IMPOUNDMENTS ON MINED MOUNTAINTOPS IN EASTERN KENTUCKY

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Abstract

Impoundments on surface-mined lands date to the beginning of surface mining and usually were unplanned. Such impoundments on contour-type mining often failed, contributing to slides and excessive stream sedimentation. In some states, legislation was planned to prohibit impoundments. In 1973, two impoundments were constructed and instrumented on a mountaintop mine in eastern Kentucky to study their effects on mined-land hydrology. A number of wells, drilled in lines four directions from the ponds, were used to keep track of water table development. Rainfall on and runoff from the drainage areas of the ponds have been maintained by automatic recorders. The relationship of water level in the ponds to water table elevations in the wells is described. Ground water recharge has resulted in the formation of a perched aquifer with its phreatic surface mounded under the ponds. Data show that impoundments control runoff, contribute to ground water recharge, and, perhaps most important, mitigate flood flows.

Introduction

Impoundments on surface-mined lands date to the beginning of surface mining. On area-type mining it has been customary to leave the last cut open. Thus, water accumulated and an impoundment was formed. Many times the impoundments were such that water was forced between the spoil ridges, leaving a system of finger-like lakes.

For a long time, impoundments on contour-type surface mining were more or less happenstances. Debris falling off the highwall often blocked the drainage system, causing water to be impounded. Such impoundments generally were in the wrong places, especially from the standpoint of spoil bank stability. As a result of our growing awareness of the environment, laws and regulations have been formulated to alleviate adverse influences of surface mining and reclamation on the water resource. Impoundments no longer are allowed as a general case; permanent water impoundments must be approved by state regulatory agencies through plans submitted in securing mining permits. Planned water impoundments must meet specific standards established by the regulatory agencies.

Sedimentation ponds are required and must be constructed in accordance with regulations before surface-mining activity is started. This requirement generally precludes the use of ponds on the mined land itself for sediment control. Such requirements may not be in the best interests of land managers insofar as water runoff and sedimentation are concerned.

The Surface Mining Control and Reclamation Act of 1977 specifically requires characterization of the hydrology of any mine site, and an assessment of the probable hydrologic consequences of the proposed mining and reclamation activities. Mining permits may not be granted until such information is provided. Yet data are scarce regarding the impact of mining on surface runoff and ground water in the mountainous regions where contour mining and mountaintop removal are acceptable practices.

The Study

To document the effects of impoundments in controlling runoff and preventing stream sedimentation from surface-mining activities, two ponds were instrumented in August 1973 that were constructed during the mining of a mountaintop in Breathitt County, Kentucky. The areas were mined during 1971 and 1972 by a method called "mountaintop removal." In this method, all overburden is removed, the coal is taken out, and the relatively flat rock surface that remains is used as a spoil dump and covered with several meters of spoil material. The spoil is then graded as part of the reclamation process. Low places on the graded spoil may become ponds, either by design or by accident. The ponds in this study were constructed so that they were on at least 10 m of spoil material.

The drainage area for Spicewood is 3.49 ha and for Two-mile 5.46 ha. A different drainage area for Spicewood has been reported in other work(1,2). Since earlier studies were reported the spoil has settled, creating depressions that accumulate water. As a result, it is felt that the entire area did not drain into the ponds under study.

The surface area of the ponds vary according to the depth of water at a given time. This was taken into account when computing the amount of runoff into the ponds. Direct rainfall into the ponds was subtracted from the total volume accumulation. A water-level recorder was installed on each pond and weighing-type precipitation recorders were set up. The ponds were mapped so that volume-depth tables could be developed (Figure 1). In 1975, a number of wells were drilled about 8 to 10 m apart in four directions from the two ponds to study recharge and groundwater development (Figure 2). Observations of depths to the water table in these wells were used to note the buildup of a water mound as a result of infiltration and percolation of water, both from the spoil itself and from the pond.

Access to the Two-Mile pond was cut off in November 1977 after nearly 2 years of observation. Measurements of the Spicewood pond were fairly regular from August 1975 through April 1980 with some periods of missing data. Water elevations in the wells at Spicewood were measured monthly for the most part from 1975 through July 1983. Even though the data are intermittent, much information has been gained over the past 10 years.

Past Work

For a long time it has been surmised that impoundments or ponds on surface-mined lands are useful in regulating water, yet there is a scarcity of published information. Hill(3) showed how to calculate runoff by measuring the rise in water level of a pond. He also suggested a method for determining the drainage area required to maintain desired pond levels. In his article "Reclaim Your Land with Lakes," Rosso(4) extols the virtue of impounded water bodies on surface-mined land. He suggests that water bodies on mined land are important sediment traps, sources for future water supply, groundwater recharge zones, and wildlife habitats. In addition, he points out that impoundments can provide some local flood protection and improve the area's aesthetic and recreational appeal, and may be useful in improving water quality from the area.

