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WINTER ICE JAMS ON THE GUNNISON RIVER

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The formation, transport, and accumulation of ice is an annual occurrence on many rivers. This report summarizes winter observations conducted on a mountain river in the State of Colorado. The Gunnison River observations were conducted along the 14-km reach of river from the Blue Mesa Reservoir upstream to the city of Gunnison, Colorado, at an elevation of 2300 m. Several variables affecting ice jam formation, such as channel morphology, climatological data, upstream and downstream reservoir operation, and river snagging and clearing operations are analyzed for the river reach observed.

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WINTER ICE JAMS ON THE GUNNISON RIVER

by

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February 1979

Hydraulics Branch
Division of Research
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Denver, Colorado

SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR • BUREAU OF RECLAMATION

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Winter 1970-71

Vern Jetley–Project photographer.

Winter 1972-73

Bruce Bartleson–Professor, Western State College, Gunnison, Colo.

Winter 1973-74

Charles Donoho–Student, Western State College, Gunnison, Colo.

Winter 1976-77

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GLOSSARY

Frazil ice.–A group of miniscule ice crystal particles which grow to form larger masses of ice. It forms in turbulent supercooled water.

Active frazil ice.–The newly formed frazil ice particles are very "active" and will agglomerate to form larger frazil slush ice, or will adhere to underwater objects. This stage of development may last only a few minutes.

Frazil slush ice.–Frazil ice becomes inactive once the river water has returned to 0 °C from the supercooled state. The frazil slush ice floats to the surface and continues to grow from atmospheric heat exchange.

Ice cover.–A continuous shore-to-shore layer of ice in any form.

Sheet ice.–A solid, continuous ice cover formed on calm water surface.

Ice jam.–An accumulation of river ice, in any form, which obstructs the normal riverflow.

Cumulative sum of degree-days.–(As used in this report): $S = \Sigma[0\ °C - (T_{max} + T_{min})/2]\,(D)$ where D is the number of days since the start of ice formation. T_{max} and T_{min} are the maximum and minimum daily air temperatures in degrees celcius, respectively.

Supercooling of water.–This occurs when water loses heat to the atmosphere, producing a temperature below freezing. Supercooling of river water normally will not go below −0.05 °C. The supercooling of water stops when the heat of fusion of ice formation produces an increase in the water temperature.

INTRODUCTION

The formation of ice on a body of water is primarily dependent on the thermal exchange between the water surface and the cold atmosphere. It is also a function of other variables including wind speed, relative humidity, and radiation.

The formation, transport, and accumulation of river ice are annual, natural phenomena. When the water is cooled to 0 °C, ice starts to form at the air-water interface and turbulence of the water determines the type of ice produced. Turbulent flow produces frazil ice,[1] and tranquil or no flow produces sheet ice. A river ice jam forms and grows upstream from a reservoir by consolidation of ice slabs, and by accumulation of frazil slush ice which has floated down the river. Main channel water sometimes comes out onto the ice at the head of the ice jam. An ice jam sometimes forces the water out of the natural river channel and causes flooding.

Most rivers pass through the annual ice formation and breakup process without causing damage. Other rivers are such that frequent ice jams are produced which result in flooding; this causes damage to the river channel and structures along the river. Often the water surface elevation produced upstream from these ice jams is higher than that caused by normal spring floods. This report summarizes observations of ice formation along the Gunnison River in Colorado throughout a 6-year period.

The Gunnison River, a principal tributary of the Colorado River, is formed by the confluence (fig. 1)[2] of the Taylor and East Rivers at Almont, Colo., about 16 km upstream from Gunnison, Colo. From there it flows about 210 km to the confluence with the Colorado River at Grand Junction, Colo. The observations were conducted in the 14-km river reach from the Blue Mesa Reservoir to the highway bridges close to the southwest of Gunnison, Colo. This river reach has an average elevation of 2300 m above sea level.

[1] Several word definitions are listed in the Glossary.
[2] All figures are at the end of the report.

CONCLUSIONS

- The Blue Mesa Reservoir water surface elevation, at the end of November, is an important factor in determining the location of the ice jam head at the start of the winter season. A direct relation was established between this location of the ice jam, and the Blue Mesa water surface elevation. For every additional meter of reservoir elevation, the ice jam started about 280 m farther upstream. In 1970-71 and 1973-74, the jams started out close to Beaver Creek (the highest starting location of the six recorded years) due to relatively high reservoir elevations.

- The clearing and snagging operations completed in the fall of 1970 resulted in little, if any, increased capability of the river channel to carry the ice load.

The additional clearing and removal work performed in September 1971 provided a large area for the ice to collect, rather than filling the upsteam river channel, and proved to be more useful. The winter of 1973-74 was similar in many respects to the 1970-71 winter, but the ice jam was about 2 km shorter. The portion of this work which proved most efficient was in the delta area at the east end of the Blue Mesa Reservoir. The delta formation constricts the flow passage into the reservoir, and along with the reservoir ice cover restriction, creates the start of the ice jam in early winter. Periodic removal of the delta sediments at the upstream end of the reservoir may be required.

- There is good correlation between the upstream progression of the ice jam and an average temperature below minus 10 °C. About 420 degree-days from the time ice first forms on the reservoir, a solid ice cover (fig. 20) insulates the majority of the upstream water surface, and the upstream progression of the ice jam is halted. The upstream progression during the 1972-73 winter stopped, after only 300 degree-days, by December 20, 1972. However, this early halt to the ice progression resulted from the "intermittent flow channel" and permitted the frazil ice to pass through the ice cover. The Gunnison River ice jam usually has stabilized by January 10.

- Large releases from Taylor Park Reservoir during periods of cold weather have added to the ice jam problem in the study reach. These large releases have increased the quantity of frazil ice in the river channel. Releases were, therefore, limited to 2.8 m³/s during the critical season. Consequently, in the fall, the Taylor Park Reservoir water surface elevation is lowered to accommodate winter inflows to the reservoir and limit the releases to 2.8 m³/s.

REVIEW OF THE LITERATURE

Bureau personnel studied the upper Arkansas River, Colorado, in 1966 [1][3] and attempted to estimate the changes in the ice formation of the river for discharges greater than the natural flow. Transmountain diversions were expected to triple the natural riverflow from 5.7 to 17.0 m³/s during the winter months. The ratio of ice-to-water was found to be less at the higher project flow than with the historic natural flows, resulting in improved ice passage.

Bolsenga [2] in an extensive review of river ice jams, lists 74 bibliographic references to river ice observations in North America and Eurasia.

Calkins [3] described a study to identify reaches of the Connecticut River near Windsor, Vermont, having a high potential for ice jams. A number of interacting conditions were identified as being responsible for initiating the frequent ice jams on that river.

McFadden documented observations of ice breakup on the Chena River, Alaska, in the spring of 1974 [4] and again in 1975 and 1976 [5]. Their observations were made to determine the potential ice and debris damage to the outlet structure of a proposed flood control dam on that river. Observations included measurements of ice thickness, river stage and discharge, water temperature, and velocity measurements under the ice.

Doyle [6] documented the 1977 spring breakup and resultant ice jam on the Athabasca River at its confluence with the Clearwater River in Alberta. This report describes the various factors involved in the jam and subsequent breakup, and provides a good example of the type of observations and analysis needed to standardize field observations.

In a paper describing observations of four ice jams in Alberta, Canada, Gerard [7] presents an ice jam classification system used there. His paper includes four summaries of ice jams detailing the specific meteorology, channel morphology, and ice conditions at each site.

A report by ECI (Engineering Consultants, Inc.) [8] describes the flood plain of the Gunnison River.

A method of predicting ice formation on a river was presented by Williams [9] who calculated heat loss from the open water surface. He summarized 20 years of observations at a powerplant on the Ottawa River in eastern Canada, and correlated frazil ice occurrence with surface heat loss. Frazil ice was a problem on the Ottawa River when the rate of heat loss averaged more than 30 (cal/cm²)/h over 12 continuous hours. He also found that frazil ice formed at or below −10 °C air temperature when the wind averaged 4.5 m/s, but required air temperature at or below −22 °C when the wind averaged 2.25 m/s.

In late fall when the ice cover has just begun to form and there are still large areas of open water surface, large quantities of frazil ice are produced during spells of cold weather (air temperature below −10 °C). As the winter progresses, sheet ice grows out from the riverbanks (fig. 19), the surface heat loss is less, and frazil ice is not produced. Frazil ice production in fast-flowing mountain streams is the dominant process in the early winter.

ICE JAM STUDY REACH

Taylor Park Reservoir

Taylor Park Reservoir is on the Taylor River approximately 40 km northeast of Gunnison, Colo. It is the only storage reservoir upstream from Blue Mesa Reservoir which can affect the flow in the Gunnison River study reach. Due to inflow to the reservoir, releases are normally made throughout the winter; however, depending on the storage available, releases from the reservoir can be less than the inflow.

[3] Numbers in brackets refer to literature cited in the bibliography.

The Gunnison River Reach

These observations were conducted along the 14-km reach of the Gunnison River starting at Steuben Creek and extending to the U.S. Highway No. 50 bridges (fig. 2) southwest of Gunnison, Colo. Figure 3 describes the streambed profile over this reach of the river. The 2800-m reach from the highway bridges to the Tomichi Creek confluence has an S_o (average slope) of 0.0053. From the Tomichi Creek confluence to Blue Mesa Reservoir, the Gunnison River has an average slope of $S_o =$ 0.0035. Winter discharges in the Gunnison River average 4.3 m^3/s and Tomichi Creek averages 1.7 m^3/s at their confluence. The river cross section at the Dos Rios estate (fig. 4) and near Moncrief's Foot Bridge (fig. 5) are shown.

The report by ECI [8] describes the flood plain of the Gunnison River as a broad plain extending between hills. The alluvial land on this flood plain consists primarily of material deposited by the river, with a texture widely variable with many cobbles and stones. The river flows in a well-defined channel in the reach from the highway bridge to the Tomichi Creek confluence. Downstream from the Tomichi confluence the river slope is less steep and the river channel is less defined. The channel can be described as braided in the reach from the Tomichi confluence to Blue Mesa Reservoir.

Blue Mesa Reservoir

Blue Mesa Reservoir is at the lower end of the study reach. The water surface elevation of the reservoir to some degree influences ice formation in the Gunnison River during the winter months. The Blue Mesa Reservoir water surface elevations, during the winters under study since 1967 when it was first filled, are shown (fig. 6). Normally, the reservoir is held as high as possible at the start of the fall season and slowly drawn down throughout the winter months for power generation at Blue Mesa Dam.

