jackson Springs
	sec.ft.	sec.ft.
March 18, 1941	8.33	______
March 19, 1941	6.67 1/	8.06
August 16, 1941	7.31	6.20
October 4, 1941	8.57	7.31

1/ Part of the flow was being diverted to fill ponds at nearby State Fish Hatchery.

In 1943 Rapid City undertook to improve Jackson Springs, which forms a boggy area where it comes to the surface, by building a concrete sump and laying open tile from it to drain the wet area. In order to maintain the water level 3 feet below normal to carry out the construction it was necessary to pump 8,000,000 gallons per day. (12.38 second-feet). Experience has indicated that the normal sustained flow of the two springs will average approximately 15 second-feet, and Rapid City depends on Jackson Springs for a minimum supply of 6 second-feet.

In addition to the gain from these springs the flow increases between Canyon Lake and Rapid City. Measurements made August 18, 1941 showed an additional net gain of 12.2 second-feet and on October 4, 1941 of 13.9 second-feet. These figures are exclusive of irrigation diversions and seepage losses of 7 to 9 second-feet in this reach. The average net gain, however, is reported to be only 3 to 4 second-feet. The gain appears to occur mainly where the stream flows through the gap in the Hogback Ridge, and as in Elk and Boxelder Creeks probably results from water flow in the alluvium being forced to the surface by barrier ledges of sandstone crossing the valley.

The use of Jackson Springs for domestic water supply has led to conflict between the city and holders of earlier appropriation rights on the stream. In order to resolve these difficulties, Rapid City is partly financing the Deerfield Dam on Castle Creek, which will store 15,000 acre-feet. This water will be released to compensate irrigators in the valley for the Jackson Springs water which would otherwise increase the stream flow.

The large springs in the Minnelusa outcrop area on Rapid Creek, and other important springs in stratigraphically similar locations on other creeks are believed to be highly significant. The average flow of Jackson and Cleghorn Springs is twice the average water loss in the sinkhole area above. The flow is far greater than could be supplied from the valley alluvium and therefore must come from bedrock fissures. Part of this flow may represent the return of water lost into sinks.

Spring Creek

Figure 4 is a detailed map of Spring Creek through the zone of loss from the Harney National Forest Boundary to Highway 16 based on a survey by the Forest Service. The sealing work on this stream is described in a subsequent section of this report.

Spring Creek flows out of the crystalline rocks just west of the Forest Boundary. Above this point the drainage area is approximately 173 square miles. It passes through a short outcrop zone of the Deadwood formation and a zone of about 300 feet of the Englewood formation. It runs through the Pahasapa limestone for approximately 11,500 feet and through the Minnelusa formation for about 12,500 feet. The distance from the Forest Boundary to Highway 16 along the creek is 30,000 feet. The first sink noted in the 1937 survey (See figure 4) was 3700 feet east of the Forest Boundary within the Pahasapa limestone. Sinks were found all the way down to the upper contact of the Minnelusa a distance of 20,600 feet, as indicated by the distribution of treatment. The lower part of the Pahasapa limestone appears more cavernous than the upper part along this stream. The probability of greater water losses in the lower part of the limestone is supported by the fact that treatment was more extensive in this zone. Powell, (9) stated that on September 17, 1937 Spring Creek was flowing 2.5 second-feet at the gaging station near Sheridan Dam about 10 miles above the first sink and 3 second-feet at the first sink. At this sink all but ½ second-foot was lost in an old (placer?) mine working about 75 feet long. The remaining flow ran without apparent loss for 1300 feet to the next sink and "cave". Powell expressed the opinion in this report that the leaks in the Pahasapa limestone were not continuous but occurred along cracks and fault planes, and therefore could be remedied by treating the area affected.

Powell (10) stated that prior to 1937 flows up to 100 second-feet were entirely lost in sinks above Highway 16. Between July 1 and Sept. 1, 1937 one small flood has a peak discharge of 161 second-feet near the Sheridan dam site and produced a flow of about 25 second-feet at Highway 16. According to Powell except for such local storms, the creek bed at Highway 16 was dry from 1935 until 1941, and probably for a long period previously.

Darton (2) stated that during dry weather in the period July 1903-November 1905 the flow of Spring Creek at Rockerville, above the sinkhole area, was from 15 to 60 times as much as at the gaging station on the road south of Rapid City (approximately the same location as Highway 16.)

When inspected by the writer on May 16, 1944 Spring Creek had a well sustained flow through the zone of sinks. The flow above the sink area was of the order of 20 second-feet and the flow at Highway 16 appeared to be diminished only about one-fourth. A discharge measurement at the Stratosphere Bowl above the zone of loss on August 4, 1944 showed a flow of 6.98 second-feet, and at Highway 16 bridge a flow of 0.84 second-feet. In September the flow at the Bowl was only 1.25 second-feet and its disappearance occurred about 2 miles above the highway bridge. These observations compare favorably with Powell's estimate that the water loss on the stream was reduced to 6 second-feet, of which half was attributable to evaporation and percolation.

It is reported that "springs" in the alluvium add considerably to the stream flow beyond the mountain canyon section. The gradient of Spring Creek through the zone of loss is fairly uniform averaging 54 feet per mile.

Battle Creek

Battle Creek crosses the outcrop of the Englewood limestone about 1700 feet below Hayward, an old mining camp at the National Forest Boundary. Above this point the drainage area is approximately 68 square miles.

The stream flows through the Englewood and Pahasapa formations for a distance of approximately 7000 feet. In this stretch, however, it impinges on limestone cliffs at only 6 places. The limestone shows the usual cavernous characteristics.

The stream flows through the outcrop belt of the Minnelusa formation for approximately 11,900 feet. The gradient through the 18,900-foot zone of loss is about 70 feet per mile.

Placer gold mining operations were carried out on this creek intermittently from 1876 to as late as the depression of the 1930's from Hayward down through the Pahasapa and most of the Minnelusa outcrop belt. Most of the narrow belt of alluvium and much of the higher terrace gravel in the canyon section have been worked over by hydraulic mining, and cruder methods of excavation and sluicing. Much of the finer material (fine sand, silt and clay) were thus separated from the coarser gravel. The gravel was left in hummocky areas and mounds while the finer material or tailings was transported downstream. Much of it was deposited over the alluvium and along the stream banks. Even today the black silt on the stream bed and banks forms an obvious contrast between this stream and the other streams examined. The silt and clay has partially sealed off sinks and areas of loss in the alluvium that might otherwise have taken up most of the stream flow.

Darton (2) reported that in May and June, 1900, gagings on Battle Creek at Keystone, about 6 miles above Hayward, showed discharges of 3.0 and 2.3 second-feet. On the same dates discharges on Squaw Creek at Otis, above the zone of loss, were 8.0 and 2.8 second-feet. The flow at Hermosa below the confluence of the streams and east of the Dakota Hogback Ridge was 9.0 and 2.3 second-feet respectively, or a net loss of 2.0 and 2.8 second-feet. Considering observed losses on Squaw Creek it might be expected that all or most of this net loss was attributable to it. Actually, however, the case is probably not so simple. There was doubtless considerable, if not total loss on both streams, but renewed surface flow farther down, particularly where the stream crosses the Hogback Ridge.

At the time of the writer's examination, May 18, 1944, Battle Creek was flowing all the way to Highway 16, and according to local residents, to the Cheyenne River. With the exception of Rapid Creek and Spring Creek, Battle Creek appeared to have the smallest proportionate loss of the several streams examined. Discharge measurements made August 5, 1944 above and below the zone of loss showed a flow of 3.85 and 3.83 second-feet, respectively. In September the flow above the zone of loss had dropped to 0.89 second-feet but the flow below the zone was 1.49 second-feet. There were no summer rains of consequence this year.

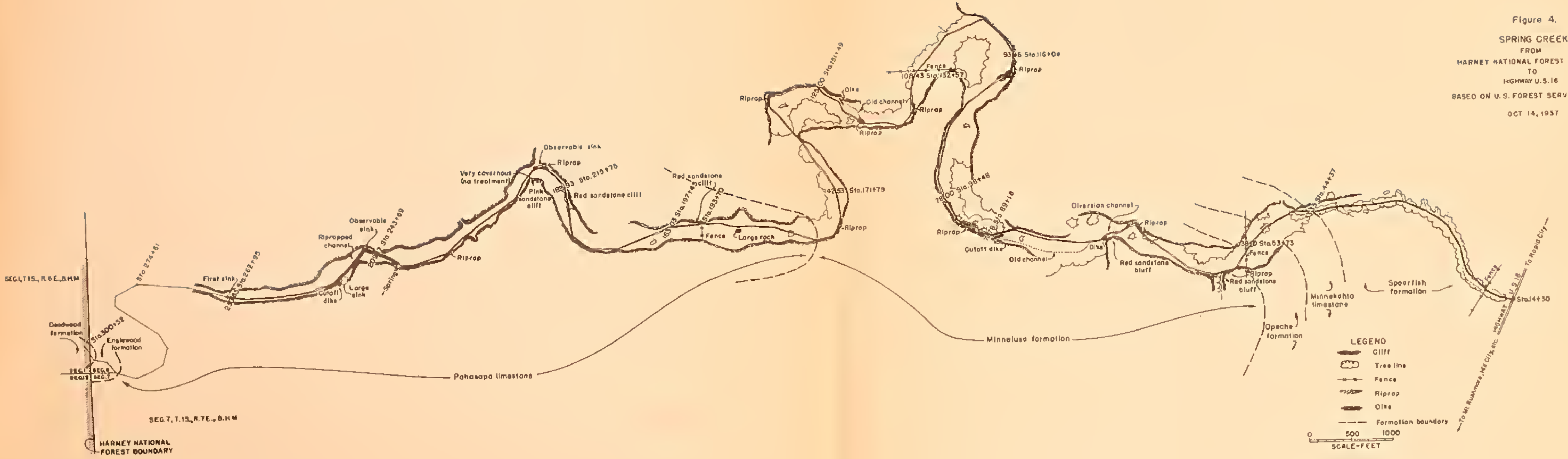


Figure 4.

SPRING CREEK
FROM
HARNEY NATIONAL FOREST BOUNDARY
TO
HIGHWAY U.S.16

BASED ON U.S. FOREST SERVICE SURVEY

OCT 14, 1937

One minor feature of significance is a tunnel (approximately sec. 15, T. 2S., R. 7E.) some 100 feet long cut through a narrow horseshoe neck on the stream many years ago to provide sluicing head for hydraulic mining operations. This tunnel through which the entire stream flow passes has caved badly and is subject to complete plugging by floating debris in a heavy flood. Removal of the caved material and deteriorated concrete dam at the upper end would cause channel scouring upstream. Closing the tunnel would also be expensive, but any sealing project on this stream must take account of the probable need for doing something about this condition.

Squaw Creek

Squaw Creek is a tributary of Battle Creek which it joins some 6 miles below the sinkhole area. Squaw Creek flows in the crystalline area to the Custer State Park Zoo (at the location shown on older maps as Otis). The drainage area above this point is approximately 27 square miles. On the date of examination, May 17, 1944, the stream flow was 7.8 second-feet at a concrete wier near the State Game Lodge about 1 mile upstream from the Zoo.

The stream passes through the contact zone of the Deadwood formation in the vicinity of the Zoo and about 1500 feet downstream makes a sharp bend to the left, impinging there on a low bluff of Englewood limestone. This limestone is thin bedded, somewhat cavernous and is undercut by the stream. This location is reported to be a prominent "sink" but this claim could not be established by observation. However, a hole on top of the bluff was reported to have been dug by the State Highway Department searching for a cave. It is said that a crack was found to extend under the stream and that a large percentage of the water is lost at this bend in dry seasons. There is another vague story that many years ago a tunnel was drilled from about this point to below the zone of loss to convey the flow of Squaw Creek, but was subsequently blasted shut after altercations concerning payment for the work.