Wildlife

Leedy(5) summarized information relating to fish and wildlife needs on surface-mined land. He indicates that for fish production in ponds, the water should be 1.5 to 1.8 m deep with deeper holes in areas subject to heavy freezing. It also is important to have adequate shallow water because bottom organisms that contribute significantly to the diet of fish grow best in shallow water and many fish spawn there. Any pond over 1/10 hectare is suitable for fish production, but larger ponds provide more opportunities for multiple fish and wildlife production.

Under a cooperative research agreement with the USDA Forest Service, the ponds in this study were stocked with bass and bluegill on April 27, 1974, by Drs. Branley Branson and Donald Batch of Eastern Kentucky University at Richmond. Cicerello(1) analyzed the results of this effort; even though the ponds lacked the most desirable features for fish habitat, stocking and subsequent fish production were considered successful.

Water Quality

The potential benefits of impoundments in the control of quality of water on mine sites has been known for a long time. Oxidation of pyritic materials in a coal seam at the edge of a strip-mine pond that receives acid mine drainage from this source sometimes can be prevented by raising the water level sufficiently to cover the seam and prevent air from reaching it(6).

Cole(7) outlined a method whereby ponds can be used in the treatment of acid drainage. The method involves rather large ponds that are treated with lime to raise the pH to 6.0 or higher. The reason for using large ponds is to build up an alkaline reserve that would take care of sudden slugs of acid either intentionally or accidentally dumped into the stream above the pond.

Sediment Control

In contour surface mining, the use of ponds is a primary method for sediment control. Generally, the basins are constructed in drainways below the mined site rather than on the disturbed land itself because they must be constructed before any mining disturbance begins. These ponds prevent surface runoff and sediments from flowing directly into streams. Water is detained long enough to allow most of the suspended solids to settle out. Detailed specifications for constructing sediment ponds are available from various state regulatory agencies. Such specifications may differ somewhat from state to state.

Results of the Study

Precipitation

A summary of monthly precipitation for the study period is presented in Table 1. The years 1973-79 were average or above in precipitation. An extended period of below normal precipitation began in 1980 and continued through 1983. The monthly averages show that precipitation generally is fairly well distributed throughout the year.

Groundwater

Sixteen wells were drilled at the Two-mile pond and 14 at Spicewood to depths such that their bottoms would be below the pond bottom so that water table elevation could be measured. Two years elapsed from the time the ponds were constructed until the wells were drilled. During that time the water table generally had been formed.

Wells were tested on June 20, 1982, to see if they were in a water-table situation or if they were merely "cisterns." It was decided that well measurements were valid if pumping a significant amount of water into the well did not result in a significant change in water elevation. Following this test, data from wells B-4, C-2, and D-4 at Spicewood were dropped. Some data from other wells were lost during the study due to vandalism.

Ponds are the primary sources for recharge water in the study areas. The sources of water inflow into the ponds are direct precipitation and surface runoff from the surrounding watershed. Water loss from the ponds is by evaporation from the water surface, transpiration from marginal vegetation, and leakage from the bottom of the pond. No overflow has taken place from the study ponds. The leakage from the bottom of the pond being studied is contributing to ground water recharge.

When the rainfall intensity exceeds the infiltration capacity of the spoil, water will run off sloping surfaces and will pond in depressions. Water will infiltrate the pond bottom and will move vertically through the spoil. When the percolating water first encounters bedrock, there will be a saturated front throughout the spoil bank and a ground water mound will develop. If water continues to be ponded on the surface, the mound will develop until its phreatic surface intersects the water level in the pond. The phreatic surface within the spoil bank will rise more rapidly in response to infiltration if the bedrock is impermeable than if leakage was significant through the bedrock. During mound formation water also is moving laterally, slowly reducing the slope of the phreatic surface.

Wardwell et al.(8) have presented equations for computing the time necessary for the various phases of ground water development. Their work involved coal-mine waste piles that are placed on less permeable materials. Spoils are considered to be similar to these piles; at least the same mechanisms are involved insofar as water movement into and through the material is concerned. It is possible that the equations could be used to estimate recharge here; however, no attempts were made to do so.

Bianchi and Haskell(9) studied recharge and ground water mound development in relation to two ponds on gently sloping alluvial fans in Fresno County, California, using well measurements to determine the level of the phreatic surface. They compared observational data with theoretical evaluations and offered equations that should be useful in predicting both ground water mound development and its lateral spreading.

Figures 3 and 4 indicate a buildup of the phreatic surface over time. When Spicewood well A-1, located about 10 m from the edge of the pond, was installed in late summer 1975, the water table was at about 24.4 m. By mid-1978, it rose to about 25.6 m but has dropped some through 1983. The level in well A-1 has not been above the elevation of the bottom of the pond and water level in the pond has been 3 m or more above that in the well. Apparently, there is very little or no recharge from the sides of the pond.