Climatological Conditions

Due to the location in a mountain valley, at nearly 2300 m elevation, this reach of the Gunnison River is exposed to severe winter temperatures. Temperature readings taken at the Gunnison Airport (near the river) for the four winters of 1970-71, 1972-73, 1973-74, and 1976-77 are summarized in tables 1 through 4. The severity of the winters is evident; for 3 days (table 1) in January 1971 the maximum temperature was −18 °C or below, and the lowest was −38 °C. In the winter of 1973-74 (table 3), there were 77 days when the temperature rose above 0 °C only five times. The cumulative sum of degree-days:

$$S = \Sigma[0\ ^\circ C - (T_{max} + T_{min})/2](D)$$

was calculated for comparative conditions.

River Snagging and Clearing Operations

There have been several river channelization projects along this study reach of the Gunnison River. In 1965, dredging and channelization work was performed by a land developer along a 3.2-km reach immediately downstream from the highway bridges in the Dos Rios Island area. This upstream river channelization resulted in aggradation of the flatter downstream channel between the Tomichi confluence and Blue Mesa Reservoir.

During 1968 through 1969, the U.S. Army Corps of Engineers placed emergency dikes along the river channel upstream from the reservoir, past the Moncrief property; and from September to December 1970, they performed major snagging and clearing work (fig. 7) along the Gunnison River. This work was coordinated with the State Department of Game, Fish and Parks. The channelization work extended from the Blue Mesa Reservoir (near Beaver Creek) to 9 km upstream from Steuben Creek.

The U.S. Government, in 1971, purchased several properties along the river immediately upstream from Blue Mesa Reservoir including the Coopers and Neversink Resorts. In September 1971, the Corps of Engineers snagged and cleared the river channel farther into the reservoir. The dikes that were previously built in the Coopers and Neversink Resort areas were removed to provide more storage for the ice flows.

Table 1.—*Winter 1970-71 air temperatures, Gunnison, Colo.*

Day of month	November Max	November Min	December Max	December Min	January Max	January Min	February Max	February Min
	°C		°C		°C		°C	
1	9	-6	-1	-17	-7	-24	9	-9
2	6	11	-6	-17	2	-12	7	-1
3	6	-13	3	-12	-4	-14	1	-6
4	10	15	0	-16	-14	-22	-3	-20
5	9	8	2	-12	-18	-36	0	-8
6	14	-2	2	-18	-21	-38	-3	-18
7	7	-4	2	-17	-21	-38	-6	-17
8	4	-3	6	-13	-8	-29	2	-17
9	7	-12	2	-8	0	-18	-1	-21
10	1	-9	1	-8	2	-19	7	-17
11	6	-11	-2	-13	-2	-21	5	-4
12	6	-3	0	-19	1	-22	4	-14
13	5	-3	-2	-22	-1	-15	6	-13
14	3	-12	-2	-19	1	-11	9	-10
15	4	-16	0	-14	-2	-19	6	-10
16	8	-14	-2	-18	2	-15	6	-8
17	7	-12	6	-12	11	-6	9	-6
18	6	-5	-1	-6	9	-1	7	-2
19	2	-12	-6	-24	7	-6	3	-10
20	7	-15	-4	-17	8	-8	-1	-7
21	8	-14	-3	-22	5	-2	-7	-12
22	8	-2	-2	-13	2	-8	-2	-20
23	10	-3	-2	-17	0	-9	1	-16
24	14	-7	-2	-24	3	-13	2	-15
25	13	-9	-2	-23	7	-9	4	-14
26	5	-1	-7	-26	7	-13	-1	-14
27	6	-3	2	-12	7	-12	-7	-22
28	0	-12	-3	-20	6	-13	-6	-22
29	2	-10	-8	-27	9	-13		
30	1	-3	0	-21	10	-8		
31			-3	-23	13	-11		

Table 2.—*Winter 1972-73 air temperatures, Gunnison, Colo.*

Day of month	November Max	November Min	December Max	December Min	January Max	January Min	February Max	February Min
	°C		°C		°C		°C	
1	1	-8	3	-17	-8	-26	-4	-25
2	5	-8	1	-20	-13	-31	-7	-28
3	7	-9	2	-19	-12	-30	-9	-29
4	7	-9	2	-11	-6	-21	1	-14
5	8	-7	0	-12	-6	-21	3	-10
6	6	-4	-9	-28	-12	-29	-6	-20
7	8	-10	0	-24	-9	-26	-1	-18
8	6	-8	-1	-18	-11	-29	-1	-18
9	3	-8	-6	-13	-7	-19	0	-17
10	5	-11	-13	-33	-4	-18	2	-16
11	4	-6	-13	-31	-12	-32	0	-7
12	2	-5	-6	-25	-9	-28	3	-11
13	4	-14	-5	-19	3	-20	-1	-21
14	1	-13	-8	-25	-4	-20	-3	-26
15	3	-12	-15	-33	-6	-22	-4	-25
16	3	-13	-12	-30	-9	-24	-9	-32
17	6	-9	-10	-28	-3	-22	-8	-32
18	3	-3	-2	-20	2	-13	-6	-29
19	3	-9	-4	-16	3	-14	-3	-27
20	0	-7	4	-16	-2	-12	-8	-28
21	2	-12	-4	-23	-7	-26	-4	-26
22	0	-12	-7	-24	-11	-31	2	-19
23	1	-18	2	-13	-11	-32	-1	-23
24	3	-17	-8	-24	-9	-29	6	-13
25	-1	-14	-4	-22	-8	-29	6	-6
26	4	-15	-8	-26	-5	-24	2	-17
27	-3	-9	-8	-26	-3	-15	3	-14
28	-7	-24	-5	-23	-10	-29	6	-10
29	-2	-21	0	-15	-11	-29		
30	4	-13	-7	-13	-9	-31		
31			-12	-29	-4	-20		

Table 3.—*Winter 1973-74 air temperatures, Gunnison Colo.*

Day of month	November Max °C	November Min °C	December Max °C	December Min °C	January Max °C	January Min °C	February Max °C	February Min °C
1	13	-4	8	-16	-11	-27	-1	-21
2	14	-4	9	-12	-11	-24	-1	-19
3	13	-4	2	-15	-16	-29	-6	-29
4	9	-2	-1	-17	-21	-38	-11	-31
5	13	-6	-1	-25	-6	-29	-5	-28
6	16	-4	-3	-24	-4	-17	-6	-27
7	17	-9	-1	-33	-2	-13	-14	-30
8	18	-11	5	-21	-1	-6	-16	-37
9	17	-9	1	-21	1	-7	-18	-32
10	16	-11	1	-21	1	-12	-15	-37
11	17	-11	3	-19	-7	-26	-14	-36
12	16	-11	3	-18	-10	-24	-12	-33
13	17	-6	-1	-6	-4	-20	-9	-30
14	12	-2	2	-7	-3	-20	-9	-24
15	7	-14	-2	-27	-6	-23	-8	-29
16	12	-15	-4	-23	-11	-26	-9	-30
17	10	-11	-1	-21	-7	-24	-9	-30
18	11	-13	-1	-20	-5	-19	-1	-13
19	8	-3	-1	-23	-3	-23	-3	-16
20	3	-7	-5	-27	-8	-23	-5	-8
21	2	-13	-7	-26	5	-11	-12	-30
22	0	-10	-7	-26	-9	-22	-11	-33
23	2	-7	-4	-19	-11	-29	-6	-26
24	1	-13	0	-13	-14	-35	-12	-36
25	2	-9	-4	-23	-17	-33	-13	-29
26	-2	-13	-7	-29	-11	-26	-11	-29
27	-3	-18	-11	-27	-9	-26	-4	-24
28	2	-19	2	-14	-11	-25	-3	-24
29	4	-18	0	-7	-11	-28		
30	4	-14	-2	-12	-12	-29		
31			-6	-28	-18	-31		

Table 4.—*Winter 1976-77 air temperatures, Gunnison, Colo.*

Day of month	November Max °C	November Min °C	December Max °C	December Min °C	January Max °C	January Min °C	February Max °C	February Min °C
1	15	-12	2	-15	0	-14	8	-17
2	17	-12	4	-19	1	-15	3	-11
3	14	-6	6	-19	-2	-11	4	-15
4	14	-11	2	-19	-1	-12	4	-20
5	17	-11	1	-13	-7	-27	3	-18
6	14	-12	-1	-15	-3	-26	8	-16
7	17	-7	6	-15	-6	-29	6	-20
8	17	-12	10	-15	-11	-32	6	-22
9	15	-13	9	-18	-11	-28	8	-21
10	14	-14	6	-12	-7	-29	11	-19
11	12	-12	4	-19	-4	-29	9	-18
12	9	-11	7	-19	-8	-32	7	-19
13	5	-7	5	-21	-7	-30	9	-17
14	4	-9	5	-21	-3	-28	7	-14
15	4	-11	5	-21	-1	-27	8	-18
16	7	-12	5	-22	-1	-25	13	-14
17	9	-14	7	-22	3	-23	13	-11
18	12	-13	7	-22	7	-17	14	-15
19	13	-12	5	-22	4	-19	12	-14
20	9	-13	2	-25	3	-22	13	-16
21	11	-13	2	-25	5	-14	12	-17
22	10	-15	2	-25	4	-9	9	-3
23	10	-16	0	-22	2	-7	-1	-11
24	9	-18	4	-18	2	-21	1	-7
25	10	-18	1	-21	-1	-24	-3	-9
26	4	-19	5	-21	3	-23	-5	-29
27	-2	-20	7	-19	3	-23	-1	-22
28	-7	-28	3	-18	6	-21	2	-25
29	1	-21	6	-24	6	-22		
30	4	-19	3	-21	4	-24		
31			2	-12	5	-21		

Descriptive Records of Ice Formation, 1967 through 1977

Construction of the Blue Mesa Dam was completed in 1965 and the subsequent filling of the reservoir was completed in 1967. Since 1967, the Bureau has made observations of ice formation on the Gunnison River. The studies conducted during several winters show the progression of the ice jam head, up the river, and identify the extent of flooding. During some winter seasons a few observations have been made; during others the observations have been quite detailed and extensive.

- Winter of 1967-68.–There was some flooding due to ice jams immediately upstream from the reservoir in early January.

- Winter of 1968-69.–Flooding again occurred upstream from the reservoir and extended at least up to the McCabe property in late January.