The stream flows beyond this bend for about 2300 feet between Englewood outcrops on the right and Deadwood outcrops on the left. It then makes a sharp swing to the right and runs for, about 4200 feet slightly north of east. By the time half the length of this latter reach is covered the stream had lost half of its flow at the time of examination, apparently by percolation into the alluvium. The alluvium in the zone of loss is particularly coarse. Boulders up to 6 feet and more in diameter with gravel, sand and some silt give this stream the appearance of a typical mountain torrent.

The contact of the Englewood and Pahasapa is near the upper end of this reach. The Pahasapa is characteristically cavernous. It appears probable, however, that the water loss is mainly into the coarse alluvium. Beyond this reach the stream makes another broad bend and passes through a culvert under a high fill on Highway 40. The total distance from the Zoo to this culvert is about 6450 feet. At the time of observation the flow extended only a short distance below the culvert, but was advancing slowly downstream probably as a result of showers within the past two days. Dead but undecomposed trout found in dry holes below the advancing head of flow indicated that running water had extended farther downstream within the last two weeks.

The contact of the Pahasapa and Minnelusa is about 5400 feet below the road fill. The stream traverses the Minnelusa for about 9800 feet, runs through an area mapped as Spearfish for about 4375 feet and then again through the Minnelusa for about 2300 feet to the gate formed by the resistant Minnekahta limestone. Down to this point the stream bed was entirely dry at the time of observation. The entire distance through the Englewood, Pahasapa and Minnelusa formations is approximately 24,000 feet.

Stream flow began again from a pool, located near the contact of the Minnelusa and Opeche formations near the head of the alluvial valley that extends downstream from this point to Battle Creek. It could not be determined whether this pool is fed by groundwater forced to the surface by rock ledges under the alluvium, or whether it comes from the underlying Minnelusa. This return flow comes from a location stratigraphically the same as that occupied by the large springs on Rapid Creek. From this point to its mouth the maintenance of flow is variable depending on irrigation diversion and alternating zones of greater or lesser percolation capacity. It is reported that the flow in the alluvial valley increases when the flow at the Zoo increases, even though the intervening reach remains dry. If this is correct a direct connection either through the alluvium or fissures and caverns of bedrock is indicated.

The gradient of Squaw Creek through the zone of loss - to the contact of the Spearfish formation is about 85 feet per mile.

French Creek

French Creek has the shortest outcrop zone through the Englewood, Pahasapa and Minnelusa formations of any of the creeks examined. The drainage area of French Creek in the crystalline area is approximately 105 square miles. The entire distance from the crystalline area to the head of the alluvial valley, which extends up to the lower outcrop of the Minnelusa is about 11,450 feet, of which 200 feet is across the Englewood, and the remainder is about half in the Pahasapa and half in the Minnelusa.

The Pahasapa limestone exhibits the usual cavernous features and the stream impinges on bluffs of it at some six or more bends. At no point, however, was the water loss sufficient to be detected by eye. At the date of examination May 17, 1944, the stream was not losing more than 1/3 of its estimated flow of 15 second feet. The loss appeared to occur gradually as the stream passed through the coarse alluvium. The alluvium contains sizable boulders, but on an average is not as coarse as on Squaw Creek. Darton (2) reported that in May and June 1900, the flow 10 miles above Fairburn was 13 and 5 second-feet, respectively. At the same time in Fairburn the flow was 3.3 and 0.2 second-feet. A discharge measurement made August 5, 1944 just above the zone of loss showed a flow of 4.09 second-feet. The flow disappeared entirely within the zone of loss, and was approximately 0.5 second-foot at the point of disappearance. In September the flow above the zone had declined to 1.83 second-feet and the point of disappearance had receded a short distance upstream.

Remnants of a small and very old irrigation ditch and flume are found along the north side of the valley through most of the zone of loss. This indicates that loss was recognized in the early days of agriculture and that an effort was made to retain the water for beneficial use by fluming it through this stretch.

The gradient of French Creek from the crystalline area to the head of the alluvial valley is approximately 92 feet per mile.

Boxelder Creek

Boxelder Creek traverses the Pahasapa and Minnelusa formations for a distance of approximately 62,500 feet, about half of the distance in each formation. Its watershed in the crystalline area contains approximately 109 square miles.

Just below its junction with Bogus Jim Creek it passes across the outcrop of the Englewood limestone. The stream strikes the first bluff of Pahasapa limestone at the mouth of Custer Gulch, about 1900 feet downstream. Just above the road crossing which is 3500 feet below the mouth of Bogus Jim Creek, the stream flows against an undercut bluff of limestone. It is reported that considerable water loss occurs in the pool here and into the talus bank just upstream from the bridge. Another sinkhole is reported just downstream from the road crossing.

It is reported that several years ago test holes were drilled under Forest Service Supervision a short distance below the road crossing to depths of about 90 to 100 feet in exploration of dam foundation conditions. It is locally understood that the limestone was found to be porous and broken and that the site was considered unfavorable for a dam.

Additional sinks are reported in bluffs on the left side of the stream (facing downstream) less than a mile below the road crossing. At one point the limestone cliff is undercut 10 feet or more.

Approximately 8300 feet below the road crossing large springs bubble up through the top of a gravel bar at an elevation some 12 feet or more above the stream surface. The level of these springs precludes any connection with the stream above through the gravelly alluvium, which is essentially an isolated bar on the inside of a bend. The water undoubtedly comes up under artesian pressure from a fissure in the underlying limestone. On the date of observation, May 19, 1944, the springs were estimated to be flowing at least 1000 gallons per minute. They are reported to flow long after the stream has dried up to a considerable distance upstream from this point, but are said to have failed in the dryest years experienced when stream flow did not extend downstream as far as the zone of loss. This suggests a direct connection through the limestone with sinks above, possibly those near the road crossing.

At a distance of approximately 12,100 feet below the road crossing the well known Dotie Spring occurs on the right bank of the stream. This spring issues directly from a limestone fissure and had an estimated flow at the time of observation of 2 to 3 second-feet. It is reported to have gone dry only once in many years, this within the recent period of drought. At this time a local man is reported to have entered the opening and crawled several hundred feet into the fissure. He is said to have stated that the fissure opened out into a room 30 feet high. This spring is reported to maintain a flow for 3/4 mile downstream when there is no flow in the stream above.

At a point known as the "Dome" from a peculiar rock formation on a bluff bordering the stream, the flow is said to be noticeably increased during low water. This may be due to another spring in the relatively deep pool at the foot of the dome. This location is approximately 22,500 feet below the upper road crossing and 3300 feet above the lower road at the Smith place. Another sink is reported near an old cabin on the right bank of the stream 2100 feet above the lower road crossing and near the contact of the Pahasapa and Minnelusa formations. The flow at the lower road crossing at the time of observation was at least two-thirds of the flow above the zone of loss.

From the lower road crossing downstream for a mile the stream flows in a flat alluvial valley nearly a quarter of a mile wide. This valley was apparently caused by a sharp flexure, which turns a resistant massive sandstone bed nearly on end and forms a narrow gate through which the stream flows. Below this gate the stream reenters the outcrop of Pahasapa exposed by folding and erosion of the stream through the overlying Minnelusa. The stream flows through the Pahasapa for about 1½ miles before it reenters the Minnelusa outcrop, which it follows in tight meanders and broad bends generally parallel with the strike until it turns east and passes through the gate of the Minnekahta limestone about 6.3 miles by stream below the lower road crossing, and 1 mile by stream above the crossing of Highway 14. The water flow was found to decrease progressively below the lower road crossing and at a distance of 22,500 feet a flow of about ¼ second-foot ran into a pool alongside an undercut bluff in a limestone member of the Minnelusa formation. No water flowed out of this pool. In dry pools below, dead trout indicated that water extended considerably farther in the past two or three weeks. The last flowing water was approximately 16,150 feet above Highway 14, but several pools of stagnant water were found in this stretch.

The gradient of Boxelder Creek through the zone of loss averages approximately 55 feet per mile. When the stream enters the alluvial valley just below the Minnekahta gate its grade drops to approximately 20 feet per mile.

The first reappearance of flow observed in Boxelder Creek was where it reaches the outcrop of the Lakota Formation in the gap through the Hogback Ridge. Here in sec. 9, T. 2 N., R. 7 E. a flow of about ½ second-feet was noted in the channel. A small flow is maintained to about the point where the stream reaches the Chicago and Northwestern Railroad in sec. 23, T. 2 N., R. 8 E. The flow disappears for a mile or so and is then renewed one mile west of Boxelder. It receives some addition from overflow of the airport wells just above this village. A flow of ¼ to 1 second-foot varying from point to point was maintained to New Underwood. It is perhaps significant that the U. S. Geological Survey topographic quadrangle (Rapid) surveyed in 1891-98 showed stretches of permanent flow between sections of intermittent flow through the alluvial valley. This condition is probably attributable to reaches of more porous or deeper alluvium alternating with reaches of shallower or tighter alluvium. In any event the condition indicates considerable down-valley movement of water in the alluvium. This is confirmed by abundant water supplies obtained from many wells in the valley, which are only 10 to 30 feet deep, and end in water-bearing gravel.

The flow of Boxelder Creek below the Hogback Ridge is largely conditioned by the amount and distribution of precipitation. The creek was said to have a good flow in 1928-29, but dried up in 1930. Some water was available in 1932-33 but none in 1934. In 1935 the flow was good, but water was generally lacking in 1936-37-38.

Elk Creek

Elk Creek has three main heads that cross the Englewood, Pahasapa and Minnelusa formations. From north to south these are Elk Creek, which has the largest drainage area, Little Elk Creek and Stage Barn Canyon.

Elk Creek proper flows out of the crystalline area at Elk Creek, a small settlement about 1/3 mile west of the Lawrence-Meade County line in sec. 24, T 4 N., R. 4 E. Above this point the drainage area is approximately 23 square miles. After crossing the Deadwood it flows through the Englewood, Pahasapa and Minnelusa formations for a distance of approximately 64,800 feet.

On the date of observation, May 21, 1944, the stream had a flow of probably 5 second-feet at the contact of the Pahasapa and Minnelusa formations. It is reported to have flowed this far for only two weeks, however. In many drier summers it does not reach the Minnelusa formation, but occasional summer storms produce enough run-off to cause flow through to the alluvial valley. Numerous springs are reported through the limestone reach above and these are said to help sustain the flow.

One and one-quarter miles downstream from the Pahasapa-Minnelusa contact the flow amounted to about 3 second-feet. The bed was composed of clean cobble 3 inches to 1 foot in diameter and the water loss resulted from gradual sinking into the bed.

The last of the flow, a mere trickle, disappeared in the gravel through the Minnekahta gate. The flow is much stronger about 3/4 mile upstream. It was apparent, however, that flow had come into this reach only within the last few days.

Between the Minnekahta gate and Highway 14 the channel runs across a well defined alluvial fan containing many boulders of crystalline rock more than 1 foot in diameter. At the highway crossing the channel is only about 5 feet wide by 3 feet deep. The bordering floodway is well grassed and it appears that significant flows in recent years have been rare. A low levee 1/4 mile long upstream from the highway on the south side of the channel indicates, however, that flows of more than channel capacity have occurred sufficiently often to cause significant damages.

Flow began again north of Piedmont Butte, where the stream cuts through the Hogback Ridge. The flow was less than 1 second-foot, but was increased on the east side of the Hogback Ridge by springs on the hillside which yield more than 50 g.p.m. The flow alternately increased and decreased downstream, but was generally less than 1 second-foot and in one reach the bed was dry.

About 7 miles downstream from Piedmont Butte in sec. 1, T. 3 N., R. 7 E. the flow was 1.4 second-feet, where measured at an irrigation diversion weir. A small flow was said to extend all the way to the Cheyenne River, but it is doubtless maintained by groundwater accretions, as evaporation would consume a flow of this amount in a much shorter reach.

The average gradient of Elk Creek through the Pahasapa-Minnelusa zone is about 100 feet per mile. In the alluvial valley east of Piedmont Butte the average gradient is less than 30 feet per mile.