Well B-5 at Spicewood (Figure 4) is 40 m from the edge of the pond. By late 1978, the water level had risen from about 1 m below to about 1 m above the bottom of the pond elevation. And, like A-1, the pond level remains above the well water level. Beginning about mid-1982, the water level in well B-5 began to drop. The cause for this has not been determined, though it could be that water is now draining laterally out of the spoil bank.

Water table elevation in wells in line A at the Two-mile pond provide a good example of the water mound buildup (Fig. 5). Well A-1 is 10 m from the edge of the pond. Wells A-2, A-3, A-4, and A-5 are 10 m apart. Figure 5 illustrates a lower water table as distance from the pond increases. Gradually, the water table will build up to an elevation equal to that of the pond surface if there is no lateral flow out of the spoil banks or if the lateral distance through the spoil is great enough to result in a fairly flat phreatic surface in the vicinity of the pond.

Figure 6 shows gains and losses in the volume of water in Spicewood pond over a 7-year period. Since there has been no overflow from the pond, we must surmise a balanced hydrologic budget, i.e., inflow equals outflow. If we assume losses through evaporation according to Kohler et al.[10], 25 to 30 cm of precipitation would be available to recharge soil water and contribute to ground water formation. Three-fourths of the evaporative loss is during May through October. It is evident from Figures 6 and 7 that this also is the period of greatest loss from the pond. So long as water remains in the pond, it is likely that the ground water mound will continue to develop from the recharge.

If only 25 to 30 cm of water are available annually to charge the spoil, the advancement of the wetting front can be estimated from assumed water-holding capacity. If the water-holding capacity of the spoil is 25 percent by volume, then 7.6 cm of precipitation will wet 30.5 cm of spoil; 30 cm of water will wet 1.22 m of spoil. Thus, a wetting front would be expected to advance at the rate of about 1.22 m per year. If the spoil depth is 14.6 m, it would take 12 years for this wetting front to reach the spoil foundation (bedrock) and start a water mound buildup. However, where a greater supply of water is available, such as underneath a pond, this process would be more rapid.

Where water is impounded on the spoil surface, the steady supply of water causes the wetting front to advance rapidly. Lateral movement of water takes place through capillary action as the wetting front descends, and when the front reaches bedrock, lateral movement may be rapid.

Surface Runoff

The primary objective of this study was to determine the effects of impoundments on surface-mined land on the control of surface runoff and erosion. Since the ponds never have overflowed, any material moved through water erosion is stored in the pond. Although sediment accumulation has not been measured, the ponds have been 100 percent effective in preventing off-site sedimentation problems.

Runoff was computed as the difference between the increase in pond volume and the amount of precipitation falling directly into the pond. Values obtained were plotted in Figure 8. More of the precipitation became runoff during the earlier years of the study than in later years. This is reasonable and can be attributed to the improving vegetative cover with the beginning of litter accumulation and organic matter formation, all of which are conducive to increased infiltration. Increased infiltration and percolation generally means reduced surface runoff. A comparison of regression equations for individual years shows a definite drop in the slope of the regression lines beginning in 1978. The equations for individual years are:

1974 $\hat{Y} = 0.58 - 0.52X$ $R = .8734$
1975 $\hat{Y} = .64 - .43X$ $R = .8575$
1976 $\hat{Y} = .52 - .37X$ $R = .8552$
1977 $\hat{Y} = .63 - .44X$ $R = .7956$
1978 $\hat{Y} = .34 - .26X$ $R = .8218$
1979 $\hat{Y} = .26 - .21X$ $R = .7179$
1980 $\hat{Y} = .19 - .02X$ $R = .6366$
where X equals precipitation.

Increase in pond volume and precipitation on the watershed have a correlation of 0.7836. The prediction equation developed from 7 years of data is shown in Figure 9. Concerning water impoundments on surface-mined land, one thing can be said for the two ponds in this study: all runoff from their drainage areas has been controlled. As was mentioned, the ponds never have overflowed.

At this point, two situations will be discussed in some detail. The first involves a storm that hit southeastern Kentucky in early April, 1977. Heavy rains fell over southeastern Kentucky, eastern Tennessee, and western Virginia and West Virginia on April 3 and 4(11,12,13). Rainfall exceeded the 100-year recurrence interval in many areas. Flood discharges exceeded any previously known on many streams. Property damages reportedly exceeded several hundred million dollars and a number of lives were lost due to the storm. Runner and Chin(12) describe the storm system and its movement in some detail. Considerable discussion of the storm, flooding, and possible factors contributing to the flooding can be found in the Commonwealth of Kentucky report(13).

Many people laid blame for the flooding directly on surface mining. Now, while some surface-mined land no doubt contributed to increased runoff, some did not. In fact, some mined land retarded flow during the storm period(11).