- Winter of 1969-70.–Flood occurred about 2.5 to 3.0 km further upstream this winter than the two previous winters.

- Winter of 1970-71.–A summary presentation of this winter, which was about the same as the previous year (fig. 8), shows the upstream movement of the head of the ice jam, Blue Mesa Reservoir elevations, releases from Taylor Park Reservoir, and an average daily temperature record. The monthly degree-day totals are shown on the daily average temperature record. The cumulative sum of degree-days was noted when the head of the ice jam stopped, and was counted from the first day that the ice cover was formed on Blue Mesa Reservoir. During the second half of November, the east end of the reservoir at the mouth of the river was covered with ice. The Corps of Engineers reported on December 3 that some ice jamming had occurred at the mouth of the river and that they would stop their clearing work for the season.

The discharge from Taylor Park Reservoir was increased December 3 from 0.85 m^3/s to 11.3 m^3/s to try to open the channel into the reservoir. By December 4, the river channel was filling rapidly with frazil slush ice and the releases were lowered to 5.7 m^3/s. Due to a large inflow at the Taylor Park Reservoir, this flow had to be maintained until December 13. From December 7 through 11, there was a warming trend which produced an open channel through the river ice jam; however, by December 13, ice was jamming (fig. 9) in the river at Coopers Resort and flooding the cabin area. On December 13, the Taylor Park Reservoir releases were cut from 5.7 to 1.4 m^3/s. The river channel was jammed with ice to just above Neversink Resort area by December 14. On December 16, the ice jam was much worse at Neversink Resort, water was approaching the cabins, and more flooding was occurring in the cabin area at the Coopers Resort. By December 17, the ice jam had moved to a point halfway between Neversink and the McCabe Bridge. Much of the riverflow was forced out of the main channel into the old flood channels, and stayed in this condition through January 3, when a new cold period began. The river channel was filled with ice to the McCabe Bridge by January 5. There was a heavy concentration of frazil slush ice at the McCabe Bridge on January 4 (fig. 10). By January 5, the open channel at the McCabe Bridge was filled with ice. Each day the ice jam moved up the river until, by January 8, the channel was full of ice up to the center of the Dos Rios area. Figure 11 shows the locations of the ice jam head as the winter progressed. Figure 12 is a view facing upstream at the ice-choked Gunnison River channel on January 8 in the same location as the cross section in figure 4. Also shown is the Corps of Engineers dike along the riverbank, built on January 8 to keep the water from the homesites in the Dos Rios area. Figure 13 is a view upstream from Moncrief's Foot Bridge. The main channel (to the left in the picture) was packed with frazil slush ice and the riverflow had diverted into the old flood channel. The picture was taken in the area of the cross section shown in figure 5. A warming trend started January 9, and the weather remained mild throughout the rest of the winter season. The view of the Gunnison River looking upstream at Neversink Resort, March 11, 1971 (fig. 14) shows the substantial thickness of the ice jam in this area.

- Winter of 1972-73.–The progression of the ice jam head by December 7, 1972, is shown in figure 15. From the summary data (fig. 16), on November 27, sheet ice had formed at the east end of the Blue Mesa Reservoir and about 1.5 km into the mouth of the Gunnison River, which was the approximate reservoir waterline elevation at that time (EL 2280 m). Upstream from this, there were no restrictions caused by ice. During the night, November 28, the temperature dropped to −24 °C. By morning the river was carrying 50 to 75 percent frazil slush ice at the water surface. This ice floated down the river, contacted the reservoir ice, and started jamming. In less than 24 hours, the head of the ice jam had moved about 1.5 km upstream. This cyclic process of frazil ice production at night resulting in ice buildup during the day, occurred several times from November 28 to December 15. (Note temperature fluctuations on fig. 16). By December 15, the ice jam head had moved upstream to 6.3 km from Steuben Creek. This process was rather irregular and discontinuous; open channels developed in the jam during the warmer days (fig. 17), and filled with ice again during the colder nights (fig. 18). Main channel water came out onto the surface of the ice at the head of the jam. The sheet ice eventually grows out over, and insulates the water, and greatly decreases the frazil ice production (fig. 19). When this shore ice has fully developed, it becomes a typically smooth ice cover extending upstream from the ice jam head (fig. 20). The greatest rate of ice jam movement upstream occurred December 10 and 11. On the morning of the 10th, the temperature was −33 °C and stayed below −13 °C for the 2 days. In 1 day the jam head had moved about 1.6 km upstream. With water temperatures above freezing during the day and below freezing at night, a 3- to 6-m-wide channel was cut into the ice jam, filling at night during frazil ice production (fig. 21) and opening during the day.

Although the head of the ice jam remained at about the same location from December 15 until the spring thaw, the overriding factor in the ice formation seemed to be the flow channel which continued to open and fill intermittently throughout the winter, and was completely open to the reservoir by January 16. The progression of the ice jam head throughout the winter is shown on the map (fig. 22). A fairly large flow channel existed throughout the reach all winter. An ice cover formed upstream from the ice jam, effectively protecting the river water from the cold. The gradual seasonal melt started February 24, continued evenly, and did not cause flooding.

- Winter 1973-74.–A summary of the data is shown in figure 23. By December 3, ice had filled the river channel from the reservoir to Beaver Creek. The ice jam progressed to the island downstream from Coopers Resort on December 5 (fig. 24), and to Neversink Resort by December 7. From December 7 through 17, the ice jam remained about the same with intermittent opening and closing of the channel. From December 17 through 21, it moved to within 0.5 km of the McCabe Bridge. The jam remained fairly stationary until December 27 when it moved 0.4 km overnight to about 0.2 km upstream from the McCabe Bridge. It again stabilized until the next period of cold weather, January 2 through 4, when it moved approximately 1.2 km upstream from McCabe Bridge. On January 5, the jam progressed another 50 m upstream to the bend in the river. Frazil ice production was generally moderate to heavy during December but there was very little in January. By January 28, the ice jam had not moved, but the river upstream was covered with sheet ice. By the first week of February the river had frozen over all the way to Almont. The river surface remained frozen until the first week of March when there was a gradual warming trend. The ice jam started to go out the second week of March, which relieved the backup of water. Although the winter was quite severe, no serious problems developed.

- Winter of 1976-77.–The summary data sheet for the season is figure 25. The first observation of this season, made on December 14 (fig. 26) showed the ice jamming 610 m upstream from Beaver Creek, and by the 17th had reached Coopers Resort. The jam had moved to within 240 m of the Neversink Resort on December 20 and by the 21st had moved upstream 60 m beyond Neversink Resort. On December 22, a 5- to 8-m-wide channel opened in the ice jam head and extended about 450 m downstream. The channel alternately closed and reopened on December 23 and 24. By January 10, the ice jam had progressed to 760 m upstream from Neversink Resort. Upstream from the jam, the river continued to freeze in from the banks. As the winter continued, there was a decrease in the production of frazil ice. During the week of January 24, the river was open from the Highway No. 50 Bridge to the ice jam, which was the start of the spring thaw on the river; by the first week of February, the channel opened for 300 m to the Neversink Resort area; by February 21, to 750 m downstream from Neversink Resort; and by March 7, 450 m downstream from Coopers Resort. The spring thaw continued without jamming or flooding.

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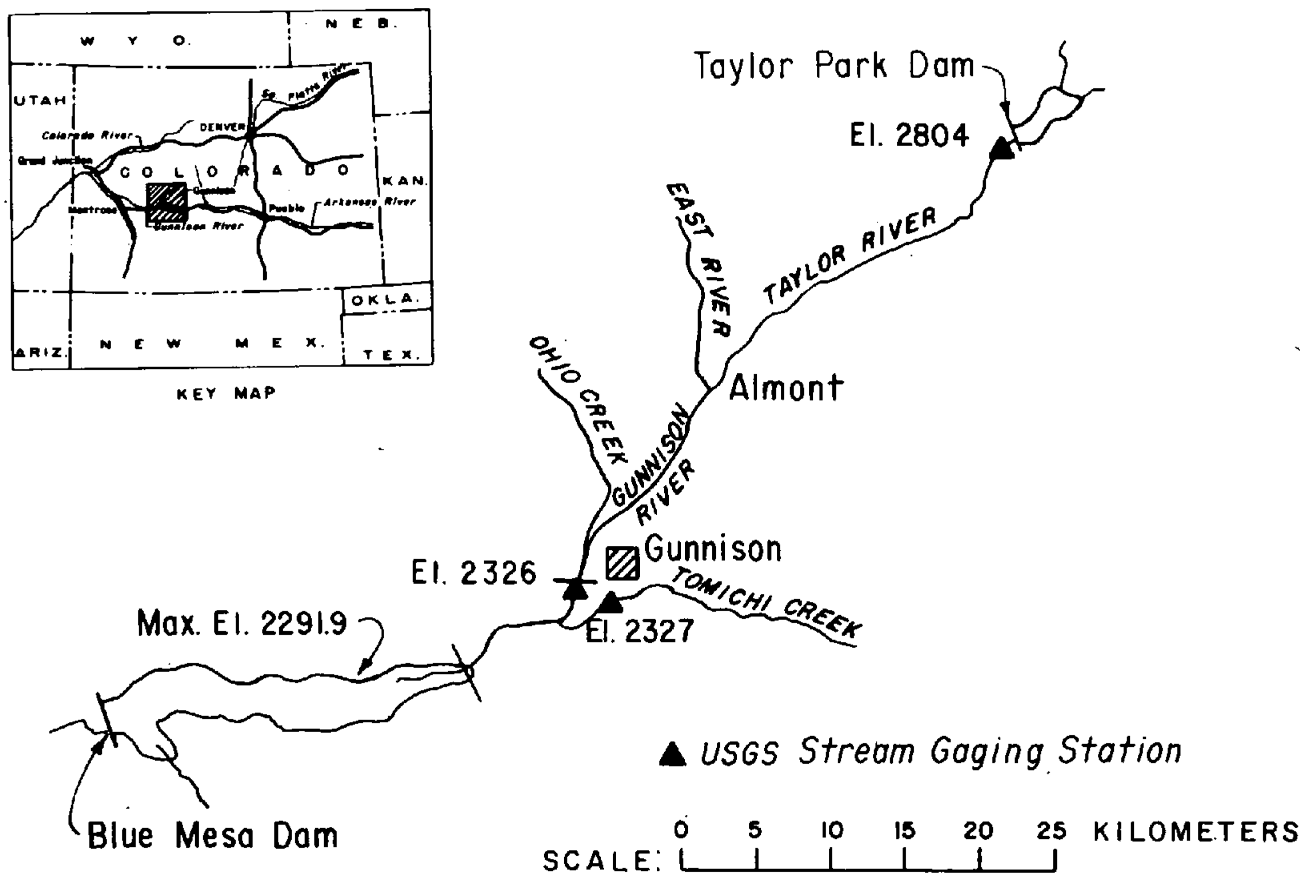

Figure 1.–Location map, Gunnison River, Colorado.