Little Elk Creek

Little Elk Creek had a flow of less than 1 second-foot coming out of the crystalline area which comprises approximately 16 square miles, at the time of examination, May 21, 1944. The total length of the Pahasapa-Minnelusa outcrop belt on this stream is approximately 9600 feet, and the Pahasapa outcrop belt alone is only about 1900 feet. This condition is due to the very sharp monoclinal flexure which produces a steep dip in the Deadwood, Englewood and Pahasapa formations where they cross Little Elk Creek. Below these formations at the Minnekahta gate the flow was only about ¼ second-foot and disappeared entirely in the well defined fan spreading out from this point to Highway 14. No return flow appeared above the junction of Little Elk and Elk Creeks. The gradient of Little Elk Creek is nearly 140 feet per mile through the short zone of loss.

McCauley (6) in 1914 reported on an investigation of the irrigation possibilities of Little Elk Creek. He stated that 4 weirs were constructed in the zone of loss, and that measurement of flow showed a gain in water rather than a loss, as was expected. His explanation was: "The gain is no doubt due to percolation into the stream from the monocline though no springs of any importance were found."

No examination was made of Stage Barn Canyon. There was no flow in this stream at or below the Minnekahta gate, and it is reported that flows are experienced only after severe storms. The canyon heads in the Pahasapa limestone.

ANNUAL AND SEASONAL RUNOFF

Any estimates of the annual and seasonal runoff, or variations in discharge, for streams other than Rapid Creek are subject to large error owing to lack of adequate stream gaging records. From fragmentary information, however, a few approximations can be made. All applicable stream flow records are given in Table 4.

A record of the discharge of Rapid Creek at Big Bend for 28 years (1915-1942, inclusive) shows an average annual water yield of approximately 54,200 acre-feet, or 163 acre-feet per square mile. This represents an annual runoff of 3.06 inches or 16.4 per cent of the average annual precipitation of 18.65 inches at Deerfield for this period. In the lowest-flow year of record, 1940, the runoff was 0.5 inch or 4.14 per cent of the precipitation. The highest runoff in 1920 was 8.04 inches or 43.2 per cent of the precipitation at Deerfield (precipitation was several inches higher at other stations). The precipitation during the 28 years of record is slightly more than the 56-year average (1888-1943) of 17.25 inches at Rapid City, but Deerfield has an average precipitation 0.81 inch greater than Rapid City. The long-term average annual runoff, therefore, should be practically the same as that indicated by the existing record.

The average annual runoff of Rapid Creek during the irrigation season, May through September, was 59 per cent of the yearly total, or 32,000 acre-feet, or 96.4 ac.ft./sq.mi. During parts of 1903-1905 discharge was measured on Boxelder Creek at Blackhawk (drainage area 157 sq.mi.), Spring Creek at the present Highway 79 (drainage area 205 square miles) and on Battle Creek at the Chicago and Northwestern Railroad Bridge (drainage area175 square miles). These locations are below the zone of water loss. During the period Oct. 1, 1937-Sept. 30, 1940 the flow of Spring Creek was measured near Hill City (drainage area 142 sq. mi.). This location (sec. 7., T. 15 S., R. 6 E.) is in the crystalline area, a few miles above the zone of loss. The monthly discharge computed from these measurements has been converted to inches runoff and plotted in figures 5 and 6 together with the runoff of Rapid Creek for the same period, and the monthly precipitation.

Several significant conclusions may be drawn from these graphs. The average runoff per square mile of Spring, Boxelder and Battle Creeks is less than the average runoff of Rapid Creek.

In considering water storage projects the total annual runoff is important, but in connection with stream sealing projects without storage, only the water yield during the irrigation season, May through September, is significant. Figure 7 shows the percentage of flow on the smaller creeks relative to the flow of Rapid Creek during all periods of record. No significant difference is apparent between different streams in different years. The wide variation of individual curves appears to be primarily a result of the fortuitous occurrence and distribution of summer precipitation in the Hills.

By taking the average of percentages of flow with respect to Rapid Creek of all streams in each month it is found that the average flow of the smaller streams during the irrigation season is 50.5 ac.ft./sq. mi. or 52.4 per cent of the Rapid Creek flow during this season. Using this estimate for average water yield, and the drainage areas above the upper end of the zone of loss, the water yields shown in Table 5 were obtained:

Table 5 - Estimated average water yields of drainage areas above the zone of loss

Stream	Drainage area above zone of loss sq. mi.	Estimated average water yield from crystalline area, May through September ac. ft.
Elk Creek	23	1160
Little Elk Creek	16	810
Boxelder Creek	109	5500
Spring Creek	173	8740
Battle Creek	68	3430
Squaw Creek	27	1360
French Creek	105	5300

The amount of water that reaches the Plains depends on three factors (1) the quantity and variation in rate of discharge of water that enters the zone of loss (2) the length of the zone of loss and (3) the average net loss per mile of the zone. Existing data are sufficient to make a reasonably satisfactory estimate of (1) the average quantity of water that enters the zone of loss (2) the proportion of years in which the volume would be too small to be useful, or large enough to supply all past requirements. The length of the zone of loss on each stream has been determined. The average net loss per mile of zone cannot be determined from existing data, and only probable limits can be assumed for the purpose of this analysis.

During 3 irrigation seasons totaling 459 days in 1937-40, the flow of Spring Creek exceeded 10 second-feet on only 23 days and for no period longer than 5 days, this being in October 1938. During 82 percent of the time the flow was less than 5 second-feet. Even had the sealing project been completed prior to this period, the flow produced above the zone of loss would have been insufficient to yield any sustained or dependable water supply for irrigation below the zone, or even to maintain a sufficient flow for fish life. Only with the advent of the much heavier precipitation of the 1941 season, the year after completion of Sheridan dam and the sealing project, was there sufficient water to sustain a flow in Spring Creek to the Plains below.

In the much wetter years, 1903-1905, flows on Spring Creek below the zone of loss were as follows: In 1903 the flow in July was all above 10 second-feet reaching a daily maximum of 29 second-feet. In August the flow was all above 6 second-feet reaching a daily maximum of 15 second-feet. In September the flow varied from 6 to 10 second-feet. In 1904 the stream was dry during March and April. In May the flow varied from

TABLE 4 RECORDS OF DISCHARGE OF STREAMS IN THE BLACK HILLS, SOUTH DAKOTA

Rapid Creek, Big Bend, South Dakota[1]
(Drainage area 332 square miles, Discharge in acre-feet)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Per Square Mile
1913	----	----	----	1100	2000	2100	1300	700	1000	1800	1500	800	-----	------
1914	----	----	----	----	2900	2200	2000	2000	1700	*5000	*3500	*2700	-----	------
1915	*2500	*2000	*2300	5640	10000	13200	11200	20900	10900	5870	3640	3310	91460	275.48
1916	3010	2990	4280	5610	8240	9100	5500	3790	2840	3200	3100	*2200	53860	162.23
1917	2100	1500	1700	3000	9300	10500	4300	3300	2400	*3500	*3400	*2400	47400	142.77
1918	*2200	*1700	*1900	*3300	*10300	*11600	*4700	*2700	3100	3200	2700	2900	49300	148.49
1919	3200	2800	3500	5400	4300	2800	2500	2100	2300	2990	2600	2700	37100	111.75
1920	2300	2200	3000	5200	67000	17300	16000	8100	6100	5900	4500	4100	142300	428.61
1921	4000	3600	5200	5500	5900	8400	5300	5200	4100	4400	4000	4000	59600	179.52
1922	3700	3100	4900	5500	7500	7400	6600	13400	5300	5100	5100	4100	71700	215.96
1923	4100	3400	4900	9100	13900	21800	9700	7600	6300	7700	6400	3900	98800	297.59
1924	3500	3500	3500	17100	10500	6700	5100	4300	3900	5000	4300	3800	71200	214.46
1925	2800	2800	5200	10500	9200	15400	8700	5700	4800	5100	4800	4100	79100	238.25
1926	3100	2800	3900	6900	6100	6400	10300	5700	4800	5100	4700	3600	63400	190.96
1927	2800	2500	3900	9700	27100	22100	10000	11400	8100	7200	6500	3900	115200	346.99
1928	2800	2300	5100	7100	8700	11800	9600	7000	5700	5700	5500	3700	75000	225.90
1929	3100	2200	4700	12300	18000	25200	10200	5600	4800	4400	3500	3800	97800	294.58
1930	3800	3100	4000	8300	6800	4500	3000	3000	2500	3700	2400	2900	48000	144.58
1931	3100	2900	3400	4000	3490	1900	1600	1600	1400	1900	1900	2300	29400	88.55
1932	1900	2100	2100	4830	6070	4750	2890	3970	2040	2360	2090	1380	35580	107.17
1933	1840	1440	2900	7620	22100	9640	4320	2930	2370	2680	2580	2410	62830	189.25
1934	2460	2180	2560	2730	1850	1740	1050	1210	1190	1720	1500	2000	22190	66.84
1935	2200	2400	2600	2220	3070	9000	3770	2210	1700	1700	1820	1600	34290	103.28
1936	1290	1380	1840	2690	1960	1300	253	587	476	1060	1280	1400	15516	46.73
1937	1400	1500	1700	1900	1540	1870	1850	644	779	823	706	627	15339	46.20
1938	855	555	1840	2220	2270	1430	980	470	579	657	815	587	13258	39.93
1939	615	333	1540	2020	1650	1010	308	705	452	722	708	809	10872	32.75
1940	653	849	926	1540	1200	776	411	409	378	611	662	601	9016	27.16
1941	547	534	853	2880	2700	8540	3260	1800	1080	1310	1200	819	25523	76.88
1942	573	615	1060	4670	14070	8930	3590	2080	1540	1910	1660	867	41565	125.20
Average					10169	8753	5249	4554	3283				54164	163.14

Rapid Creek, Rapid City, South Dakota[2]
(Drainage area 410 square miles, Discharge in acre-feet)

1903	----	----	----	-----	-----	9700/	7190	4610	4340	3870	3090	#2380	------	------
1904	*2100	*1960	#3570	7140	8730	25800	10800	5000	5240	5340	5090	4870	85640	208.88
1905	#5000	#3050	4460	4950	10600	7800	22100	12000	6070	5180	#4790	#3100	89100	217.32
1906	*3100	*2800	*3100	4030	7750	8810	4570	10200	5180	5020	4200	----	58760/	143.32/

Rapid Creek, Creston, South Dakota[2]
(Drainage area 710 square miles, Discharge in acre-feet.)

1929	----	----	----	8690/	22000	38700	12300	3710	4280	7010	7680	----	------	------
1930	----	----	12900	10700	8360	2020	30	867	1010	6330	4570	5210	------	------
1931	5230	4830	4680	5640	2530	375	154	0	0	1080	2360	2770	29649	41.76
1932	3070	6330	13300	10900	25800	6190	-----	-----	-----	----	----	----	------	------

Boxelder Creek, Blackhawk, South Dakota[2]
(Drainage area 157 square miles. Discharge in acre-feet)

1903	----	----	----	-----	-----	-----	898	652	393	167	30	*30	------	------
1904	*62	*116	*186	#445	1750	10800	2230	248	325	284	79	*62	16587	105.65
1905	*62	*500	*1500	*5000	#6490	2110	12800	5200	1290	1170	482	----	36704/	233.78/

Spring Creek, near Rapid City, South Dakota[2]
(Drainage area 205 square miles. Dishcarge in acre-feet)

1903	----	----	----	-----	-----	-----	910	615	400	369	240	198	------	-------
1904	*156	*230	#326	13	652	9580	3600	953	478	512	402	*250	17152	83.67
1905	*250	*224	*279	*270	#646	1020	5240	4780	1330	756	732	----	15527/	75.74/

Spring Creek near Hill City, South Dakota.[2]
(Drainage area 142 square miles. Discharge in acre-feet)

1937	----	----	----	-----	-----	-----	-----	-----	-----	65	59	85	-----	------
1938	65	62	126	668	462	378	360	99	180	216	88	59	2609[3]	18.37
1939	42	37	67	181	119	115	76	408	40	60	56	50	1448[3]	10.20
1940	68	62	44	256	186	248	164	293	34	----	----	----	1521[3]	10.71

Battle Creek, Hermosa, South Dakota[2]
(Drainage area 175 square miles. Discharge in acre-feet.)