Specific data from the Spicewood pond have been compiled for April 2, 3, and 4, 1977. The spoil area draining into Spicewood pond was 5.5 ha. Rainfall was measured at 8.33 cm at the site, 1.50 cm of which came late on April 2; the remaining 6.83 cm came late on April 3. The pond began to rise almost as soon as the rain started and continued to rise until about midnight on the 4th. The increases in volume of water in the pond was 1875 m^3. This is equivalent to 3.40 cm over the drainage area and amounts to 41 percent of the storm precipitation. Streamflow from an unmined watershed amounted to 76 percent of the precipitation over the same period(2). To carry this one step farther, even though surface runoff was 3.40 area cm during the storm, the total amount was caught in the pond and none contributed to the flood.

On December 7, 8, and 9, 1978, another major storm hit eastern Kentucky, resulting in severe flooding along the Kentucky River with a record crest at Frankfort. During that storm, 12.45 cm of rain were recorded at the Spicewood pond site. Runoff into the pond amounted to 4.90 cm over the drainage area. Again, about 40 percent of the precipitation became runoff. As in the April, 1977 storm, the pond held all of the runoff and 5.5 ha of mined land did not contribute to the flood.

Discussion

Eventually, water tables will build up in all spoil banks underlain by impermeable bedrock. There is wetting front throughout the spoil area, but in eastern Kentucky only about 25 percent of the annual precipitation is available to charge the spoil and to promote the wetting front. According to Kohler and others (10), the average annual lake evaporation for the study site is approximately 86 cm. About 73 percent (63 cm) of this annual evaporation takes place from May through October.

Water mounds can be expected to build up faster in mine spoils under a water impoundment than when there is no impoundment. Where ponds are present, most of the water infiltration and percolation from the pond is straight down. When this percolate reaches bedrock, mound development begins. Some lateral movement also begins early. As the mound builds higher, lateral spread increases. If the phreatic surface of the mound intersects the spoil surface, a seep or spring is likely to develop. This is why we must pay close attention to location, design, and construction of ponds on surface mines in mountainous regions. Distance of the pond from the edge of the spoil should be a major consideration, as should the placement of any spillway. Perhaps a subterranean spillway should be used to move excess water to the most desirable position for spillage.

Ponds can be used successfully to control runoff from disturbed areas. In fact, ponds could be used not only to control water but to regulate it. In addition, ponds can, in many cases, be developed into multiple-use areas.

Conclusions

Water levels in two ponds in Breathitt County, Kentucky, and levels in wells installed around these ponds have been analyzed in relation to water table development and changes in pond storage during storms.

A water mound develops rapidly where ponds are located on the spoil surface and bedrock under the spoil is impermeable. The mound spreads laterally and a water table is formed in the spoil mass.

Neither of the ponds in this study has overflowed even during major storms in April 1977 and in December 1978. Thus, not only did these areas not contribute to flooding, they did not even contribute the quantities of water that would have come from the same area in an unmined condition. Since the ponds never have overflowed, they have been 100 percent effective in sedimentation control.

Acknowledgment

I thank Falcon Coal Company for constructing the ponds for study and for permission to work in the area to collect data on rainfall, runoff, pond storage, and ground water in the vicinity of the ponds. I also thank the Kentucky Bureau of Surface Mining for help in initiating the study.

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Table 1. Precipitation (in inches) at the Spicewood pond in Breathitt County, Kentucky (1 inch = 2.54 cm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1970	1.18	3.97	4.28	6.29	2.62	3.95	2.88	5.76	3.92	5.14	2.53	5.38	47.90
1971	4.86	3.34	2.42	3.61	6.76	4.38	6.48	3.06	6.98	3.08	2.07	2.21	49.25
1972	7.59	7.35	4.47	9.38	3.11	2.55	4.48	1.20	5.96	2.06	4.10	7.13	59.38
1973	1.50	2.50	4.49	4.89	5.14	3.09	4.21	1.52	3.06	3.50	8.78	3.84	46.52
1974	8.46	1.74	8.39	4.53	5.28	9.12	4.08	5.05	3.20	1.86	4.95	3.64	60.30
1975	3.78	3.52	10.18	3.46	6.29	3.79	1.28	2.96	6.16	3.35	3.44	3.41	51.62
1976	3.05	3.24	5.55	.71	2.44	5.61	4.70	3.64	4.65	4.99	2.95	4.82	46.35
1977	5.48	1.77	2.64	5.15	2.92	5.67	3.43	6.49	2.12	3.75	3.28	1.99	44.69
1978	2.79	2.31	2.92	3.13	4.45	2.52	6.19	6.45	1.00	1.16	2.88	9.18	44.98
1979	6.11	3.03	2.89	4.15	4.19	3.52	5.84	4.06	4.48	2.14	3.62	3.55	47.58
1980	2.40	1.11	4.24	2.35	1.28	0.88	4.32	1.91	2.32	0.30	3.91	2.93	27.95
1981	0.22	3.83	2.86	4.47	4.67	4.94	4.74	2.32	1.94	3.64	0.72	3.00	37.35
1982	5.27	0.33	6.43	1.58	3.74	4.04	2.42	4.38	4.06	1.54	4.47	2.58	40.84
1983	0.71	2.08	2.03	2.83	7.06	2.62	2.56	3.57	1.93	3.79	2.09	2.36	33.63
Monthly average	3.81	2.87	4.56	4.04	4.28	4.05	4.11	3.74	3.70	2.88	3.56	4.00	45.60