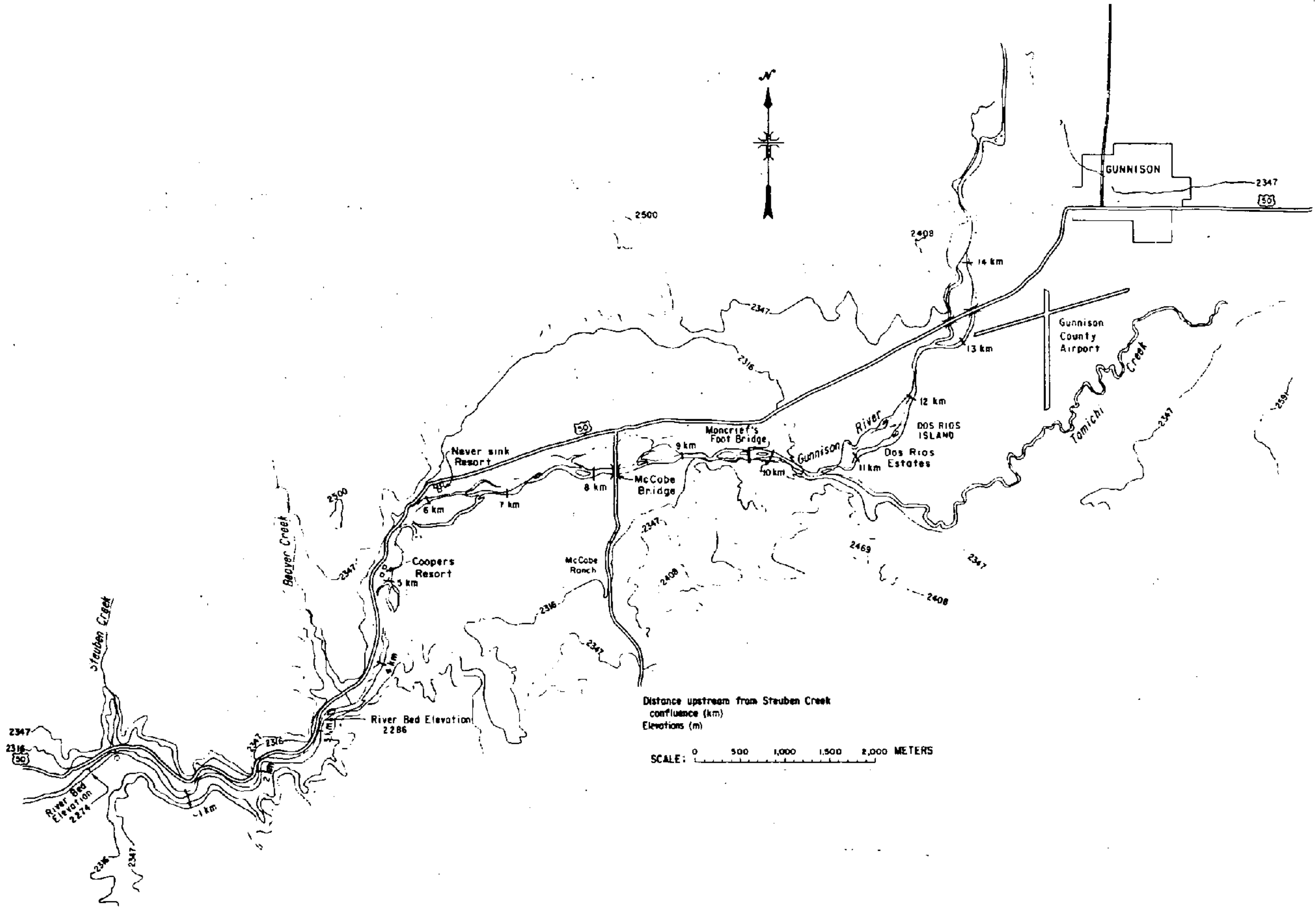

Figure 2.–Location map of 14-km study reach.

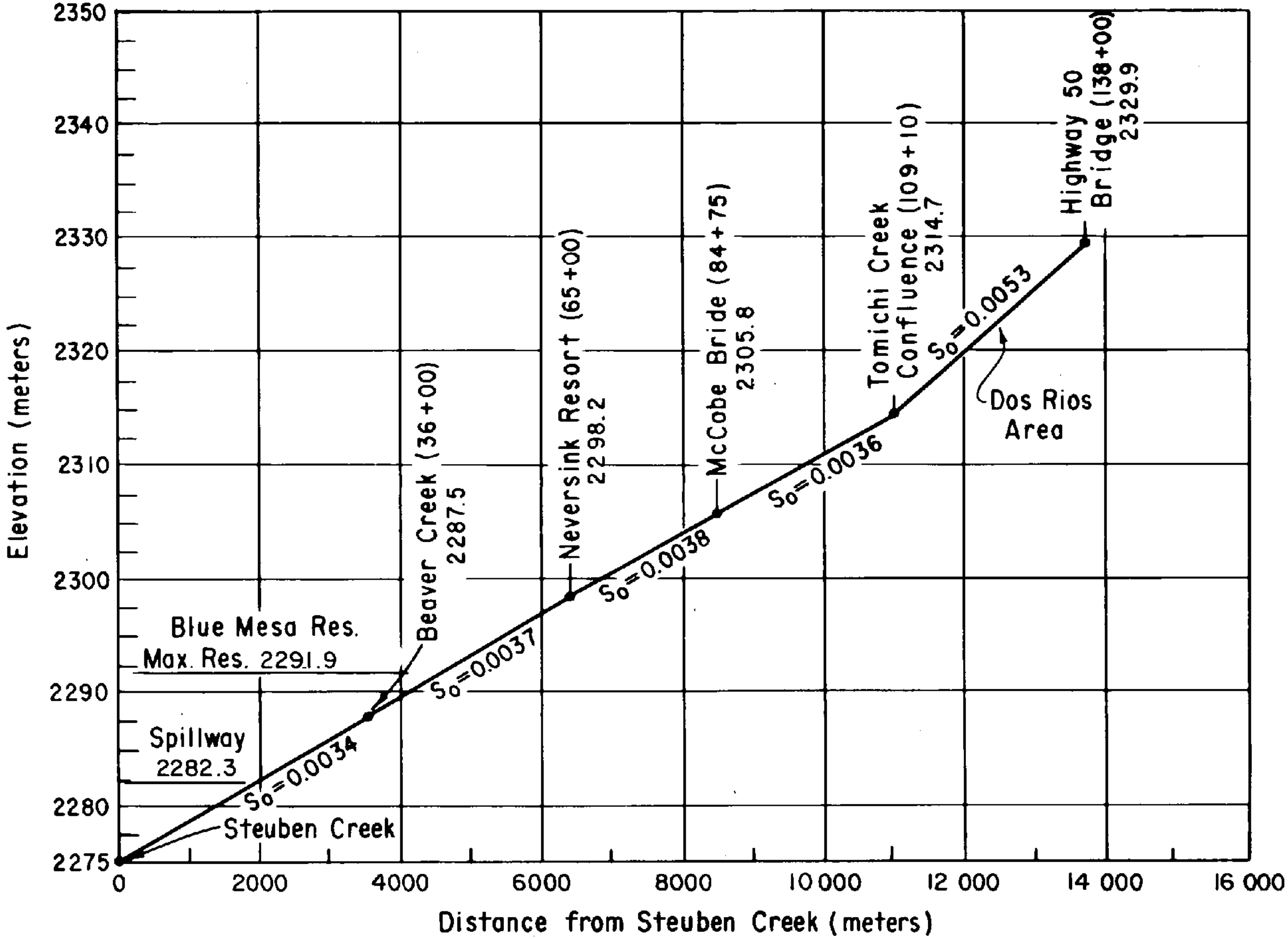

Figure 3.–Streambed profile along the study reach.

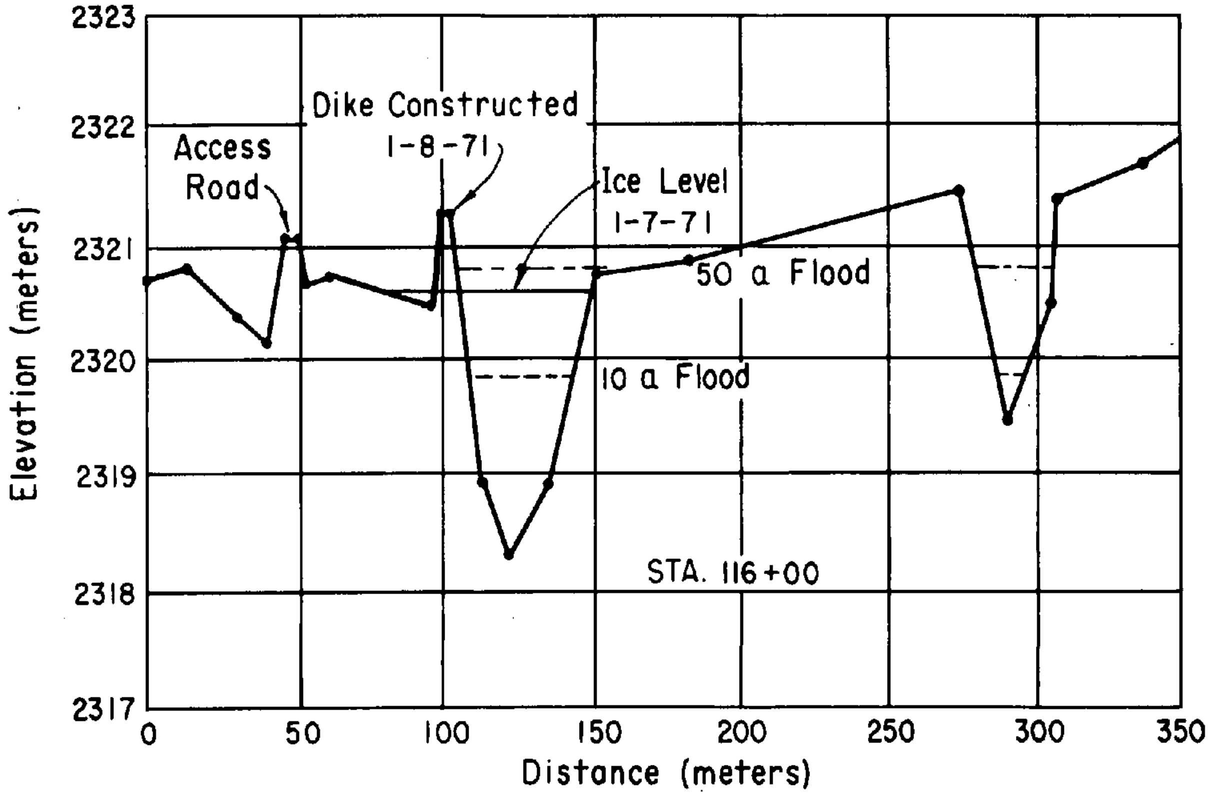

Figure 4.–River cross section at Dos Rios Island (facing downstream).