1903	----	----	----	-----	-----	-----	-----	-----	#638	#259	#119	-----	------	------

[1] Source of data: April 1913 - September 1914 from U.S.B.H. report on Rapid Valley Irrigation Project, based on unpublished Forest Service measurements; October 1914 - March 1915 estimated or partially estimated by U. S. Engineers (H.D. 190, 72nd. Cong. 2nd. Sess. p. 122) from Forest Service gage heights; April 1915 - September 1916 from U.S.G.S. Water Supply papers; October 1916- April 1929, estimated by U.S. Engineers from gage heights recorded by Forest Service. Discharge estimated from rating curve below 400 second-feet. Figures have been rounded out to nearest 100 acre-feet; April 1929 - March 1932 discharge estimated as 104 percent of discharge at Pactola (drainage area 319 square miles); April 1932 - December 1942 from U.S.G.S. water supply papers.

[2] Source of data: U.S.G.S. water supply papers and H.D. 190. Estimated or partially estimated figures from H.D. 190 except on Battle Creek where estimates were made by writer.

[3] Water year October 1 - September 30.

* Estimated

\# Partially estimated

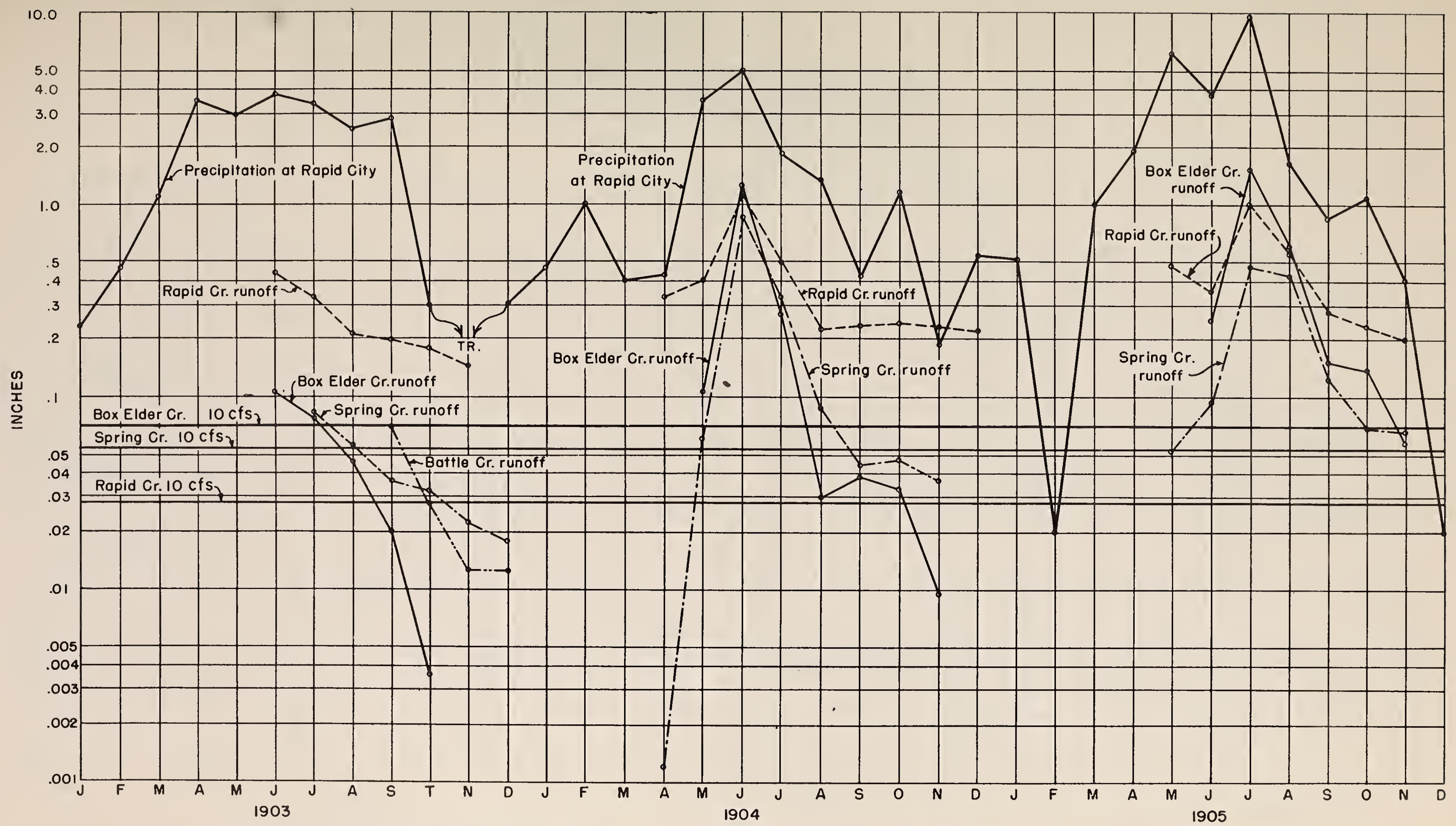


Figure 5.—Relation of precipitation at Rapid City to runoff of Rapid, Spring, Box Elder, and Battle Creeks, 1903-1905

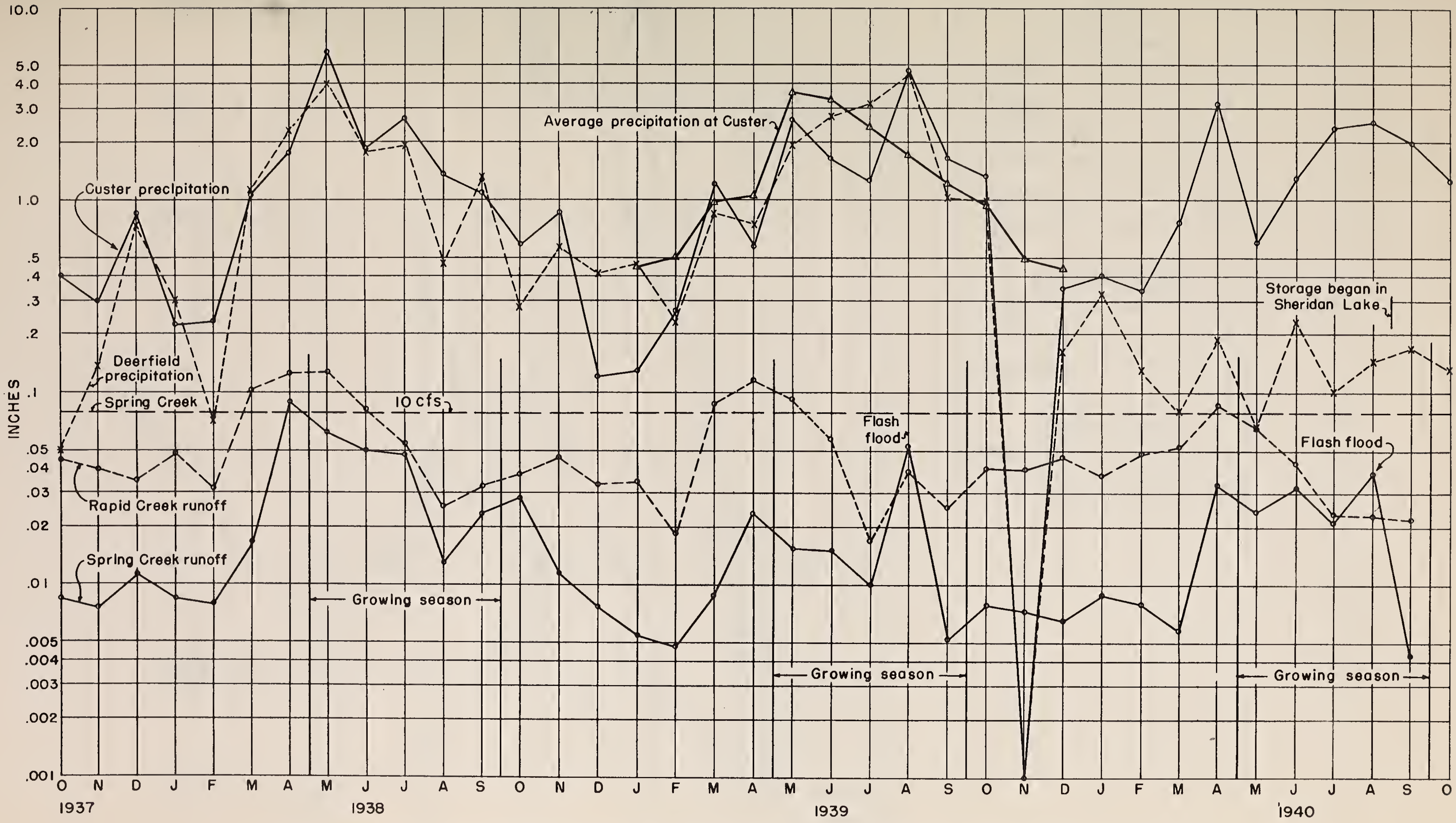


Figure 6 — Relation of precipitation at Custer and Deerfield to runoff of Rapid and Spring Creeks, 1937-1940

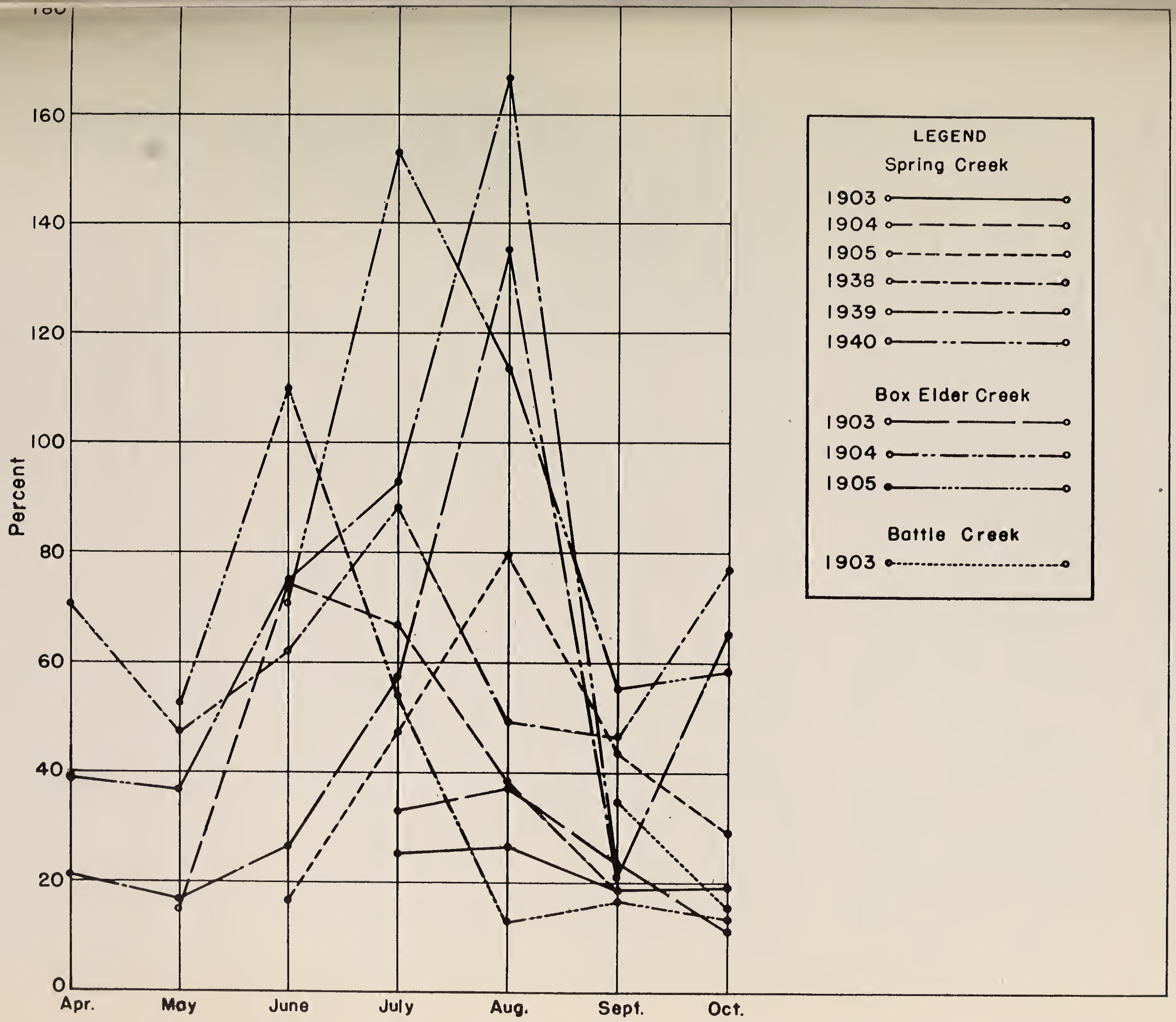


Figure 7—Relation of flow of smaller creeks to Rapid Creek per square mile of drainage area

6 to 29 second-feet, in June, with 5.07 inches of rain following 3.50 inches in May the flow ranged from 47 to 255 second-feet. In July with 1.84 inches, the daily flow was 21 to 325 second-feet with a peak of more than 500 second-feet. In August with only 1.36 inches the flow declined to 10-29 second feet and in September with 0.43 inch, to 6-21 second-feet.