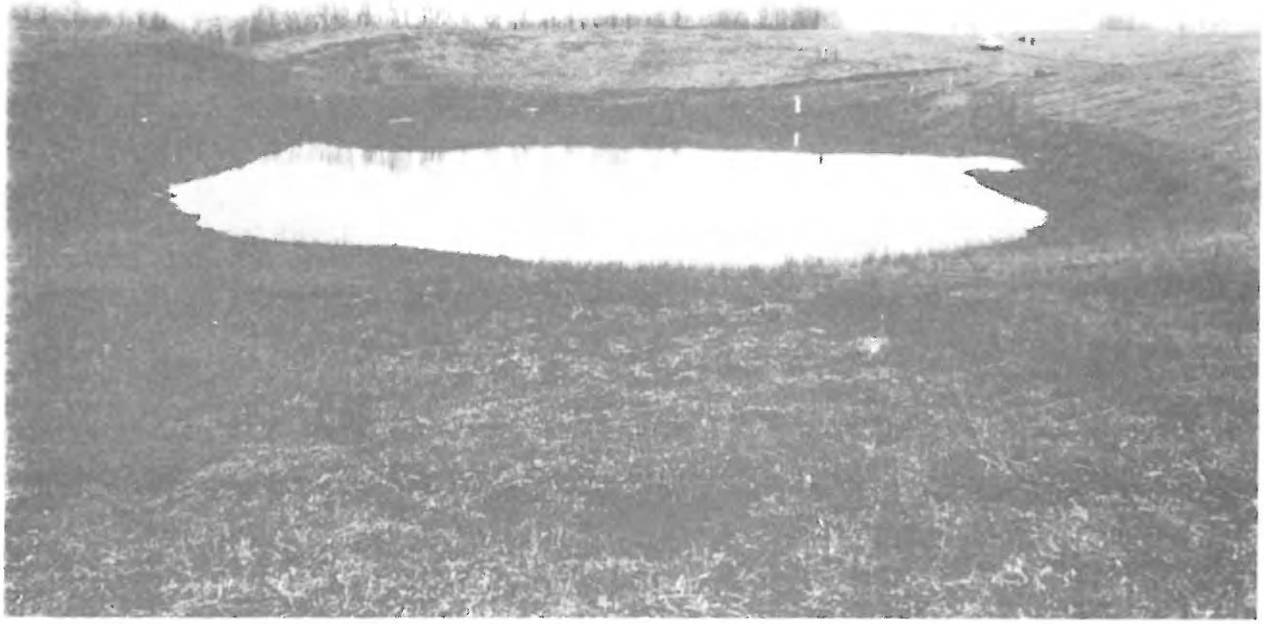

Figure 1. Spicewood pond showing the water level recorder, rain gage, and two observation wells.