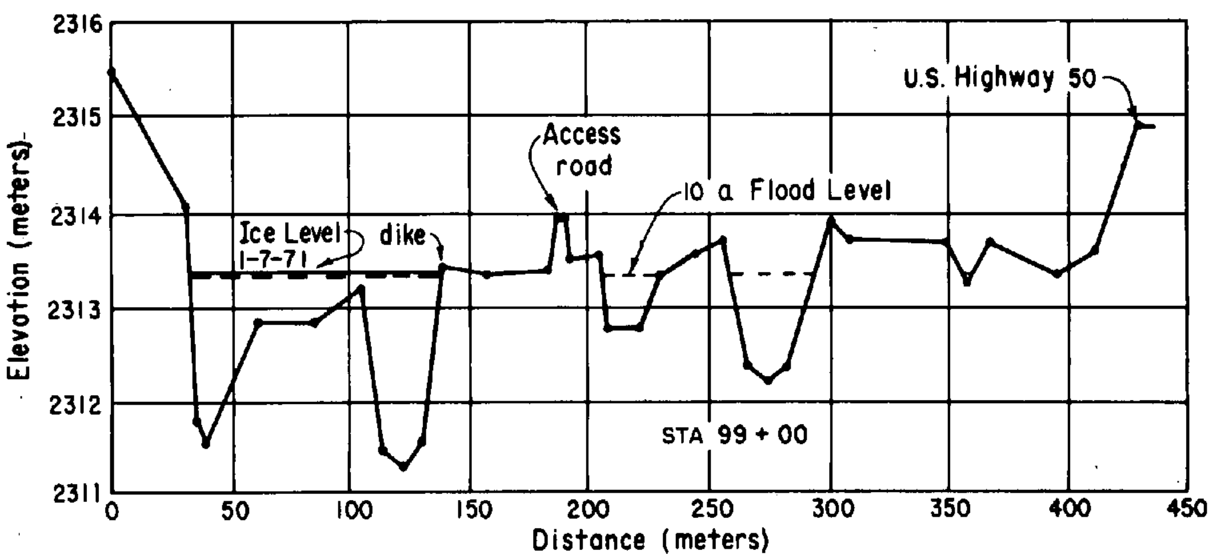

Figure 5.–River cross section at Moncrief's Foot Bridge (facing downstream).

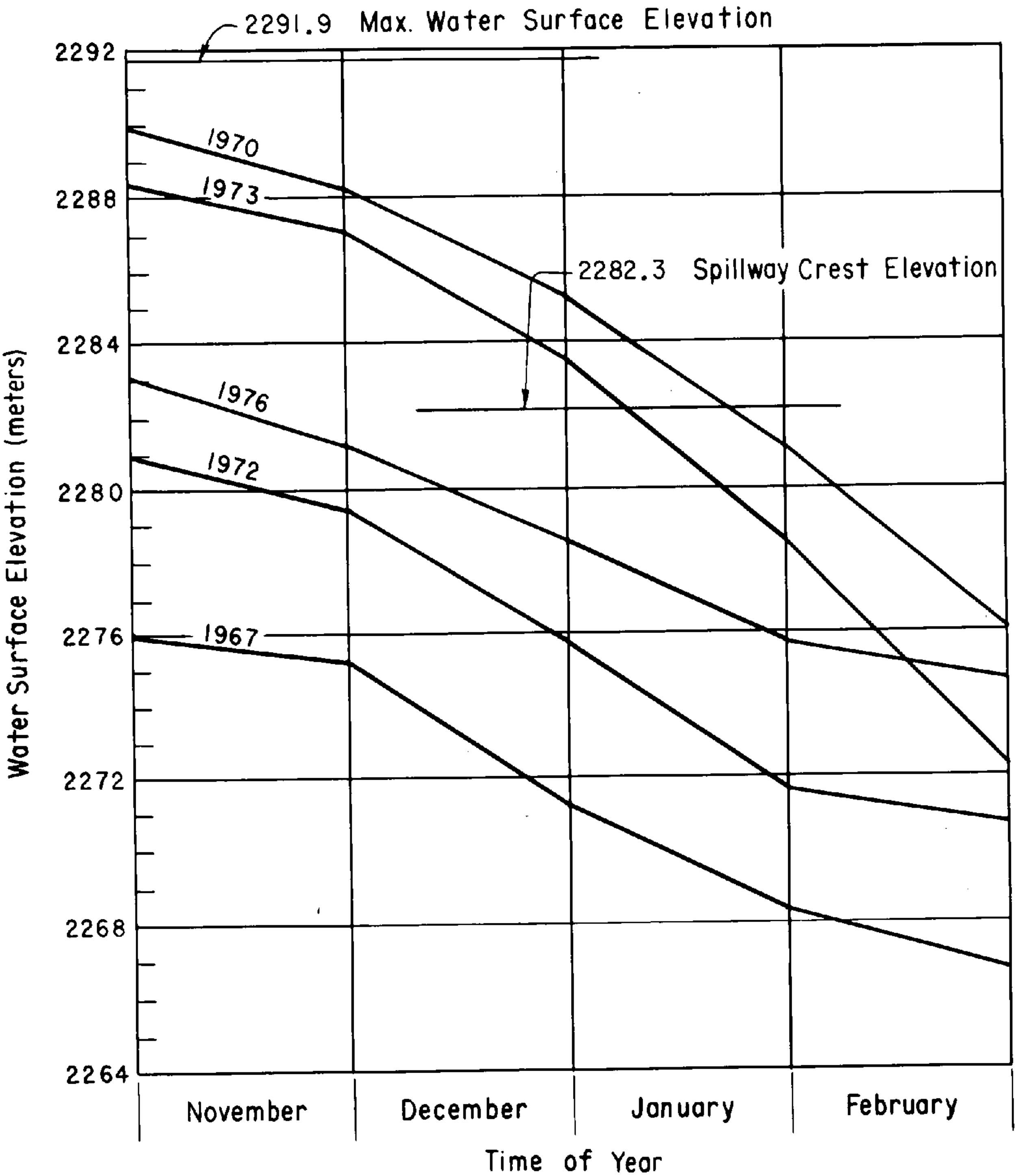

Figure 6.-Blue Mesa Reservoir water surface elevations.

Figure 7.–Aerial view looking downstream with Neversink Resort in the background. (9-15-70) (Note clearing and snagging work, shown in progress.) Photo P622A-427-11351

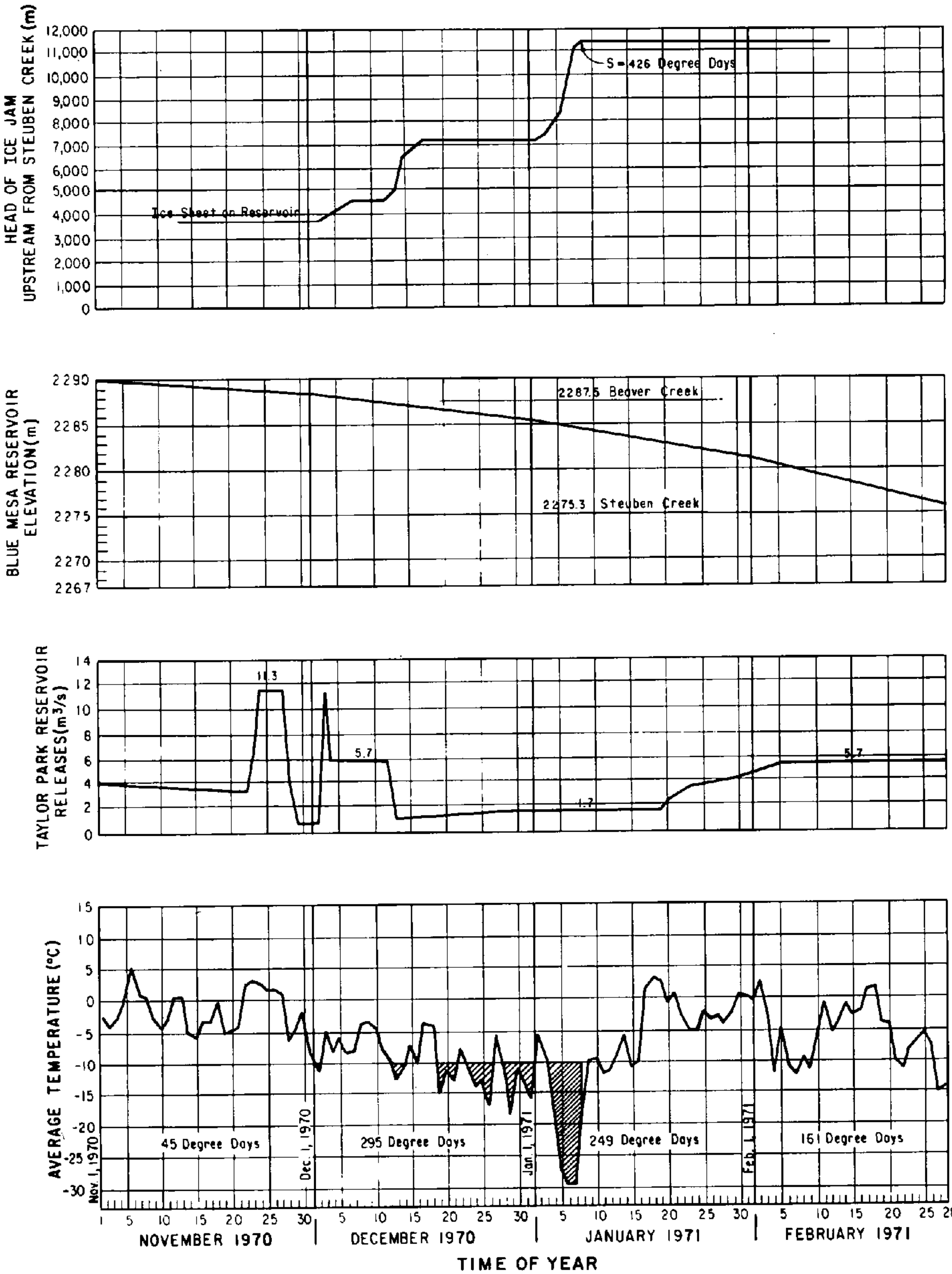

Figure 8.–Summary of data for the 1970-71 winter.