In 1905 the heavy May precipitation of 6.25 inches followed by 3.65 inches in June was not reflected in runoff, which ranged from 4-21 second-feet in these months. This suggests that a period in the spring with heavy precipitation is required to saturate the alluvium and fill the water channels in limestone through the zone of loss. Thereafter, the loss may be less if the flow from above is well sustained. In July 1905 the exceptional rainfall of 9.66 inches produced a daily flow of 15 to 415 second-feet, and rainfall of 1.66 inches in August sustained this flow at 29-397 second-feet. In September and October with 0.85 and 1.08 inches the flow declined to 10-29 second-feet.

On Boxelder Creek the flow averaged fore than 10 second-feet during July and August, 1903, and from the middle of April 1904 through July, with an average flow of 182 second-feet in June. The flow was well sustained at more than 10 second-feet from May through September 1905.

Although it is not possible to make a statistical analysis of the relation of rainfall and runoff, owing to the short runoff records, a comparison of the characteristics of flow and precipitation in the years 1903-05 and 1938-40 with the rainfall distribution during the months April through September for the 56 years, 1888-1943, seems to warrant the following generalization. In 15 years, or 25 per cent of this period, either the total rainfall was so deficient or was so poorly distributed that, even with effective stream sealing, water would not have reached the Plains during most of the summer in sufficient quantity for irrigation of even limited acreages, nor would the flow have been sufficient to sustain fish life between the crystalline area and the Plains. This estimate is made on the assumption that complete loss of flows of less than 5 to 10 second-feet through evaporation, transpiration and seepage in the zone of loss could not be economically prevented. During these years the total precipitation varied from less than 8 to 17 inches, but in the years of higher totals 3 or 4 months of the growing season were very deficient.

In 40 percent of the years the runoff was probably sufficient to sustain flows through the zone of loss during the entire growing season providing adequate water for fish, for all stockwater requirements on the Plains and permitting full or nearly full irrigation of feed crops on several hundred to several thousand acres in the valleys of Elk, Boxelder, Spring, Battle and French Creeks. In these years annual precipitation varied from 17 inches concentrated in and well distributed over the growing season to more than 27 inches. Stream sealing without storage on the Plains would have been of very little advantage in most of these years of plentiful water supply for, as pointed out subsequently, irrigation facilities would not be installed to utilize the excess flow of 40 percent of the years. In some of these years there would have been slight benefits from one additional irrigation late in the season. It is probable that stream flow on the Plains in some years is considerably increased by direct runoff, as indicated by comparison of the flow of Rapid Creek at Pactola and at Creston near its mouth, shown in Figure 8.

In the remaining 35 percent of the years annual precipitation varied from 13 to 20 inches and was either moderately deficient during most of the growing season or was especially deficient in two or three months. In these years the prevention of water loss in the streams would have produced considerable benefits. The flow probably would have been sustained sufficiently to maintain fish life all summer and to provide ample stock water. The land fully irrigated could have been increased probably several hundred acres on each stream. That is, the land under irrigation could have been more fully irrigated with increased yields, or more land could have been partially irrigated, or both. A reasonable assurance of better sustained flow in these years by reason of stream sealing would warrant the installation and maintenance of facilities to irrigate a larger acreage, but not in excess of the amount of land that has been irrigated at one time or another in the past. For example, land that could be irrigated in 40 percent of the years is not irrigated because the hazard of water deficiency in more than one out of every two years is too great to warrant installation or maintenance of the necessary facilities, particularly the substantial diversion dams and headgates necessary to withstand occasional floods. If, however, the reasonable certainity of sufficient water in 3 out of 4 years existed, then a number of such installations might become economically feasible.

FLOOD FLOWS

The velocity, discharge and duration of flood flows is an important consideration in the design and construction of stream-sealing works, and of the irrigation diversion structures necessary to utilize stream flow in the Plains. Lack of stream gaging records makes it impossible to predict the frequency of floods of any magnitude. In fact, none of the larger known floods in the streams under consideration have been gaged, so that their discharge can be only approximated.

The largest flow recorded in the U. S. Geological Survey records on Rapid Creek at or above Rapid City was 1570 second-feet or 4.73 sec. ft. /sq.mi. on May 24, 1933. At the Creston station near the mouth of Rapid Creek a flood of 16,000 second-feet or 22.5 sec.ft./sq.mi. was recorded May 6, 1932 but this originated entirely from a storm over the Plains east of Rapid City. No flood of really serious proportions has occurred at Rapid City since May 1920, and the same is probably true of the other streams under consideration. Between the date of settlement in 1876 and 1920, however, at least four major floods and several lesser ones all larger than any subsequent flood occurred on Rapid Creek and probably on the other streams. The floods are of two types (1) those due to warm spring rains on a heavy snow cover and (2) summer cloudbursts.

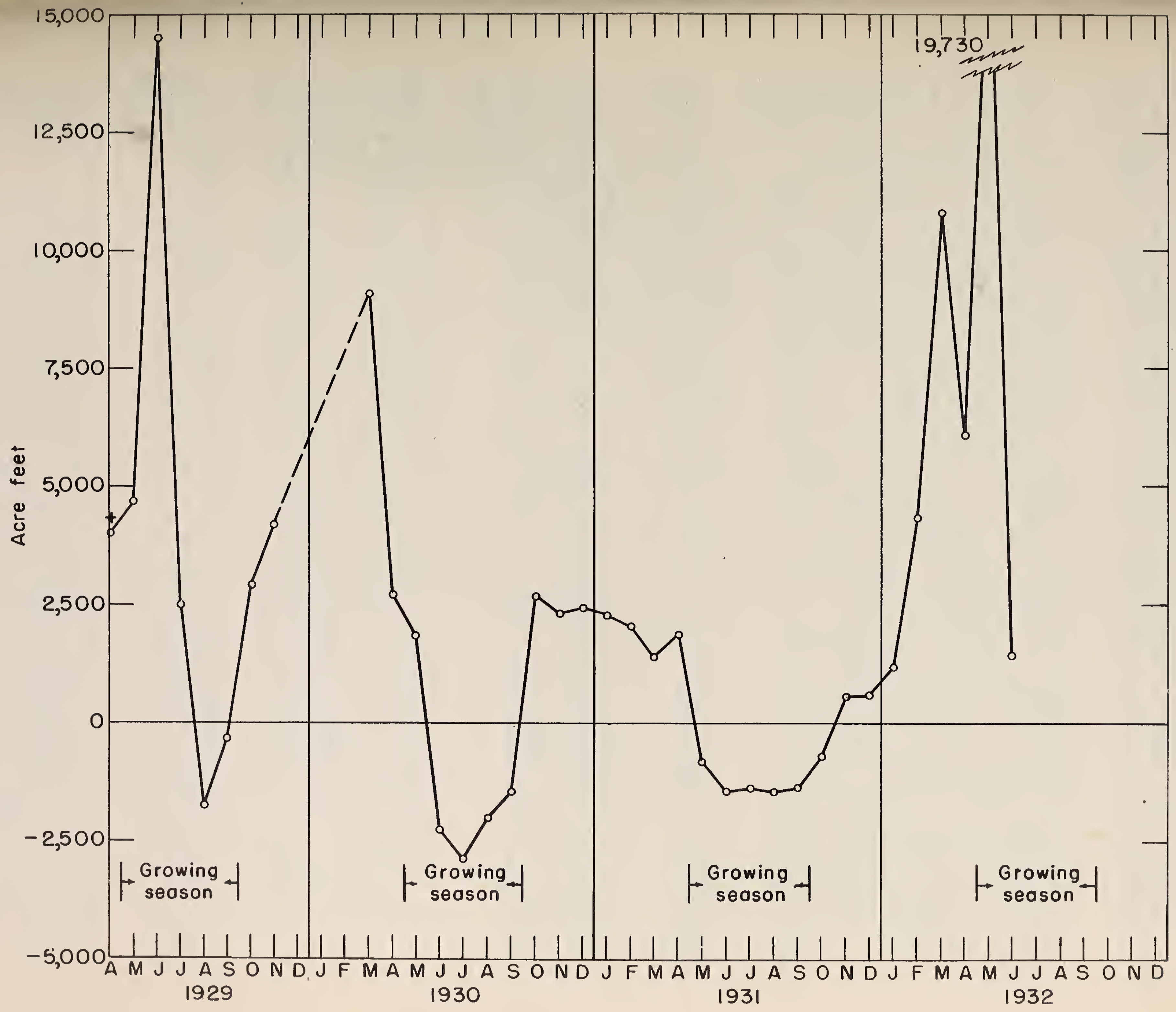


Figure 8:-Rapid Creek - Excess or deficiency of monthly flow at Creston over flow at Pactola.

The first recorded flood on Rapid Creek occurred July 12, 1878, resulting from a summer cloudburst following heavy spring and summer precipitation, including rainfall of 7.8 inches in June. The gap through the Hogback Ridge on the west side of Rapid City was said to have been covered by water.

The second major flood occurred during the period May 17-25, 1883, and was caused by warm rain beginning on May 17 while the mountains were still blanketed by snow. Extremely heavy damage was done at Deadwood and Lead where a substantial portion of the buildings was washed away. A dispatch from Rapid City on May 19 reported that "This city is entirely surrounded by water, and many buildings will be swept away. The Rapid Creek Valley, more than forty miles in length, all of which has already been seeded, is entirely submerged. Many of the houses up the valley are being washed away . . . ". Much of the valley above the Hogback Ridge gap was inundated. A large diversion dam belonging to the Lower Rapid Irrigation Company was washed away. The Indians were quoted as saying that water extended from bluff to bluff on the main Cheyenne River below the Forks.

On June 5, 1885 another major flood occurred on Rapid, Boxelder and Elk Creeks. A minor flood was reported in August 1888. Heavy rain and minor flooding occurred June 4 and 5, 1890.

On August 10, 1890, the water went overbank on Rapid Creek and washed out buildings, flumes and all bridges on the Creek. On June 6, 1892, nearly 3 inches of rain caused washout of two miles of railroad track below Rapid. A minor flood resulted in July 1901 from 4.83 inches of rain. On June 6, 1904 a peak flow of 1170 second-feet was measured at Rapid City.