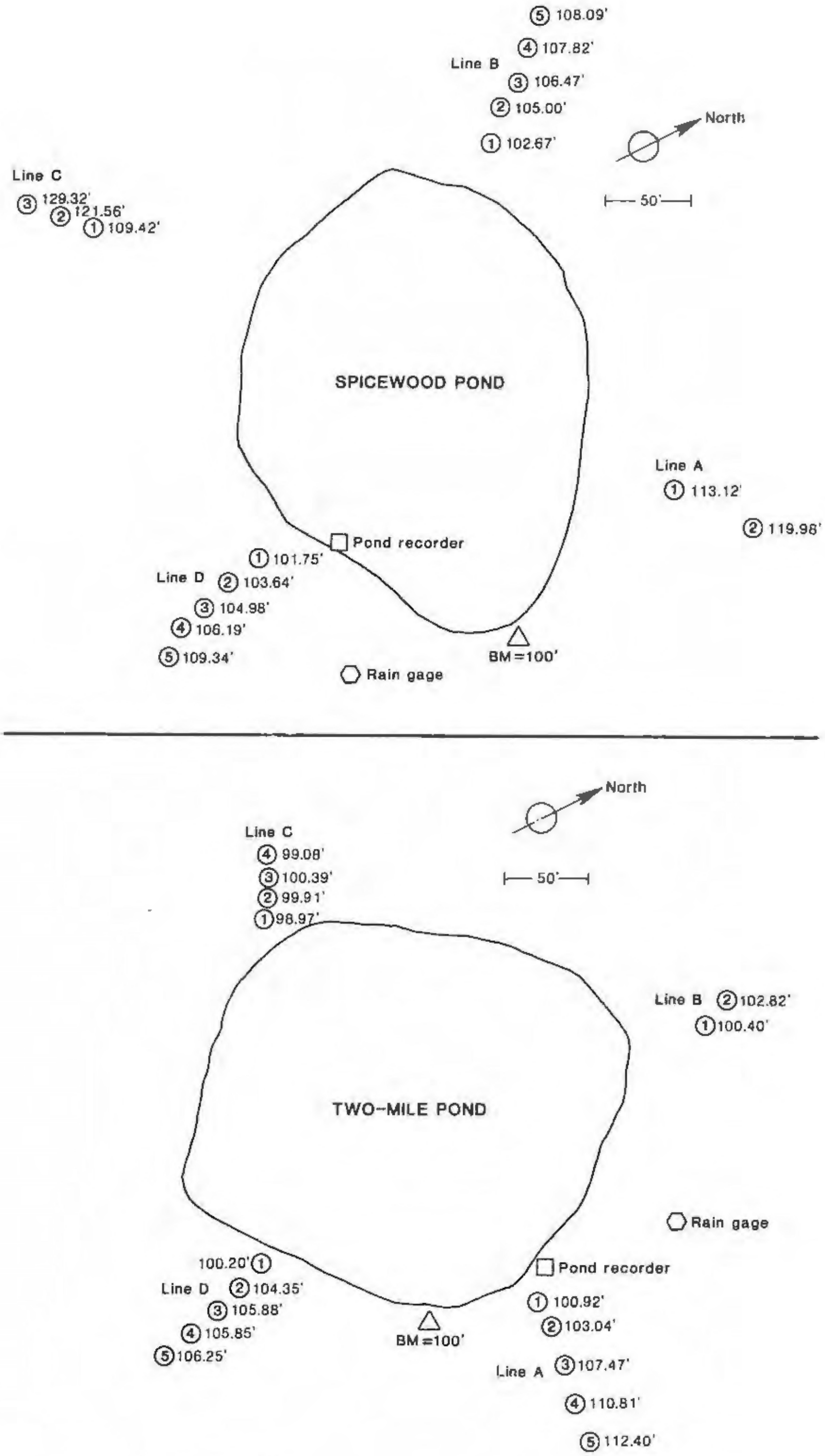

Figure 2. Well elevations in relation to bench mark datum and locations in relation to the ponds (1 foot = .305 m).