Figure 9.–Looking upstream at flooding around cabins in the Coopers Resort area. (12-13-70) Photo P622A-427-11403

Figure 10.–Looking downstream from the McCabe Bridge. (1-4-71) (Note frazil slush ice floating at the water surface.) Photo P622A-427-11434

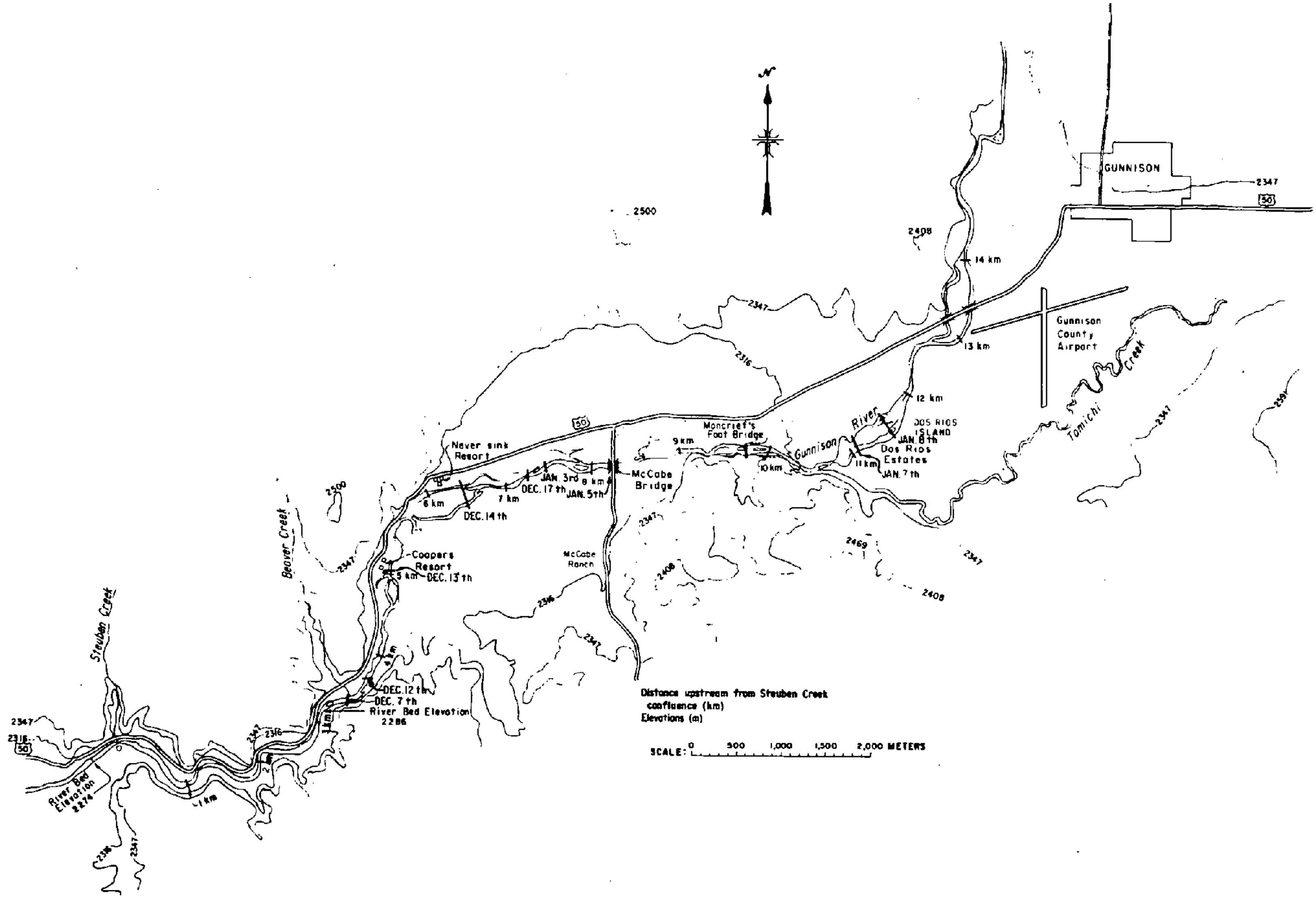

Figure 11.-Locations of the ice jam head during the 1970-71 winter.

Figure 12.–Looking upstream, adjacent to the Dos Rios homesites. (1-8-71) (Note emergency diking underway to stop flow of water into homesite area.) Photo P622A-427-11458

Figure 13.–Looking upstream from Moncrief's Foot Bridge. (1-8-71) Photo P622A-427-11446

Figure 14.–Looking upstream adjacent to Neversink Resort showing the ice breakup. (3-11-71) Photo P622A-427-11530

Figure 15.–Looking upstream at the head of the ice jam. (12-7-72) (Note frazil slush ice compacting into jam.) Photo P622A-427-11832

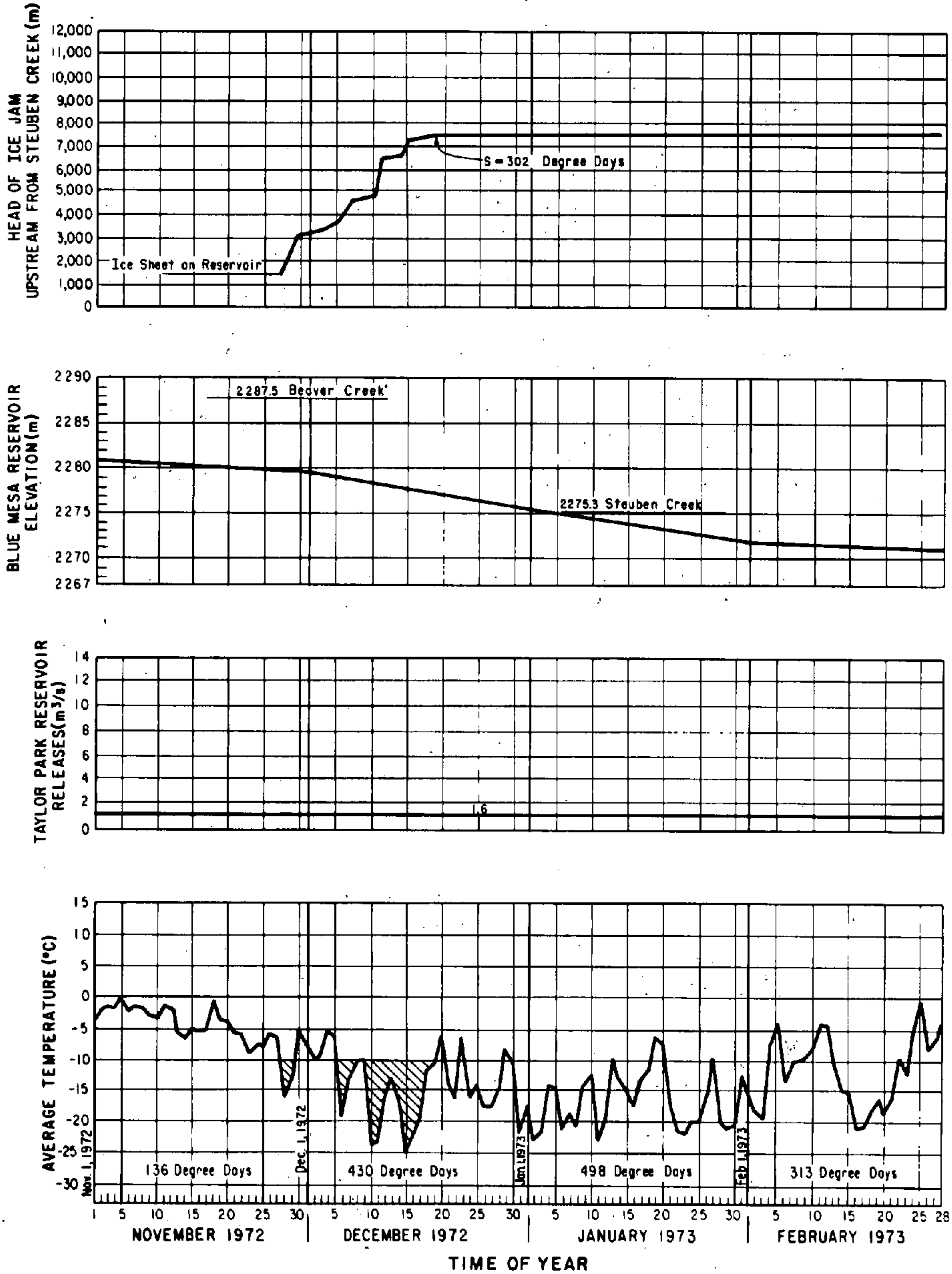

Figure 16.–Summary of data for the 1972-73 winter.

