SHEEP CREEK DAM

HYDRAULICS STUDY

Project #1358

By

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Sheep Creek Dam, near Elgin in Grant County, has had a history of problems throughout its life. The dam was constructed in 1969 by the North Dakota State Water Commission. The dam failed in 1970 after a reported six (6) inches of rain fell within the drainage basin. Probable causes of the failure are listed as leaky joints in the concrete pipe, lack of quality control in the backfilling of the embankment and differental settlement of the outlet structure. It was noted that prior to the failure loud noises or pounding sounds were heard in the area of the outlet structure.

In 1970, the dam was reconstructed with preventive measures taken to avoid a reoccurrence of the earlier failure. In 1972, after a rainstorm in the drainage basin the level of the reservoir rose to about nine (9) feet above the inlet. With the water at this stage a loud slugging noise was again noted in the area of the outlet structure. In an attempt to reduce the slugging a four (4) inch vent pipe was installed in the discharge pipe at the head wall of the inlet. It was assumed that a vacuum was being formed in the pipe as the flow reached a certain point and the vent pipe would resolve the slugging problem. Since the vent pipe was installed, the reservoir level has never reached the point that had previously caused the slugging.

During 1974, plans had been discussed to do an on-site hydraulic study should the expected reservoir elevation approach the critical level. The reservoir did not approach this level in 1974. However, after the severe snow storm of March 26-29, 1975, the authors of this report thought the snow conditions and resulting snow melt would cause a reservoir rise exceeding the critical level.

Snow samples were taken on April 7, 1975, within the drainage basin to determine moisture content of the snow. Results of the samples were as follows:

Sample Number	Location (Sec-Twp-Rge)	Snow Depth (Inches)	Moisture Content (Inches)
1	15-133-89 (¼ line, 200 feet west of N-S road)	8	2.41
1-A	16-132-89 (NW corner of Sec. 200 ft. south of road)	8.25	3.05
2	15-133-89 (1/8 mile west of NE corner 200 ft. south of road)	8.125	2.96
3	21-133-89 (1/3 mile west of Sheep Creek crossing, 200 ft. north of road)	12.5	4.18
4	4-133-89 (SW corner of Sec., 200 ft. east of N-S road)	5.875	2.15
	Average	8.55	2.95

Using the snow sample data, a flood routing estimate was made assuming that 1.5 inches of moisture would run off from the entire basin. This estimate showed that the peak reservoir level would be approximately one (1) foot above the emergency spillway. The drainage area was rechecked and found to be 14% larger than earlier estimates or a total drainage area of 57.9 square miles.

The following set of conditions were to be monitored when the field investigation was begun:

I. Conditions to be determined

1. Snow pack depth and moisture content

2. Inflow hydrograph

3. Weir coefficient

4. Pipe discharge

5. Point of Transition from weir control to pipe control

6. Weir depth and pipe velocity at the time the pipe slugs

7. Effect of vent pipe on flow conditions within the pipe

8. Conditions in the S.A.F. Basin

II. Parameters to be recorded

1. Air temperature

2. Water temperature

3. Reservoir stages

4. Upstream inflow

5. Water content of snow

6. Velocity at upstream end of pipe

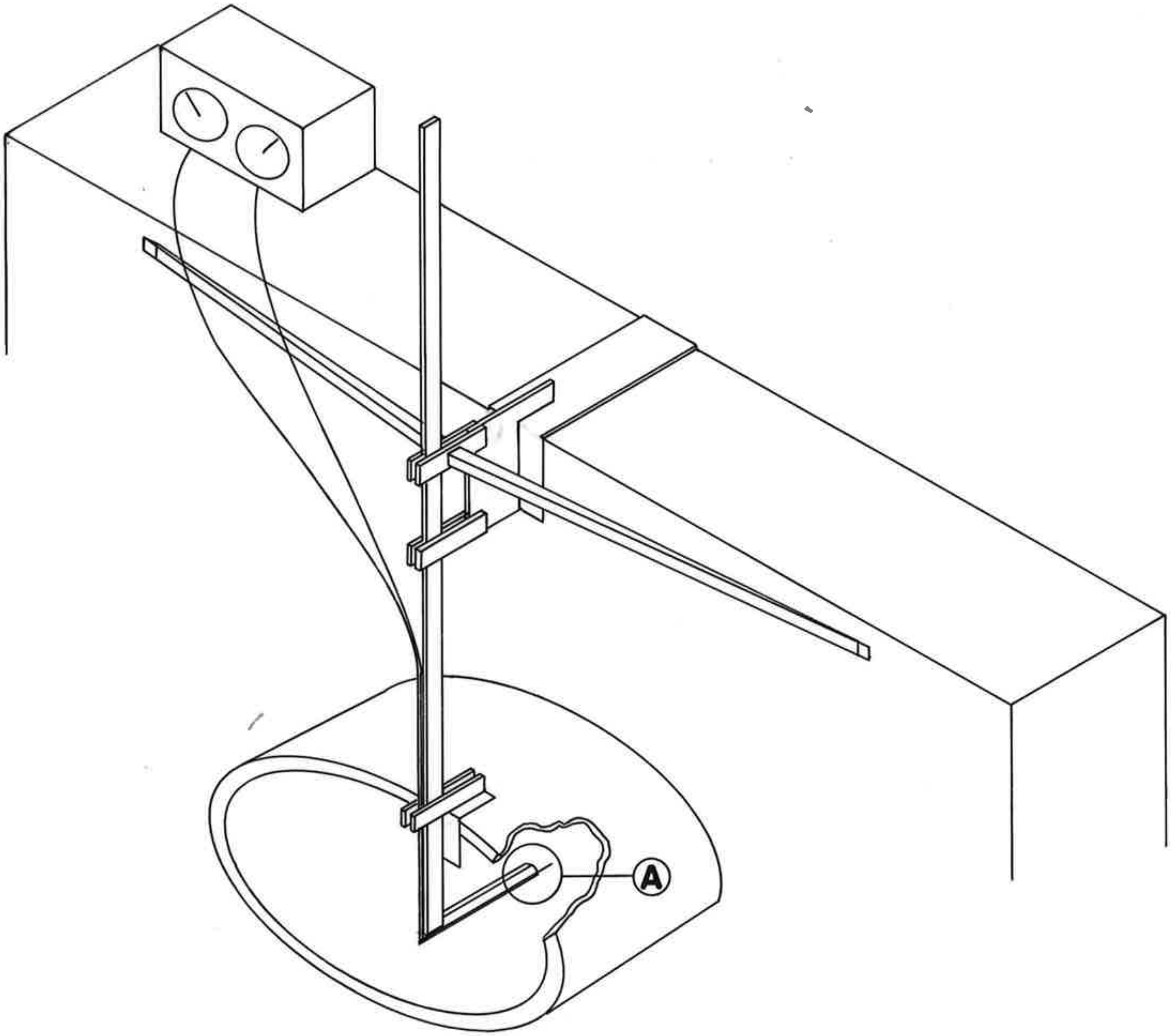
7. Velocity at downstream end of pipe

8. Discharge through pipe

9. Depth of water at the weir

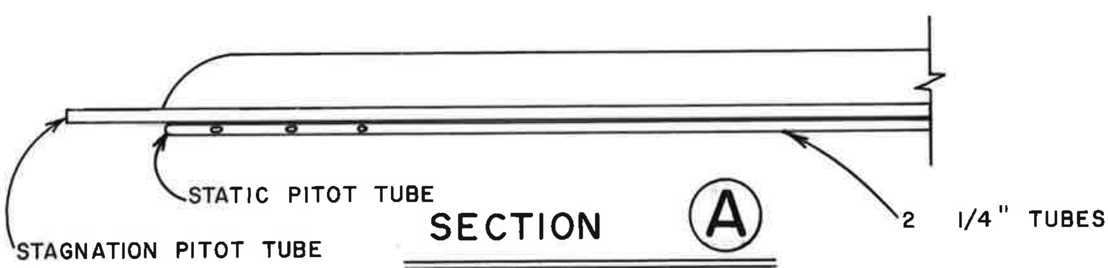
The primary object of the field study was to monitor the flow in the principal spillway pipe as the water level rose in the reservoir to accurately determine the head-discharge relationship. Flows were monitored in the principal spillway pipe using a pitot tube, Figure 1. The pitot tube was constructed of two ¼-inch rigid copper for measuring the stagnation and static pressures. The pitot tube was connected to the pressure gage using rubber hoses. The gages measured pressure in feet of head from zero to 125 feet. Photo numbers 1 through 3 show the pitot tube apparatus. In addition to monitoring the flow in the pipe it was decided to observe as

FIGURE 1 PITOT TUBE AND RELATED APPARATUS



ISOMETRIC

SCALE - 1/2" = 1'-0"



SECTION (A)

SCALE - 3" = 1'-0"

many factors of snowmelt runoff as possible. This was to be done with the intention of standardizing the method of determining design inflow hydrographs for future projects.