The flood of June 13-14, 1907 was one of the most destructive at Rapid City. Heavy cloudbursts in the Hills early in June followed exceptional precipitation of 8.09 inches on snow in May. The water is reported to have come down the creek suddenly with great force taking everything before it. Many railroad and highway bridges were washed out. Damage to the Rapid City, Black Hills and Western Railroad was $35,000. The total damage on Rapid Creek was estimated at $75,000. A flash flood came down Stagebarn Canyon at the same time and killed two children.

McCauley (6) stated in 1914 that this flood caused water to rise 15 to 20 feet on Little Elk Creek. He calculated from high water marks that the peak flow was approximately 5000 second-feet, or 312 sec.ft./sq. mi.

The last major flood on Rapid Creek was that of May 10-12, 1920. The Creek reached a stage 6 feet above normal and spread 1 1/2 miles wide in the north part of Rapid City. Many homes were inundated, 20 railroad bridges were washed out, and many highway and private bridges were lost. The flow was estimated at the Big Bend power plant to be 8000 to 10,000 second-feet, which is equivalent to 24.1 to 30.1 sec.ft./sq.mi. A flow of 3600 second-feet was estimated at Big Bend on May 12, 1930.

A flash flood on Beaver Creek near Buffalo Gap in the southern part of the Black Hills on Sept. 4, 1938 had a discharge of 11,700 second-feet or 88.6 sec.ft./sq.mi. The gage reading was 16.45. A reading of 18.0 was reported during a flood in 1927.

According to Powell (9) a small flood on Newton Fork, a tributary of Spring Creek in 1936 produced 16 sec.ft./sq.mi. from a 15-square mile drainage area. A 60-square mile area near Hot Springs on June 17, 1931 produced 100 sec.ft./sq mi. In computing the spillway capacity for Sheridan Dam Forest Service engineers assumed a maximum hourly precipitation of 3 inches, a time of concentration of 10 hours and a runoff factor of .30. This would produce a discharge of 8700 second-feet or 61.3 sec.ft./sq.mi. Bismark Dam on French Creek was provided with a spillway capacity of 426 sec.ft./sq.mi. for a drainage area of 5.4 square miles.

The Bureau of Reclamation (13) has estimated that flood frequencies on Rapid Creek resulting from spring runoff will have discharges of the following order of magnitude.

Average frequency of flood years	Momentary peak rate of discharge per square mile sec.ft.
Maximum	157
1000	78
500	63
200	44
100	31
50	19
25	12.5
10	6.3

Summer cloudburst storms may be expected to have somewhat higher rates of peak discharge for the same average frequency of occurrence.

The size of boulders carried from the crystalline area to the fans below the zone of loss testifies amply to the great velocity attained during flood stages in the canyon sections of these streams. The canyons are generally narrow and discharges of 10 sec.ft./sq.mi., which may be expected more frequently than once in 10 years on the larger streams such as Spring and French Creeks will move boulders of one to several feet in diameter. The force of the current and its load of detritus during such flows would severely test any works constructed in the channel. Dry riprap might be dislodged rapidly. Even channels lined with masonry might be overtopped during peak flows with consequent danger of the masonry being undermined. Large accumulations of detris in the channels would have to be anticipated. Large maintenance costs would be incurred for almost any type of sealing or protective works constructed.

EFFECTS OF RESERVOIR STORAGE

Reservoir storage has a material effect on the feasibility of stream-sealing projects in several ways: (1) Reservoir storage can be utilized to regulate and equalize stream flow by impounding the higher spring run-off or summer flood flows and releasing stored water for irrigation during low flow months in the growing season. (2) Flood control storage will reduce the strain on stream-sealing works, and hence the installation or maintenance costs. (3) Reservoirs cause a net water loss by evaporation in this climatic region.

Reservoirs developed for recreation already exist on several of the streams under consideration. The largest of these is Sheridan Lake (also known as Lake of the Pines and Dakota Lake) on Spring Creek, located 10 miles above the zone of loss. This reservoir is created by a dam 110 feet high, has a surface area at spillway level of approximately 380 acres, and a capacity of 12,088 acre feet. The drainage area above it is 153 square miles, compared with 173 square miles at the upper end of the zone of loss and 205 square miles at Highway 79. The spillway has a freeboard of 10 feet, which allows for flood detention of 4000 acre-feet of water. As the spillway capacity is reported by Powell (10) to be 2,000 second-feet, and as there is no gate control above spillway level, it is obvious that if the lake is at spillway stage only the largest flood flows will be much detained or their peaks greatly lessened. The plan of operation does not provide for drawdown of the lake for flood protection, nor for release of more than the inflow for irrigation use. Either of these operations is considered to be contrary to maintaining the lake at a nearly constant stage for recreation, water fowl preservation and fish culture.

Net evaporation (evaporation minus rainfall) at Rapid City is given as 34 inches by Meyer (7). At the higher elevation of Sheridan Dam it may be somewhat lower. Assume 30 inches. If the lake is at or near crest stage most of the year the average net loss would be 950 acre-feet or 12.3 per cent of the estimated average annual runoff of 7,726 acre-feet based on 50.5 ac.ft./sq.mi. x 153 square miles. In drought years, however, the effect would be much more important. In the water years 1939 and 1940 the inflow to Sheridan Lake would have been approximately 1500 acre-feet per year, and if the lake had remained at spillway level, evaporation would have consumed 60 per cent of the inflow, leaving less than 600 acre-feet per year or less than 1 second-foot average outflow. Of course, in these years the stream flow would not have reached the Plains with or without the dam.

Other reservoirs, mostly small, on headwaters of these streams include:

Spring Creek: Mitchell Lake; Major Lake near Hill City; Newton Fork Lake; and Sylvan Lake

Squaw Creek: Center Lake

Battle Creek: Horse Thief Lake

French Creek: Stockade Lake - A larger lake covering 122 acres at crest stage, built by the Forest Service in 1933; Bismark Lake - On a tributary just above Stockade Lake, covering an area of 23.8 acres; and a small lake at Custer

Boxelder Creek: Roubaix Lake

Little Elk Creek: Dalton Lake

In addition there are a large number of beaver ponds.

It is concluded that storage reservoirs in the Hills, if operated on a plan for keeping the water surface as nearly as possible up to spillway level, will have only slight effect on flood flows, and because of evaporation will reduce the total water supply to the Plains. In the drier years this would make no difference as water would not reach the Plains anyway. In the wetter years evaporation would reduce the water supply to the Plains by only a negligible proportion. In the years of intermediate or poorly distributed precipitation reservoir storage will reduce the net water supply to the Plains unless water release is greater than inflow. Appreciable drawdown of the reservoirs to maintain stream flow would affect their esthetic and recreational value. Under present conditions, release of enough water to overcome losses in the limestones would be an unjustifiable wastage. If the zones of loss were successfully sealed, there would remain the problem of resolving the conflict in part of the years on the most beneficial use of water as between recreational values in the Hills and irrigation potentialities in the Plains. With the exception of Sheridan Lake and Stockade Lake the existing reservoirs are not large enough to have much effect one way or another.

Considering the high cost of reservoirs in the Hills, per acre-foot of storage, and the smaller water yields of these streams compared with Rapid Creek, it seems likely that agricultural benefits would support only a small part of the cost of reservoir construction. If the reservoirs are justified primarily for recreational values, they should, of course, be operated primarily to best serve recreational purposes.

SPRING CREEK SEALING PROJECT

The Spring Creek sealing project appears to have originated from fears of irrigators down the valley that construction of Sheridan Dam would so regulate the flow of the stream that the quantity of water released would at all times disappear in passing the limestone formations.

The first recorded sealing work was done by a Forest Service crew during the last week of September 1937 near the upper end of the zone of loss. The first recognizable sink was plugged with earth by a 10-man crew working 10 hours. This permitted the water to run 1,800 feet farther where it disappeared in a cave. A by-pass was then constructed around the cave and the water then continued 1000 feet farther, being finally absorbed in the alluvium. The flow during the last week in September was only 2 to 3 second-feet. This appears to have been all the work done at this time as insufficient water was available for testing sinks farther downstream.

The principal sealing working was carried out over a period of 14 months in 1939 and early 1940 by a W.P.A. project under the technical supervision of the Forest Service. The location of the main areas of treatment is shown in Figure 4. Three principal types of work were done.

1. Removal of overburden from the limestone on the bed or banks where visible leaks occurred, and replacement with sand or soil interlayered with clay or bentonite, with protection on the surface secured by hand placed riprap.

2. Removal of two to three feet of the bed where the alluvium appeared to be pervious and replacement with a similar impervious channel lining protected on the banks by riprap.

3. Construction of dikes to divert the stream away from visable leakages into old, relatively impervious channels, which were generally improved by some excavation.

The impervious seal was effected generally by placing a 6-inch layer of sand or loam, covering this with a 1-inch layer of bentonite or clay, and covering this layer by another 6 inches of sand or loam. On top a riprap layer consisting of selected blocks of sandstone or limestone from the bordering cliffs, or boulders from the alluvium, was hand placed to form as tight a pavement as possible without cement. The riprap blocks were generally 12 to 18 inches in diameter. Approximately 100 tons of bentonite was used in the sealing layer. After it was exhausted clay from a bed on Spring Creek was hauled in for a substitute.

The project was carried out entirely by hand labor except for use of a RD-6 bulldozer for about 10 days in channel reconstruction around the "cave" near the upper end of the zone of loss.

At two places water was observed in May 1944 to be disappearing through the riprap, indicating that the sealing layer at these points may not have been sufficiently thick or impervious.

The riprap has withstood successfully all flow during the past 4 years. It is unofficially reported that 4 feet of water was discharged over a 40-foot ogee spillway at Sheridan Lake in 1942. This indicates a discharge somewhat higher than the evidence observed along Spring Creek would suggest, but the channel may have passed considerably more than 100 second-feet without damage.

Although the WPA records are no longer available, it is unofficially reported that $28,000 was allotted to the project. Mr. Powell states that the total cost of the work was probably about $40,000.

EFFECT OF STREAM SEALING ON ARTESIAN AND GROUND WATER SUPPLIES

The recognizable water loss into bedrock formations occurs as streams cross the outcrops of the Englewood limestone, Pahasapa limestone and Minnelusa formation. Any loss of surface flow below these formations represents, at first, an addition to groundwater flow through the valley alluvium. Slow losses from the alluvium to underlying formations may occur, but there is no ready method of determining the extent of such losses. The Pahasapa and Minnelusa formations are only slightly developed and the Englewood not at all as artesian water supply sources because of their great depth at a distance of a few miles east of the Black Hills. The principal artesian water supply of western and central South Dakota and adjacent parts of neighboring states comes from the sandstones of the Dakota group of formations. The top of the Minnelusa formation is about 1000 feet below the base of the Dakota group.

Sandstones of the Minnelusa formation have furnished copious supplies of artesian water in a few wells. The Bear Butte Well (SW 1/4, sec 18, T. 6 N., R. 6 E.) about 5.5 miles north and east of Sturgis, which was originally drilled as an oil test hole to a depth of 690 feet and abandoned because of the large quantity of water was reported (11) to flow 3000 g.p.m. at the time of drilling. On July 31, 1935 it was running wild with a flow of 700-800 g.p.m. A well 1225 feet deep at St. Martin's Academy in Sturges, drilled in 1935, yielded water of good quality and quantity by pumping. Seven or more wells at Spearfish 275-700 feet deep obtain water from the Minnelusa.

The Rapid City Municipal Park well (NW 1/4 sec. 9, T. 1 N., R. 7 E.) drilled in 1935 to a depth of 1463 feet passed through the Minnelusa formation at 920 feet was extended down to the Deadwood formation. The initial flow from the Minnelusa was about 300 g.p.m. Other wells obtaining water from the Minnelusa are (1) at the lime plant (SE 1/4, sec. 28 T. 2 N., R. 7 E.) 250 feet deep ending in the Minnelusa, which flows about 00 g.p.m., (2) in the NE 1/4 of sec. 28 which obtains a similar supply from a depth of 205 feet, and (3) in the SW 1/4 sec. 34, nearly a mile southeast of the second, which is 500 feet deep and flows about 60 g.p.m.