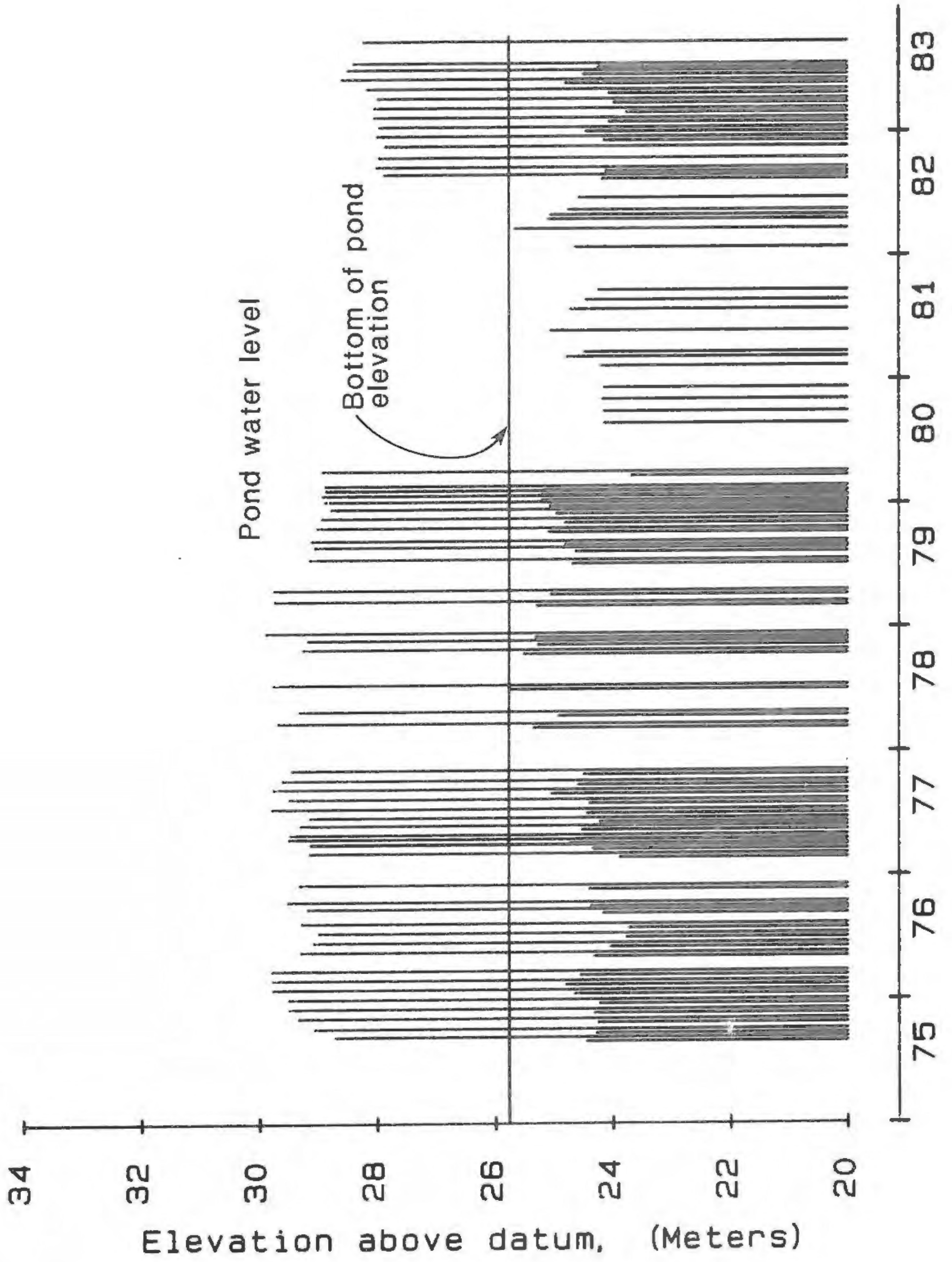

Figure 3. Water table elevations in Spicewood well A-1 in relation to pond bottom and pond water level elevations. Pond level data were not collected from April 1980 to August 1982.