Figure 17.–Looking upstream toward Neversink Resort from just above Coopers Resort. (12-10-72) (Note the open channel in the middle of the ice jam.) Photo P622A-427-11843

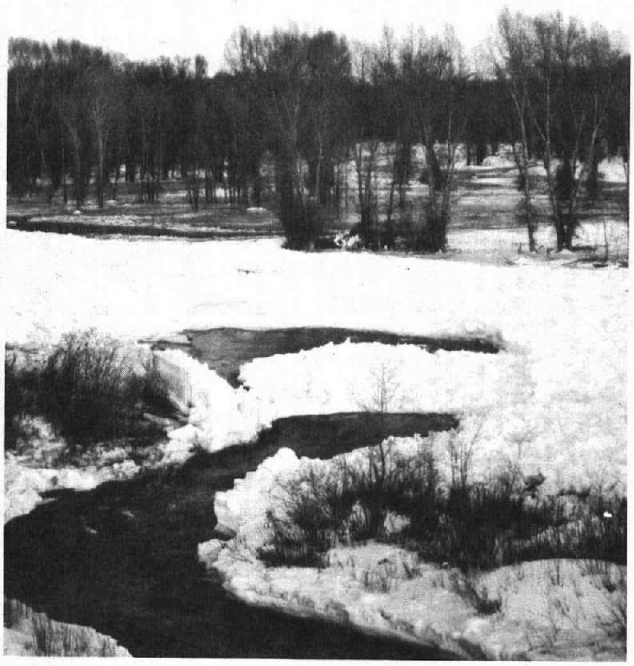

Figure 18.–The channel (fig. 17) filled with ice the next day. (12-11-72) Photo P622A-427-11842

Figure 19.–Looking downstream at the confluence of the Tomichi River with the Gunnison River. (12-7-72) (Note partial ice cover.) Photo P622A-427-11839

Figure 20 –Looking downstream below the confluence (fig. 19). (12-19-72) (Note the smooth ice cover which formed 12 days later.) Photo P622A-427-11844

Figure 21.–Looking upstream from Neversink Resort at the ice jam. (1-4-73) (Note central channel which opens and closes.) Photo P622A-427-11846

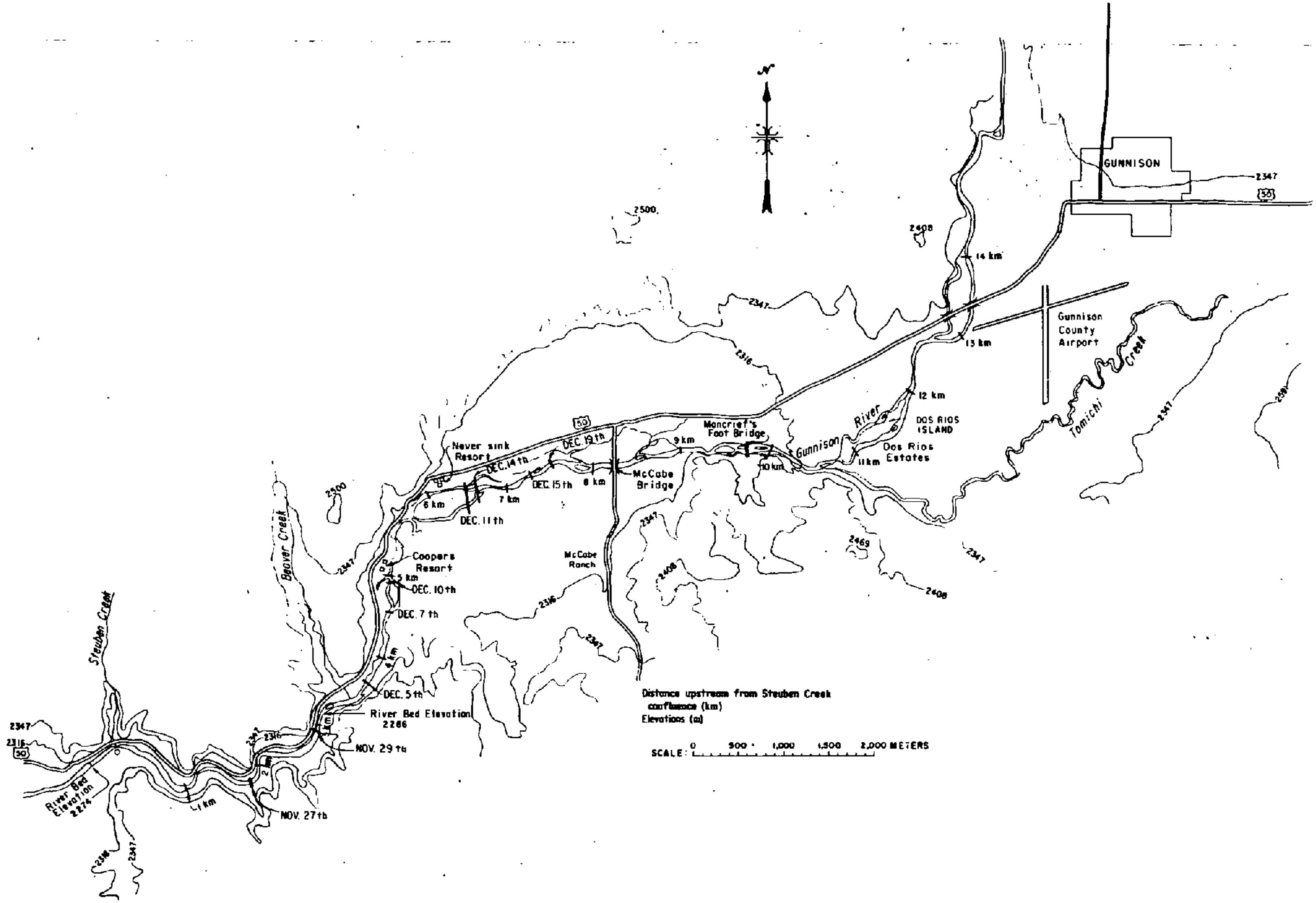

Figure 22.–Locations of ice jam head during the 1972-73 winter.

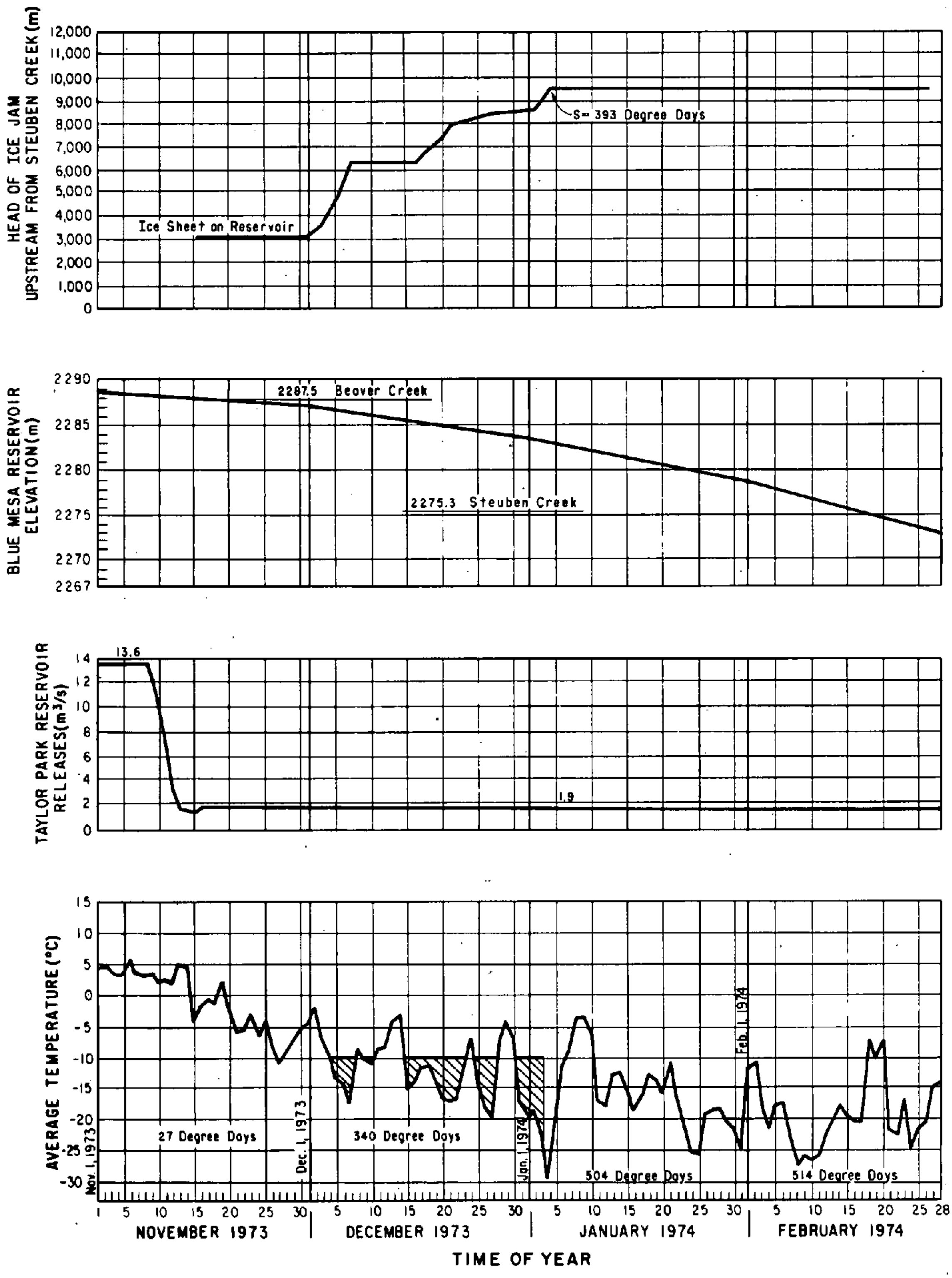

Figure 23.–Summary of data for the 1973-74 winter.