The new deep wells at the Rapid City Airport pass through the Minnelusa, which was reported to be "tight" and yielded much less water than the underlying Pahasapa. Two deep wells drilled farther east for oil passed through the Minnelusa. The Hunter No. 1 well drilled by the Gypsy Oil Co. in 1931 in eastern Pennington Co., 50 miles directly east of Rapid City (SW 1/4 sec. 28, T. 3 N., R. 16 E.) passed through the Minnelusa at depths of 4820 to 4490 feet. Water from the Minnelusa was under less pressure than that from the Pahasapa but water raised 3850 feet from a depth of 4855 feet.

The Standing Butte Well in Stanley County (sec. 9, T. 7 N., R. 27 E.) passed through the Minnelusa between 2615 and 3027 feet. Flowing water was obtained from the formation, but the quantity is not recorded.

The only wells in which the water supply is reported to come from the Pahasapa formation are the two new wells at the Rapid City airport. (3) Well No. 1 was drilled to a depth of 4645 feet ending in the basal Pahasapa or upper Englewood. The static level of water from the Pahasapa was 543 feet below the casing head. The temperature of the water was 121° F. Well No. 2 was drilled 4436 feet deep ending near the base of the Pahasapa. Tests of samples of the Pahasapa from these wells were said to show fairly high porosity owing to recrystallization and dolomitization. No evidence of open fissures or crevasses were found in these wells. The cavernous zone of the limestone probably extends to depths measured in hundreds rather than thousands of feet from the surface.

It seems doubtful that much lateral migration of water takes place in these formations near the Hills. They are taking in water along their exposures entirely around the Hills. This water would naturally tend to move down the dip at all points unless deflected by structures or major fissures and caverns. There are no known structures along the eastern front of the Hills which would tend to deflect the water movement away from a direction normal to the strike of the outcrop belt. Therefore, wells at Sturgis would tend to be supplied by water percolating into the formation north of Elk Creek. Wells at Rapid City would tend to be supplied by percolation in the Rapid Creek watershed. There are no wells drilled to these formations directly down the dip from outcrops on the streams under consideration.

Furthermore, the amount of water obtained from existing wells is but a very minute fraction of the water entering these formations from stream flow and percolation along the outcrop. It is concluded, therefore, that sealing the stream beds across the outcrop of the Englewood, Pahasapa and Minnelusa formations would have no effect on existing developments of artesian water supply.

The alluvial valley on all of the streams extends up to or nearly to the outcrop of the Minnelusa. Stream sealing through the alluvial valley section of these streams would be impracticable under any circumstances. The entire channel would have to be made impervious to prevent seepage losses. This would prevent seepage gains, which increase the stream flow from place to place. It would be cheaper to convey water by canal, flume or pipe from the upper end of the alluvial valley to points of irrigation than it would to attempt to seal the natural channels.

The effect of sealing in the zone of loss would be to increase the water reaching the alluvial valley. This would tend to sustain or increase groundwater supplies in shallow wells. If any water is percolating from the alluvium into the sandstones of the Dakota group, the sealing work above would tend to increase the supply of water available for percolation, and would therefore tend to increase the recharge of the principal aquifers of the state. It is the opinion of the writer, however, that this effect would be negligible. Although no quantitative comparison can be made, it seems probable that the amount of water entering the Dakota sandstones along the short reaches of stream channels crossing them is only a small fraction of the water they take in along their outcrop directly from preciptation.

Stream sealing in the zone of loss might decrease or stop the flow of some springs that issue from bedrock such as those on Boxelder Creek. As none of these springs are utilized independently of stream flow, the only effect would be that of maintaining the flow on the surface rather than through underground channels.

USE OF WATER

Two classes of benefits have been claimed for stream sealing. (1) that if permanent flow could be maintained from the Hills to the Cheyenne River, about 150 miles of stream channel could be stocked with fish and that this would add to state revenue and local income from tourist trade, (2) that the resulting increase in stream flow would overcome deficiencies of stockwater supply and would increase the area irrigated and hence agricultural income.

Undoubtedly the progressive State Game and Fish Commission would amply stock the streams if permanent flow were assured. This would increase the recreational and tourist assets of the area. It would be difficult to evaluate the monetary benefits involved without a comprehensive economic study. It must be borne in mind that even if the streams were successfully sealed through the zone of loss, there would not be a continuous flow to the Cheyenne in about 25 per cent of the years. On the other hand, the dry years appear to run in cycles, most of them being concentrated in the 1890's and 1930's. Thus, while restocking would be necessary following dry years, stream sealing, over a long-term period, would increase the number and length of periods of successive years of sustained flow. The benefits to fishing, and to some extent to other wildlife, would probably be the most important benefits from stream sealing.

A thorough economic evaluation of the agricultural benefits from stream sealing could not be made as part of the present investigation. Such a study would be the first requirement, however, in determining the expenditure that could be justified from this standpoint.

Most of the ranchers use stream flow, when available, for livestock water but water can be developed at not too much expense from shallow groundwater wells and stock ponds. Not a very large value, on the whole, could be placed on stream flow for livestock water if alternative sources can be developed at not too great expense.

The extent of past and present irrigation, the extent of water appropriation and the general type of water use in the several valleys was determined by hasty reconnaissance, review of pertinent reports and from questionnaires sent to landowners by local Soil Conservation Districts. The general situation in each valley is as follows:

Elk Creek

The 1940 Census report (12) shows that, in 1939, 36 farms along Elk Creek reported irrigation on a total of 325 acres, of which 275 acres were listed as pasture (hay or alfalfa) and 50 acres as harvested cropland. The total irrigable area in the enterprises was reported as 2473 acres, of which all but 7 acres could be served by existing ditches. The cost of these irrigation works is given as $20,300 or $8.23 per acre. Irrigation was entirely by diversion of natural stream flow by relatively inexpensive diversion dams. The water delivered that year was only 110 acre-feet or 0.4 acre-foot per acre irrigated. The cost of water per acre was $1.56 and per acre-foot $3.89. The maximum beneficial use of water is between 3 and 4 acre-feet per acre.

Water rights on Elk Creek in 1940 totalled 396.16 second-feet or many times the average annual water supply. The area reported under irrigation in 1909 was 75 acres, but projects then under development were expected to bring the area up to 802 acres by 1913. (5)

Fourteen landowners who returned questionnaires in the summer of 1944 reported a total of 870 acres under irrigation this year out of a total of 1920 acres under ditch. As they represent about 45 percent of all the landowners in the valley, but include the principal irrigators it is concluded that about 1000 acres was under irrigation in this year of relatively good runoff compared with only 350 acres in 1939. It is further concluded that the maximum acreage under ditch at one time or another is about 3000 acres.

Of the land reported under irrigation in 1944, 52 percent was in hay and wild grass, 39 percent in alfalfa, 40 acres in small grain and 40 acres in corn.

Boxelder Creek

The first settlement was made on lower Boxelder Creek in 1877 and by 1882, 4000 acres were under cultivation. The first irrigation ditch on the creek is reported to have been dug in 1886. Twenty landowners who returned questionnaires in 1944 reported a total of 290 acres under irrigation, and 1230 acres under old ditches. Approximately 52 percent of the irrigated land was in alfalfa and most of the remainder was in hay.

The 1940 Census report shows less than 100 acres irrigated in 1939, and no land was irrigated in 1940. The maximum acreage ever under irrigation on Boxelder Creek is estimated to be 2000 acres. Water has been appropriated to the extent of 165 second-feet, several times the long-term average annual flow of the stream.

Spring Creek

The first settlements were made on lower Spring Creek in 1877 and 3000 acres of land were under cultivation in 1882. The principal irrigation project on this stream is east of Hermosa on the land of Ferdinand Reub and adjacent landowners. The ditch for this project was constructed in 1909 and at present can supply water to 2200 acres. Irrigation was almost continuous up to 1930; some land was irrigated in 1935; and the works were put in operation again in 1941. Six out of 14 questionnaires returned in 1944 showed 858 acres under irrigation. Hay and wild grass was grown on 60 percent of irrigated acreage, wheat on 17 percent, alfalfa on 10 percent and small grains and corn on the remainder. There is no irrigation of consequence above this project. There is one old system below covering about 2000 acres, which may be reconditioned if some land transfers are consummated.

In 1939, according to the Irrigation Census, there were 20 irrigation enterprises on Spring and Battle Creeks combined. A total of 764 acres was irrigated on the two creeks in that dry year; 327 acres of cropland was harvested, 247 acres had crop failures and 190 acres of pasture was irrigated. The irrigable area in the enterprises was 5,455 acres, of which much more than half was on Spring Creek. The investment in irrigation facilities of these enterprises was $29,363 or $5.38 per acre. The average cost per acre irrigated in 1939 was $0.69 and the cost per acre-foot of water was $1.99. The average application of water was only 0.5 foot. Appropriations of water from Spring Creek total 850.70 second-feet, of which 272.55 second-feet were appropriated for irrigation and 150.95 sec.ft. for mining since 1907. Although flow used for mining largely returns to the stream, the total appropriation is many times the average seasonal flow.

The estimated maximum area irrigated in the past is 5000 acres.

Battle and Squaw Creeks

On Squaw Creek there are four irrigation enterprises, in addition to which the farm lying in the confluence of Squaw and Battle Creeks takes part of its flow from each stream. Irrigation is mainly for hay and alfalfa with some truck crops. Except in the driest years these farms are said to receive most of the water required for irigation of land now equipped with facilities. The maximum area irrigated on Squaw Creek is estimated to be 250 acres.

The first settlements on lower Battle Creek were made in 1877. In 1909 the area irrigated (including Squaw Creek) was reported to be 148.66 acres, with facilities under construction to irrigate an additional 461.70 acres. (7) The 1939 census figures, combined with Spring Creek are given above. In 1940 the irrigated area was reported to total 250 acres including Squaw Creek. The maximum acreage irrigated in the past is reported to have been about 2500 acres, largely in the vicinity of Hermosa. Diversion was entirely from low wooden or earth and rock dams. The total water appropriated is 435.50 second-feet, far more than the normal supply. Only a limited amount of irrigation was underway in 1944, but numerous old ditches were in evidence. The maximum area irrigated on Battle Creek is estimated to be 1000 acres.

French Creek

No irrigation on French Creek has been recorded in official reports. Returns from 7 out of 18 questionnaires in 1944, however, showed 590 acres under irrigation on these farms, of which 53 percent was hay, 36 percent small grains, and the remainder in alfalfa and miscellaneous crops.

Some local residents have estimated that 2000 acres or more have been irrigated on French Creek at one time or another.

VALUE OF WATER FOR IRRIGATION

The United States Army Engineers in their "308" report (14 p.33) on the Cheyenne River concluded that the average maximum charge that can be carried by any project in this region for irrigation facilities, including operation and maintenance, is $3.50 per acre. They report that according to local opinion $30 or $35 per acre was the maximum first cost that the land could carry. These figures are based on the assumption of a "full irrigation supply" estimated to be 1.8 acre-feet per acre at the field with a 40 per cent loss in transmission. This is equal to a requirement of 3 acre-feet per acre in the stream, or a value of water in the stream of $1.17 per acre-foot.

The Bureau of Reclamation has arrived at substantially the same conclusion (13). On the basis of water use on the Belle Fourche Irrigation project the farm delivery required for a full irrigation supply on the Rapid Valley project was estimated to be 1.95 ac.ft./ac. Water losses in main canals and laterals were estimated to average 35 per cent of diversions, so that the average diversion requirement would be 3.00 ac.ft./ac.