Photo 1. Pitot Tube Operating Through Ice

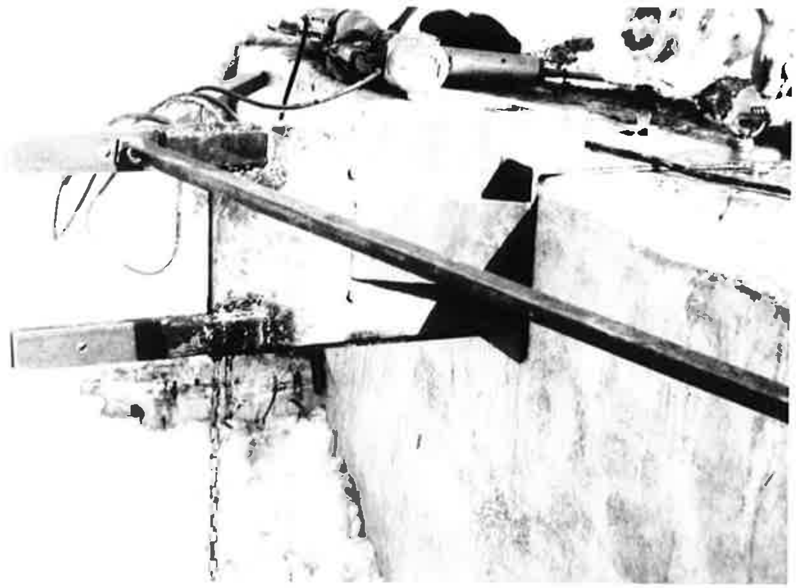


Photo 2. Pitot Tube Wall Bracket

Photo 3. Pitot Tube in Stowed Position

ON SITE STUDY

On April 7 the water level in the water was approximately 4¼ inches below the front wall of the box inlet. Water was trickling into the box inlet at the headwall. The weir of the box inlet does not set level and the elevation of the corners are as follows:

Corner	Elevation (msl)
Northwest	2224.20
Southwest	2224.60
Southeast	2224.62
Northeast	2224.27

The pipe at the outlet (S.A.F. Basin) was covered with ice to a level of three (3) inches above the top. The ice surface appeared to be the level of the creek immediately downstream from the stilling basin. It did appear that water was moving under the ice in the bottom of the spillway pipe. Sheep Creek two miles upstream from the dam was completely snow blocked and there was no evident streamflow.

Mr. Harry Zacher, Chairman of the Grant County Water Management Board was contacted and he extended his full cooperation to any study which would be done. From April 8 on, Mr. Zacher kept the dam under surveillance making observations at the dam daily as necessary.

On April 10, a survey crew placed two staff gages in the northwest corner of the reservoir near the west end of the embankment. The gages were set to monitor the reservoir elevations.

On April 11, the authors of this report investigated the conditions at the reservoir and over the entire drainage basin. Reservoir levels were recorded, Table 1. There was still considerable snow in most of the basin, with the south half having greater snow depths. Some melting was occurring as could be seen in the far upper reaches of the tributaries to Sheep Creek. No flow was evident in the main channel of Sheep Creek.

TABLE 1 - STAFF GAGE READINGS AND DISCHARGES

Date	Time	Reservoir Elevation	Calculated Weir Discharge[1/] (cfs)
11 Apr 75	1400	2224.48	
	1900	2224.48	
12 Apr 75	1030	2224.48	
	1245	2224.48	
16 Apr 75	1515	2225.01	35.6
	1745	2225.01	35.6
	2120	2225.02	38.4
17 Apr 75	0920	2225.07[2/]	43.7
	1745	2225.48	100.9
	1850	2225.505	104.2
	1950	2225.52	110.5
	2115	2225.57	118.3
	2225	2225.58	119.9
	2300	2225.59	124.8
18 Apr 75	0000	2225.605	127.0
	0300	2225.64	133.7
	0600	2225.60	126.8
	0800	2225.56	116.8
	1000	2225.51	108.8
	1400	2225.47	99.6
	1500	2225.48	100.9
	1600	2225.50	104.0
	1630	2225.52	110.5
	1800	2225.52	110.5
	1930	2225.53	112.1
	2030	2225.54	113.5
19 Apr 75	1300	2225.30	73.0
20 Apr 75	1600	2225.25	66.5

[1/] Calculated using the equation $Q=CLH^{3/2}$ taking into account the sloping sidewalls of the box inlet.