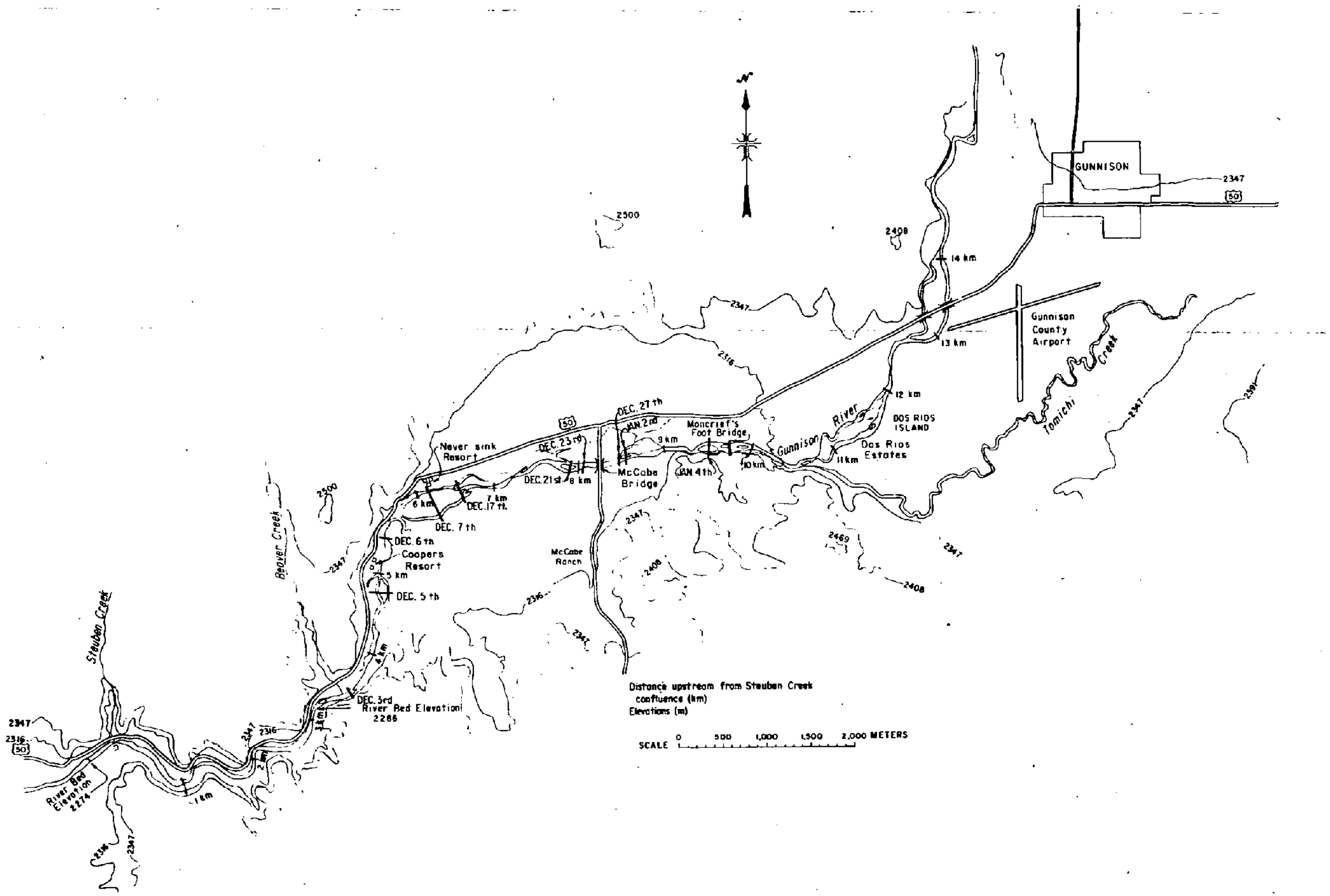

Figure 24.–Locations of the ice jam head during the 1973-74 winter.

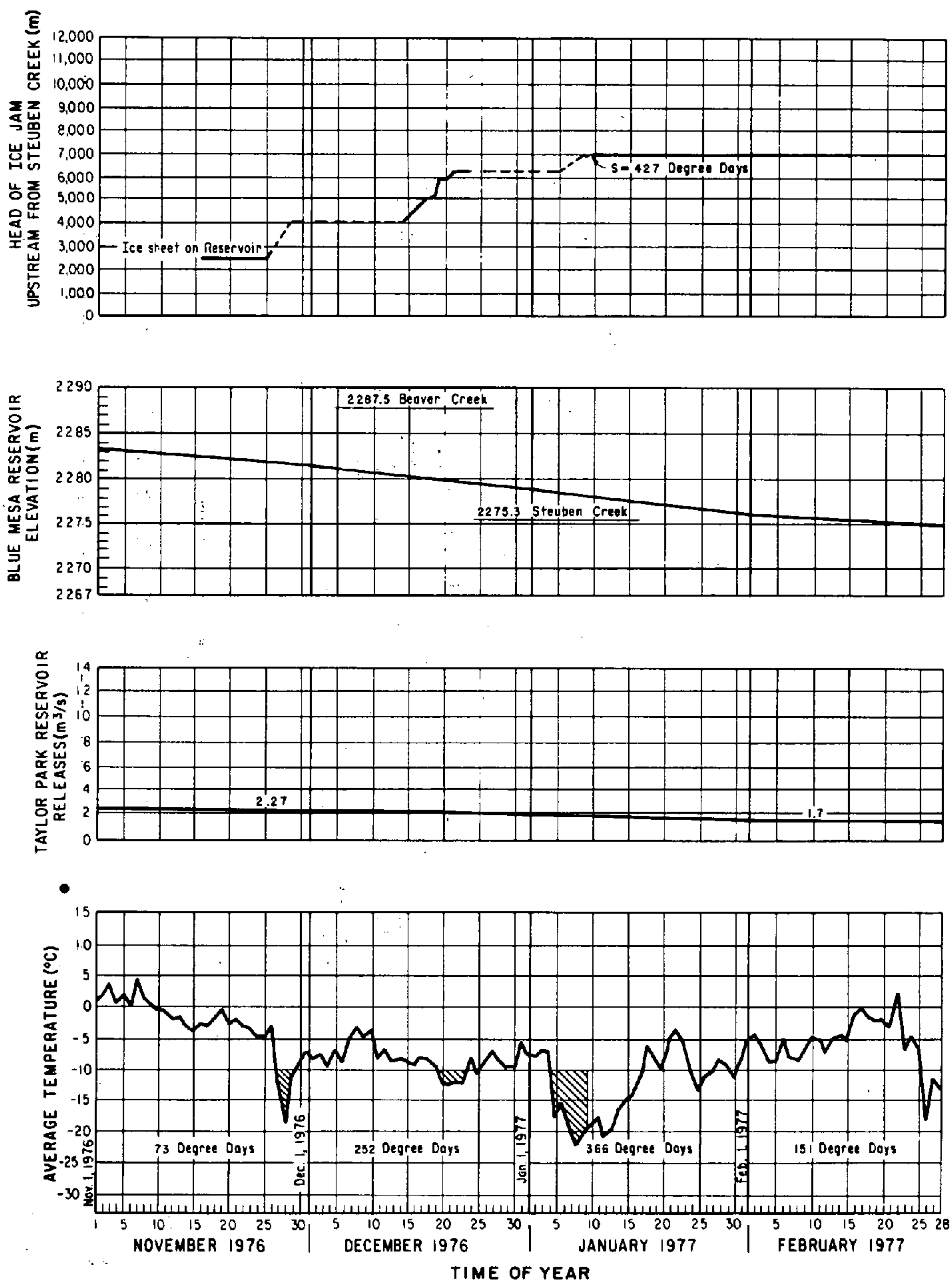

Figure 25.–Summary of data for the 1976-77 winter.

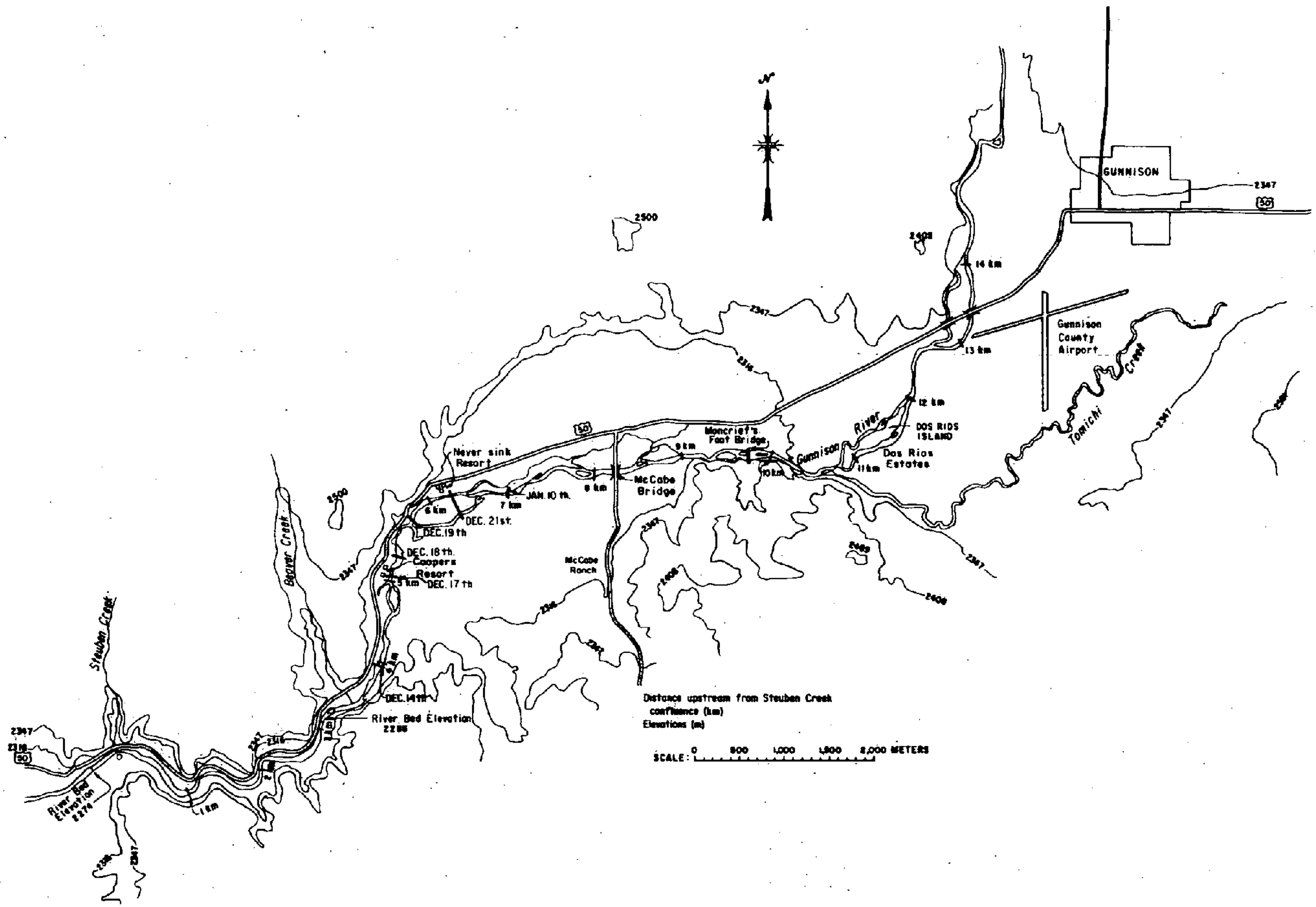

Figure 26.–Locations of the ice jam head during the 1976-77 winter.