The 1940 census (12) shows that in Rapid Valley, where the irrigable area in enterprises is 15,176 acres (including a small acreage on Boxelder Creek) the investment in irrigation facilities is $134,820, including $4,000 for water rights. This is equal to $8.94 per acre in the enterprises. The average annual charge per acre assessed was $0.62 and the cost of operation and maintenance $0.35, or a total water charge of $0.97 per acre. The cost of 10,875 acre-feet of water actually delivered to 6,327 acres in 1939 was $0.74 per acre or $0.43 per acre-foot. In Battle and Spring Creeks fixed charges, operation and maintenance of enterprises was $1.43 per acre. The cost of water actually delivered is given as $0.69 per acre or $1.99 per acre-foot.

An analysis of agricultural production records from Rapid Valley in connection with the development of storage facilities indicated that farmers could afford to pay $2.50 per acre for supplemental stored water to assure a full irrigation supply. As present payments average about $1.00 per acre, this would increase the payment to the average maximum cost that projects in this area can sustain, according to U. S. Engineer estimates. Farmers in Rapid Valley are said to have evinced a willingness to pay $1.00 per acre-foot for supplemental stored water, or almost as much as the average practicable limit.

The foregoing estimates are based on an assured supply from reservoir storage to be made available at the times needed during the irrigation season. Without reservoir storage, operated for irrigation purposes, in the valleys under consideration what would be the economic benefits of stream sealing?

In the first place it is not likely that any appreciable expansion would occur in the maximum acreage that has been irrigated in the past. The maximum acreage represents the area irrigated only in the years of heavier runoff. The greater the runoff the smaller is the percentage lost in the limestone sinks. The effect of sealing would be primarily to increase the percentage of years in which the maximum acreage would receive a full water supply. Assuming that this acreage has senior water rights, it would be generally too expensive for other farmers to install facilities to utilize water in the years of higher runoff when it would be available. On the basis of runoff data previously cited, it appears that the maximum irrigated acreage or the senior rights would receive ample or almost ample water without a sealing project in 40 percent of the years, and insufficient or no water in 25 percent of the years. With a sealing project the senior rights might receive a full or nearly full supply in 75 percent of the years. The junior rights or additional acreage, even if irrigation facilities were installed, could expect to receive sufficient water in no more than 40 percent of the years. Under these conditions it is doubtful whether many, if any, new facilities would be installed. Some of the old systems might not even be reconditioned.

If the benefits of supplemental water, considered on the basis of averages, would occur in only 35 percent of the years, and if the water were worth $2.50 per acre in these years, (or $0.833 per acre-foot at 3 acre-feet per acre in the stream) then the farmer could afford at most only 35 percent of this value or $0.29 per acre-foot to assure this supplemental supply.

This assumption, however, would extend every benefit to doubt in favor of a maximum value of supplemental water, because it implies that in the 35 percent of marginal years water would be received as needed during the irrigation season. This would not be the case without reservoir storage. Therefore, the value of water would presumably be worth less than supplemental water in Rapid Valley where reservoir storage will assure needed seasonal distribution. Offsetting this to some extent but not entirely is the fact that stream sealing would assure a better distribution of water in the 40 percent of years when the total supply is adequate.

Without allowing any charges for reconditioning of irrigation facilities or other costs such as land levelling incident to obtaining the advantage of this supplemental water, the installation and future maintenance of the sealing project for irrigation might warrant an expenditure not greater than the capitalized value of $0.29 at 4 percent interest or $7.25 per acre-foot of water saved. This would certainly seem to be the maximum value that could be claimed, and a comprehensive study might indicate a considerably smaller value.

COSTS OF STREAM SEALING AND RELATION TO BENEFITS

Without detailed surveys of the zone of loss on each stream, it is not possible to make specific cost estimates for the various methods that might be used to prevent water loss into the limestones. Only the order of magnitude of costs can be given on the basis of present information.

Installations of pipe or flume to carry 25 second-feet of water through the zone of loss would cost at least $10 per linear foot or $50,000 per mile. Pipes or flumes would have to be supported on the valley slopes, or a very expensive type of pipe would have to be laid along the stream to prevent excessive damage by floods. The cost of making the entire channel impervious with surfacing of a permanent nature, such as concrete lining, would be considerably more than the cost of piping or fluming. Even a concrete lined channel would require constant maintenance, such as removal of boulders.

The only type of project that might be developed within costs anywhere near proportial to the benefits received would be similar to that on Spring Creek. Limitation of this type of project to reasonable cost would be contingent on finding that most of the water loss occurs at only a few points along the stream. There is no positive evidence that this is the case. It may be inferred from the work on Spring Creek that much of the former loss has been prevented by treatment of a relatively small proportion - less than 10 per cent - of the total length of stream through the zone of loss. This work is reported to have cost approximately $40,000. If it were assumed that the job might have been accomplished somewhat more economically per unit of treatment by using force account labor and earth-moving equipment, wherever possible, the cost of a comparable job might be estimated at $30,000 or approximately $6,700 per mile.

The Spring Creek work would not be permanent on a stream lacking flood-control storage. It would be subject to heavy damage by floods having an average frequency of once in 10 years or less; and to more gradual attrition as shown by losses through the riprap in at least two places. If such work is to be permanently maintained it would be advisable to allow a future maintenance cost of not less than $670 per mile per year.

The cost of detailed surveys of the streams and preparation of plans for treatment would be at least $100 per mile. The cost of determining specific points of water loss is estimated at $500 per mile on the assumption that 10 temporary installations of a Parshall flume would be required per mile at a cost of $50 per installation. Because of the irregular nature of the channel, and the large amount of boulders there are few sites where discharge can be measured sufficiently accurately with a current meter to detect losses of ¼ to 1 second-foot from a flow of 10-20 second-feet. This cost could be reduced, or perhaps eliminated, by careful study of the points of disappearance of flow during the late summer and fall over a period of serveral years.

In summary, if it were necessary to contemplate early construction of stream-sealing projects the average minimum costs to be considered would be:

	Per mile
Surveys and measurements	$600
Construction	6,700
Total initial cost	7,300
Capitalized annual maintenance $670 per mile 4%	16,750
Overall cost per mile	$24,050

The costs on Battle Creek may be somewhat below average because of the natural sealing that has resulted from placer mining operations.

Based on the measurements from Rapid Creek and estimates for Spring Creek the unpreventable loss from seepage, evaporation and transpiration through the zone of loss would be not less than 1 second-foot per mile or 303 acre-feet per mile for the 5-month irrigation season.

On all of the streams this loss would amount to more than the average gain from tributaries entering through the zone of loss plus the net gain from springs, if allowance is made for the probability that much, if not most, of the spring flow is a return of water lost within the zone.

In all cases if tributary flow exceeded the unpreventable loss, the corollary would be that runoff per square mile on the tributaries was greater than in the crystalline area. As most of the tributary watersheds are in the limestone where surface percolation as well as channel loss is known to be high this corollary appears untenable. At most, therefore, the water that could be saved would not exceed the yield of the crystalline area. On some streams it would be less for another reason, namely, that part of the flow in average years already goes through the zone of loss. This appears to be true of French Creek, because the zone is not long and the flow is relatively large, and on Battle Creek partly for the same reason and partly because of natural sealing.

These factors are cited to show that probably on all streams the useful supplemental water would be less than the average water yield of the crystalline area. Table 6 gives a comparison of the estimated cost of treatment on each stream with the estimated value of water for irrigation, assuming that the net average water yield of the crystalline area is now lost, but could be entirely saved by sealing. This analysis, it is believed, places the benefit of every reasonable doubt in favor of the maximum amount and value of water saving from sealing.

Table 6 shows an unfavorable ratio of costs to agricultural benefits for all the streams. The ratios are close enough for Spring, Battle and French Creeks, however, that the additional benefits from fishing might be found to give a favorable aspect to the project. On Spring Creek the job is one of maintenance of work already installed with probably some additional treatment. The cost of treatment on Battle Creek may be lower than the average because of the extent of natural sealing.

TABLE 6 COMPARISON OF ESTIMATED COSTS OF STREAM SEALING WITH ESTIMATED CAPITALIZED VALUE FOR IRRIGATION OF AVERAGE WATER YIELD ABOVE ZONE OF LOSS

Stream	Length of Zone of Loss	Estimated Initial Cost of Sealing 1/	Estimated Capitalized Maintenance Cost 2/	Estimated Total Cost	Estimated Average Water Yield Above Zone of Loss	Estimated Capitalized Value of Water Saved at $7.25 per acre-foot 3/
	Miles	Dollars	Dollars	Dollars	Ac.-Ft.	Dollars
Elk Creek	12.27	89571	205522	295093	1160	8410
Little Elk Creek	1.82	13286	30485	43771	810	5872
Boxelder Creek	11.84	86432	198320	284752	5500	39875
Spring Creek	4.6	-----	77050	77050	8740	63365
Battle Creek	3.58	26134 4/	59965 4/	86099 4/	3430	24867
Squaw Creek	4.54	33142	76045	109187	1360	9860
French Creek	2.17	15841	36347	52188	5300	38425

1/ Based on $7300 per mile.
2/ Based on $16,750 per mile.
3/ Based on the assumption that all of the water yield is now lost and all would be saved by sealing. This is the maximum possible value and exceeds the true value in all cases as explained in the text.
4/ The cost on Battle Creek may be smaller than average because of the natural sealing which has resulted from placer mining.

The cost of treatment on Elk and Boxelder Creeks is out of all proportion to possible agricultural and fishing benefits because of the length of the zone requiring treatment. The ratios of costs to benefits on Little Elk and Squaw are also highly unfavorable because of the small water yield as compared with the length of zone to be treated.

ADDITIONAL INVESTIGATIONS NEEDED

Before a final evaluation can be made of the feasibility of stream sealing projects for French and Battle Creeks, or additional work and maintenance on Spring Creek, several investigations will be required:

Evaluation of Agricultural Benefits

An economic study should be made of the value of increased stream flow to farmers and ranchers in the valleys under the conditions described in this report. This investigation should attempt to determine the expenditure justified in the light of prospective benefits. Factors to be appraised include (1) the value for stockwater of increased stream flow as compared with shallow well development in the valleys and stockwater ponds in the adjacent Plains (2) the area of land that would be irrigated in the present farm units and the increased return to the landowners if water were available 3 years out of 4 on an average (3) the willingness of landowners to make fairly large capital outlays for substantial diversion dams necessary to withstand flood flows and to accept charges for part of the stream-sealing costs.

Evaluation of Recreational Benefits

An effort should be made to place some monetary value on the recreational benefits of maintaining stream flow. This evaluation should be supported insofar as possible by data on additional tourist trade that might be expected, additional revenue to be anticipated from fishing licenses, etc. Factors that sould be considered are (1) whether the permanent streams and lakes in the Central Black Hills can be made to support all the fishing that may be expected from tourists after the War (2) whether fishing in the Plains below the Hills would be attractive to tourists as compared with the Hills area, and whether fishing on private lands would be permitted (3) whether landowners in the Plains would obtain substantial amounts of food, revenue or pleasure from fishing in these streams.

Determination of Priority of Water Rights

The status of water rights on Spring, Battle and French Creeks seems to be very confused, as a result of long disuse of many rights and legal uncertainties involved in the state laws of South Dakota. The determination of water-right priorities by the State Engineer and the adjudication of any disputes would seem to be essential before any

Federal aid was extended in the development of projects to promote irrigation.

Detailed Surveys of the Zone of Loss

Before a determination can be made of the actual cost of sealing operations on Battle and French Creeks, detailed surveys must be completed. The cost of such surveys could not be justified until the prospective agricultural and recreational benefits from stream sealing were determined through appropriate investigations. In addition to surveys from which estimates can be made of the yardage of material to be moved, the yardage of channel to be made impervious, and other costs, it will be necessary to determine the exact location of places of loss.

Stream Gaging

Any program that will assure the most beneficial use of water resources is dependent on accurate knowledge of stream flow. Any developments on these streams at present must be based to a considerable extent on assumptions that cannot be verified. The first step in the ultimate solution of the problems of these streams should be the establishment of gaging stations just above the zone of loss, and preferably of additional stations just below this zone or near the head of the alluvial valley.

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