[2/] Error suspected in gage, no change in reading for next three hours, at which time work was begun to reset gage.

The brackets as shown in Figure 1 were installed. Ice was chipped from the pipe and found to be approximately 30 inches thick extending down from the top of the pipe. There was flow in the bottom of the pipe, with no change in the reservoir level on the days of April 10 or 11.

For the next three days there was no change in the level of the reservoir from the reports of Mr. Zacher. On the afternoon of April 15, Mr. Zacher called to report that the water had suddenly began to rise and the creek two miles upstream had started to flow. Flow at the bridge upstream was estimated to be eight feet wide and three feet deep. At 9:30 that evening the reservoir had risen to two (2) inches over the inlet. By 9:00 the next morning the water level had risen to six inches above the inlet and water was still flowing at the upstream bridge as it had the day before. Photos numbered 4 and 5 show the inlet and outlet at this level. It was at this point that the investigators went to the dam.

Photo 4. Sheep Creek Inlet

Photo 5. Sheep Creek Outlet and Channel

On the afternoon of April 16 the authors measured the flow to be five inches over the south wall of the inlet. The ice in the outlet had been blown out, except for a section in the top inside of the pipe. This ice stayed in the pipe for the duration of the study. Photo number 6 shows the ice. The flow in the stream at the upstream bridge was estimated to be 120 cfs. The level of the reservoir appeared to be fairly steady as is evident from the gage readings in Table 1. Although it is not known for sure, but the gage reading for April 16 may not have been accurate. On the morning of April 17 it was evident that the staff gage had slipped out of place and had to be reset.

Photo 6. Ice in Outlet Pipe

Photo 7. Pitot Tube in Place with Restraining Bracket

At 1000 hours on April 17 the first series of pressure gage readings in the outlet pipe were taken. The depth of the water at this time was measured at 0.77 feet. A series of three readings were taken at holes number 1, 2, and 3. The position of the holes as shown on Figure 2 were chosen such that each would represent concentric equal areas of full pipe flow. From the three pressure readings taken an average pressure was calculated at 11.12 psi. Photo number 7 shows the gage as the readings were being taken. To the average gage reading a corrected head was added to compensate for the rise of the water in the hoses leading to the gages. This adjusted average pressure is known as the stagnation pressure since it represents the sum of the velocity pressure and the static pressure at each reading. The static head was determined to be equal to half of the water depth in the pipe when full pipe flow was not apparent. The static head was subtracted from the stagnation pressure to yield the velocity head. Once the velocity head was determined, the following equation was used to determine the average velocity:

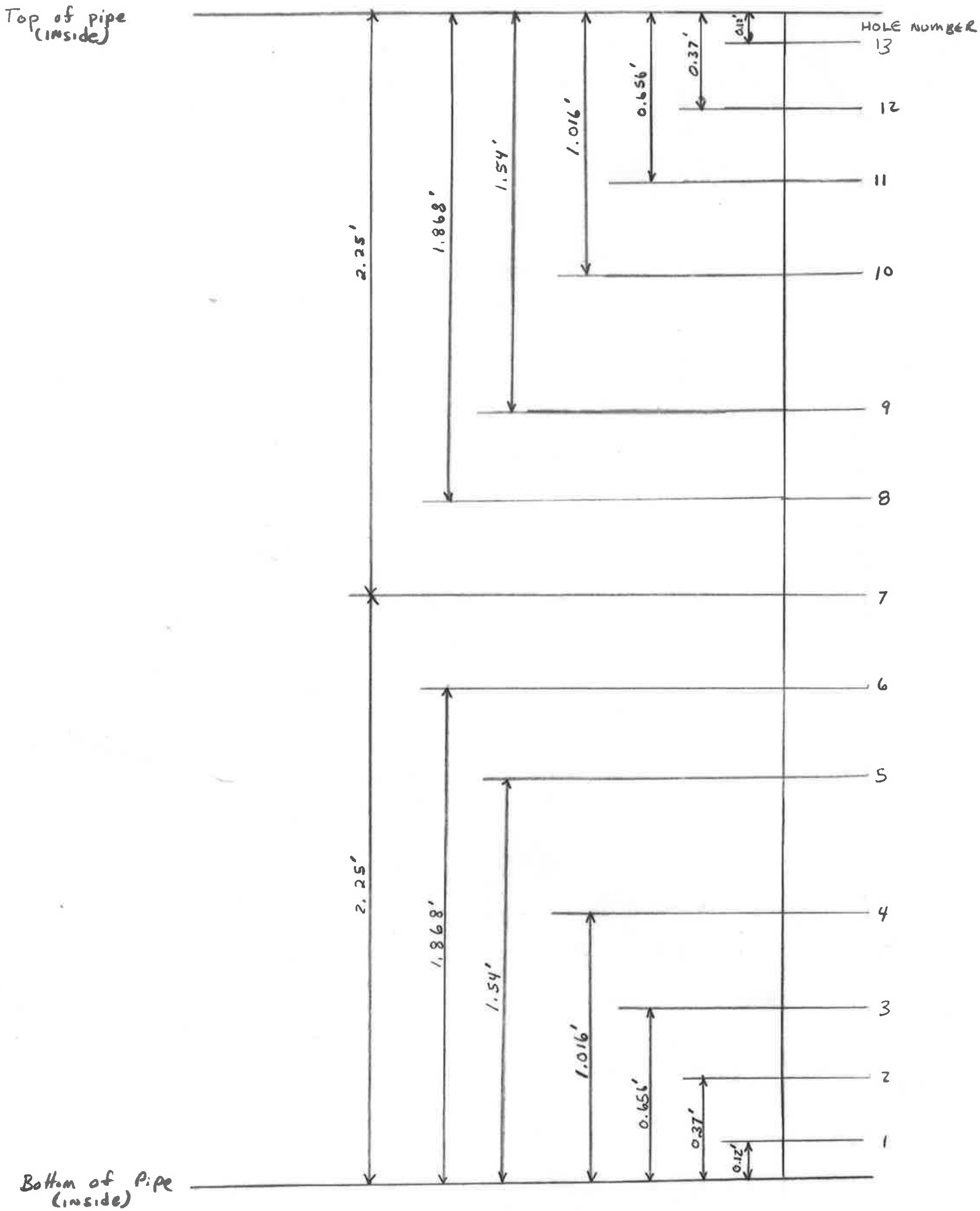
$$Vo = \frac{2\ (Pv)}{\rho}$$

Where Vo is the average velocity in feet per second (fps), Pv is the average pressure in psi and ρ is a constant equal to 1.94 $(lb\text{-}sec^2)/ft^4$. From this equation the average velocity was found to be 40.32 fps. Once the depth of the water was determined the area was found; using this and the average velocity the discharge was calculated by the equation:

$$Q=VA$$

Where Q is the discharge in cfs, V is the velocity in fps and A is the

Figure 2 Location of Pitot Readings



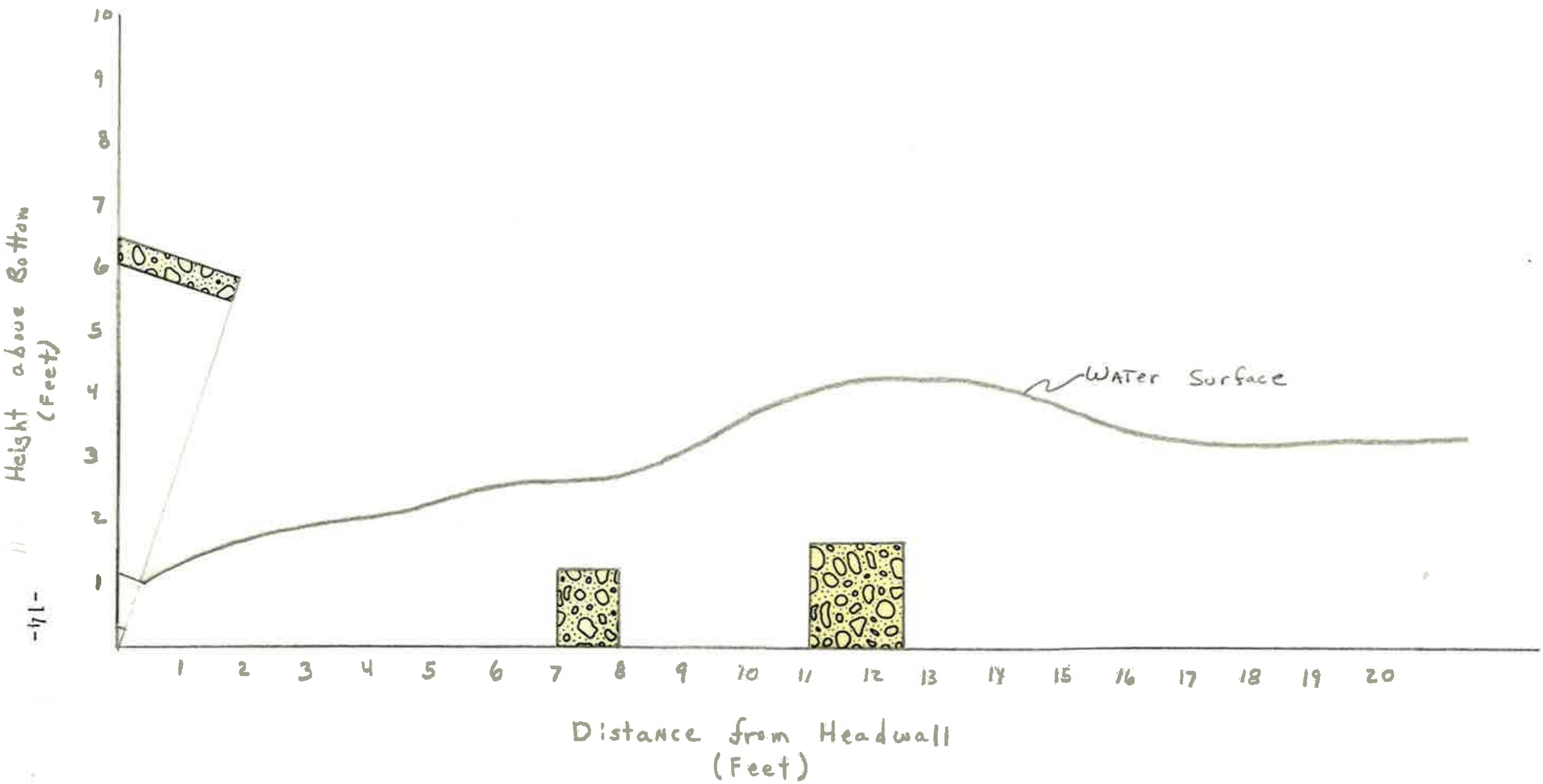
area in square feet. Table 2 shows the results of the gage readings and the calculated discharges. The calculated weir discharges are also listed.

At 1000 hours on April 17 a water surface profile was made at the side-walls of the stilling basin. Figure 3 shows this profile. Although the actual surface of the standing wave was only 4.25 feet, the spray reached heights of 7-9 feet above the water surface. Photo number 8 shows the wave and the spray.

Photo 8. Hydraulic Jump in Outlet

Photo 9. Deflection of Pitot Tube Arm

Figure 3 Water Surface Profile in Stilling Basin



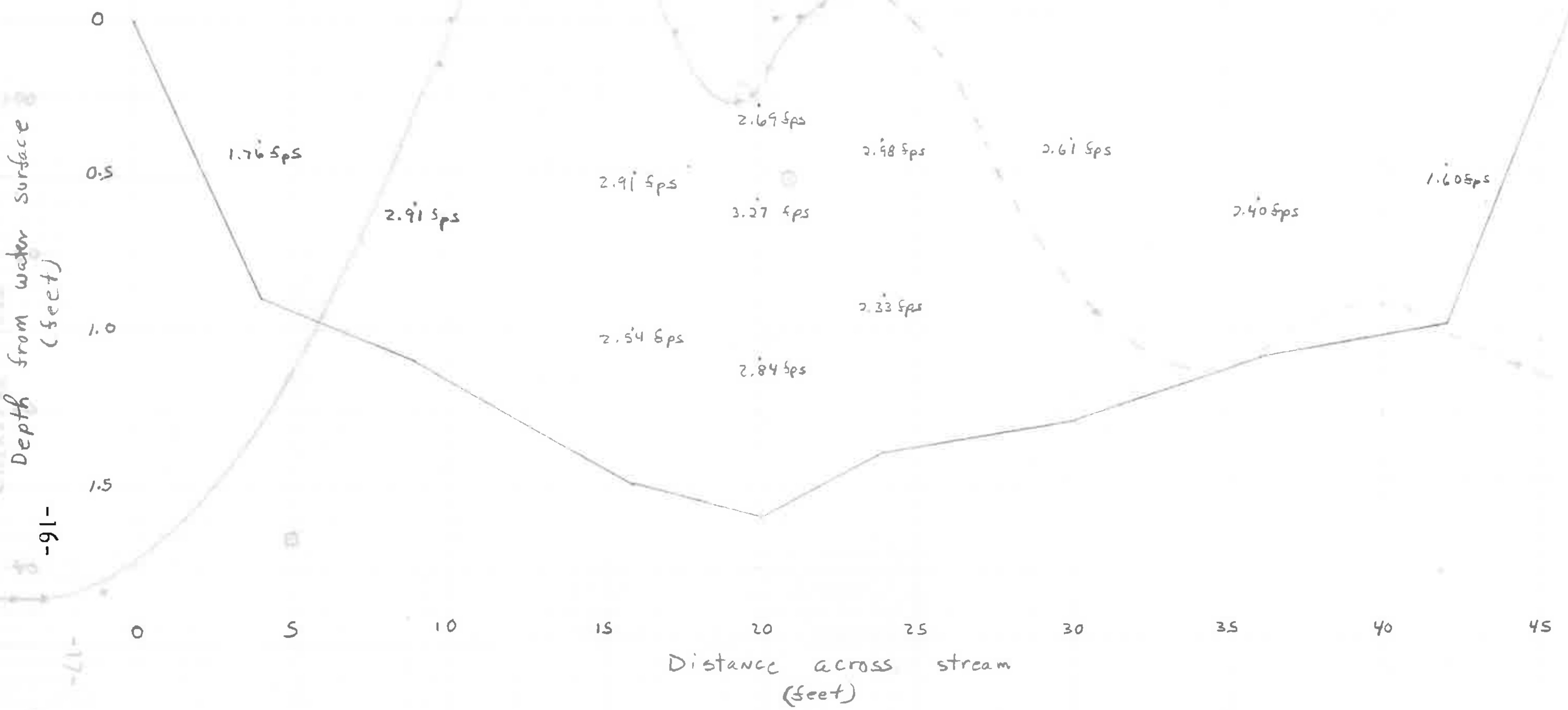
At 1900 hours on April 17 a stream gaging profile of Sheep Creek was made with a current meter at a point 1000 feet upstream from the bridge which is located two miles upstream from the dam. Figure 4 shows the results of the gaging profile and the corrected velocities at each point of measurement. The average flow velocity of the stream was calculated at 2.52 fps, yielding a flow of 130.7 cfs. The bottom of the stream was covered with a slushy ice-snow material to a depth of approximately 18 inches. Figure 4 represents the bottom of the flow and not the actual stream bottom.

On April 18 pressure readings and staff gage readings were made at regular intervals as shown in Tables 1 and 2. A stream gaging profile was also made at 1715 hours which showed a resulting inflow of 90.3 cfs.

It was evident on the morning of April 18 that the peak discharge which had occurred at 0300 hours reflected the peak inflow in Sheep Creek for the 1975 snowmelt.

Figure 5 graphically illustrates the discharge hydrograph as calculated from the staff gage readings. These discharges were calculated using a modified form of the equation $Q=CLH^{3/2}$, taking into account the sloping sides of the box inlet. C was varied between 3.0 and 3.4 according to St. Anthony Falls Technical Paper number 19, series B, page 11. From this it can be seen that the rise to the peak discharges is very short and rapid. In this case a matter of 30 hours. From this peak discharge, the volume of discharge continues for several days, although the peak discharge is never again approached. The 24 hour period centered around the peak discharges represents 34% of the total runoff under the hydrograph. This 34% should approximate

Figure 4 Stream Gaging Cross Section



Area of Flow - 51.9 square feet
Average velocity - 2.52 fps
Calculated Flow - 130.7 cfs

the 24 hour snowmelt runoff which causes the greatest problem to drainage areas. In this particular case the 24 hour runoff was dampened due to the fact that freezing of the snowpack was evident each night. Had this not happened the runoff volume would have been greater as well as the 24 hour runoff. In North Dakota it is accepted that the 24 hour runoff from a snowmelt is approximately 50% of the total runoff.

The rate of snowmelt was checked against calculated snowmelt. Calculated snowmelt is found by the following equation:

$$M = KD$$

Where M = Watershed snowmelt in inches per day, K = a constant which varies with watershed and climatic conditions and D = the number of degree days for a given day. This equation is known as the degree day method. Based on the above equation and a K of 0.06, which is average for the area, the following rate of snowmelt was calculated:

Date	Water Equivalent (inches)	Degree Days	Calculated Snowmelt (inches)	Remaining Water Equivalent (inches)
7 Apr 75	2.95	4	0.24	2.71
8 Apr 75		3	0.18	2.53
9 Apr 75		1	0.06	2.47
10 Apr 75		2	0.12	2.35
11 Apr 75		0	0	2.35
12 Apr 75		1	0.06	2.29
13 Apr 75		2	0.12	2.17
14 Apr 75		4	0.24	1.93
15 Apr 75		6	0.36	1.57
16 Apr 75		2	0.12	1.45
17 Apr 75		6	0.36	1.09
18 Apr 75		7	0.42	0.67
19 Apr 75		6	0.36	0.31
20 Apr 75		7	0.42	0

The calculated date of zero moisture conditions corresponds very well to the observed date, which also was April 20.

TABLE 2

Date	Time	Gage (MSL)	Water Depth in Pipe (ft.)	Area $(ft.^2)$	Adjusted Average Gage Pressure (Stagnation) (PSI)	Static Head (PSI)	Velocity Head (PSI)	Velocity (ft./sec)	Q (CFS)	Calculated Weir Discharge (CFS)
4-17	1000	___ 1/	0.77	1.79	11.12	0.17	10.95	40.32	72.2	
4-17	1745	25.48	0.974	2.52	11.85	0.21	11.64	41.57	104.8	100.9
4-17	2007	25.52	1.016	2.67	11.80	0.22	11.58	41.46	110.7	110.5
4-17	2245	25.59	1.079	2.91	12.15	0.23	11.92	42.07	122.4	124.8
4-18	1400	25.47	0.974	2.52	11.68	0.21	11.47	41.26	104.0	99.6
4-18	1640	25.52	1.016	2.67	11.92	0.22	11.7	41.68	111.3	110.5
4-18	2030	25.54	1.016	2.67	12.09	0.22	11.87	41.98	112.1	110.5

1/ Staff gage in error.

STUDY SUMMARY AND RECOMMENDATIONS

This study was initiated to answer the problem of slugging in the discharge pipe at Sheep Creek Dam and to check the methodology for determining hydrographs of snowmelt. Neither of the questions were answered completely by the study. The main reason for the incomplete results of the study was the manner in which the snowpack melted. There were warm days and below freeze nights. The night-time freeze cut of the inflow from the upper reaches of the drainage basin and effectively cut the peak inflows. This is reflected by the number of degree-days which was low. This condition prevented any major flooding in western North Dakota.

The inflow which reached the reservoir did cause a rise sufficient enough to measure pipe velocity. The velocities in the pipe under open channel flow condition was measured to be 41 fps. This velocity is much greater than the critical velocity for an open channel flow. These high velocities lead the authors to believe that the slugging problem is caused by the separation of the flow lines from the upper wall of the pipe as the pipe approaches full pipe flow. Future design should include the investigation of not allowing the velocity to exceed the critical velocity for the pipe under open channel flow conditions.

The weir coefficients were checked against the present design standards. These discharge coefficients (C) ranged from 3.0 to 3.4. The railing posts appear to have no effect on the discharge over the weir at the lower discharges. The maximum discharge coefficient would be approximately 4.6 according to the St. Anthony Falls Report.

The stop-blocks in the stilling basin appear to be doing a good job of dissipating the energy of the water at these lower discharges. Under future studies the velocity downstream of the stilling basin should be checked to evaluate the effectiveness of the stilling basin.

The degree day method did prove to be an accurate method of measuring snowmelt in this area of the state. It could be used in future studies to estimate snowmelt.

Future study should include a stage-discharge cure for Sheep Creek above the reservoir. This could be used to monitor the inflow hydrograph at regular intervals.

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