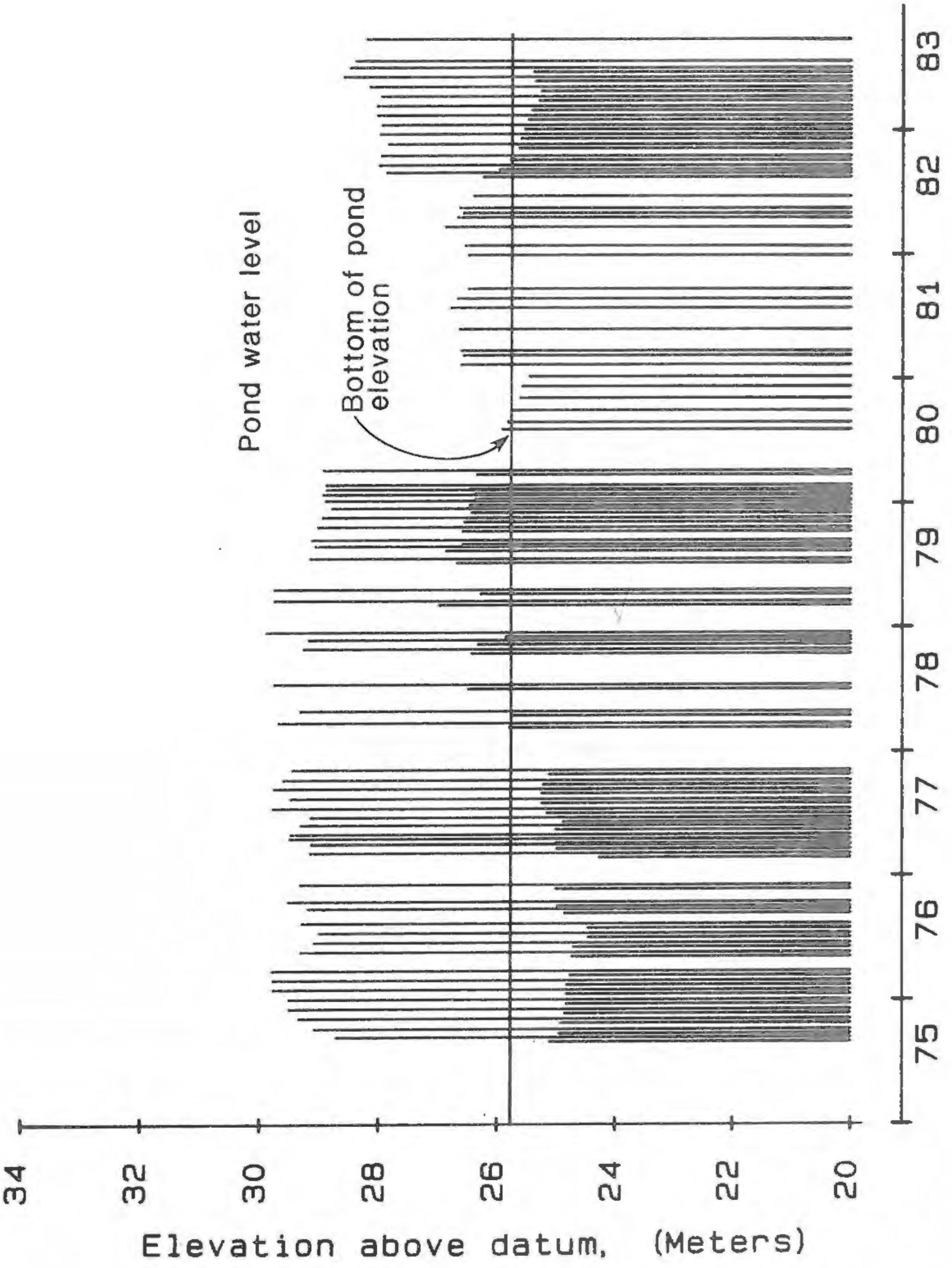

Figure 4. Water table elevations in Spicewood well B-5 in relation to pond bottom and pond water elevations. Pond level data were not collected from April 1980 to August 1982.

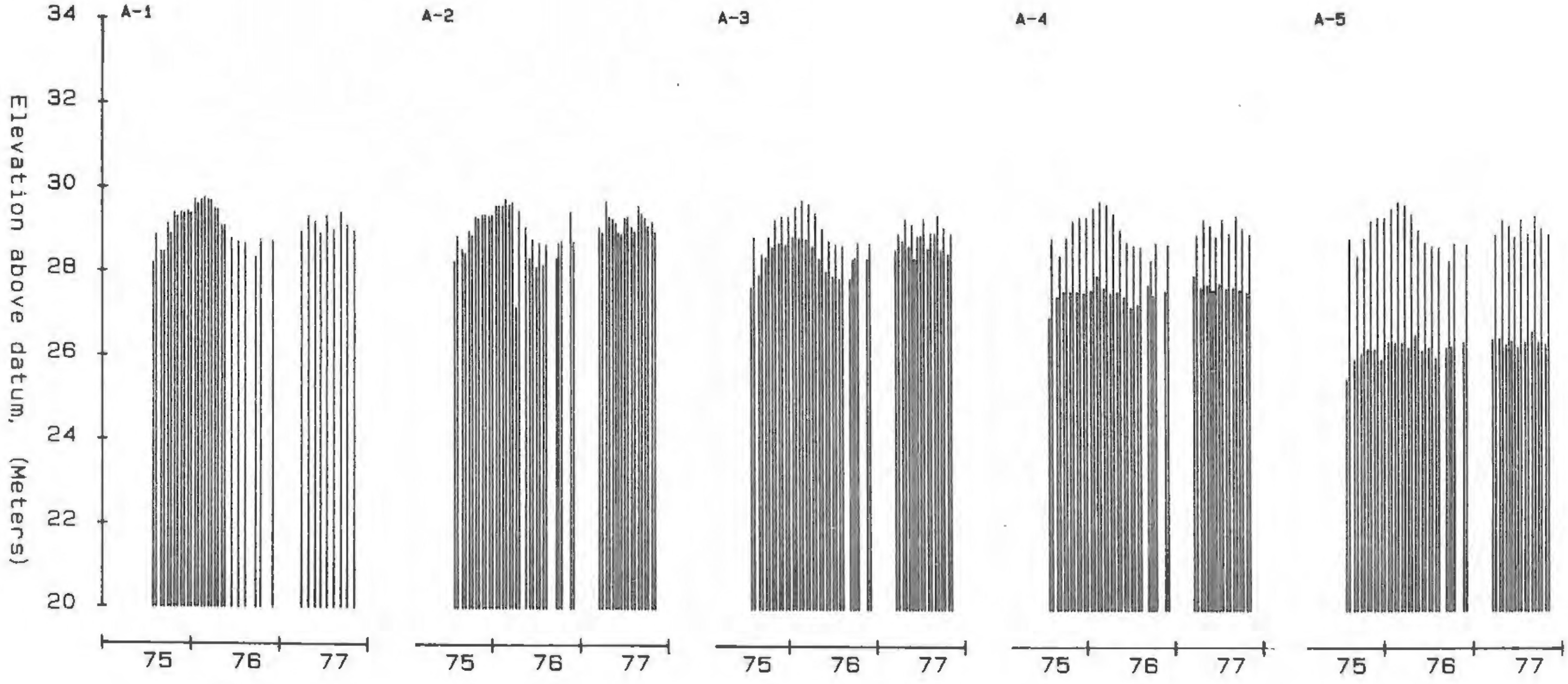

Figure 5. Water table elevations in 5 wells in row A at the Two-mile site in relation to pond water level. Data collection from well A-1 was discontinued in April 1976 due to vandalism.

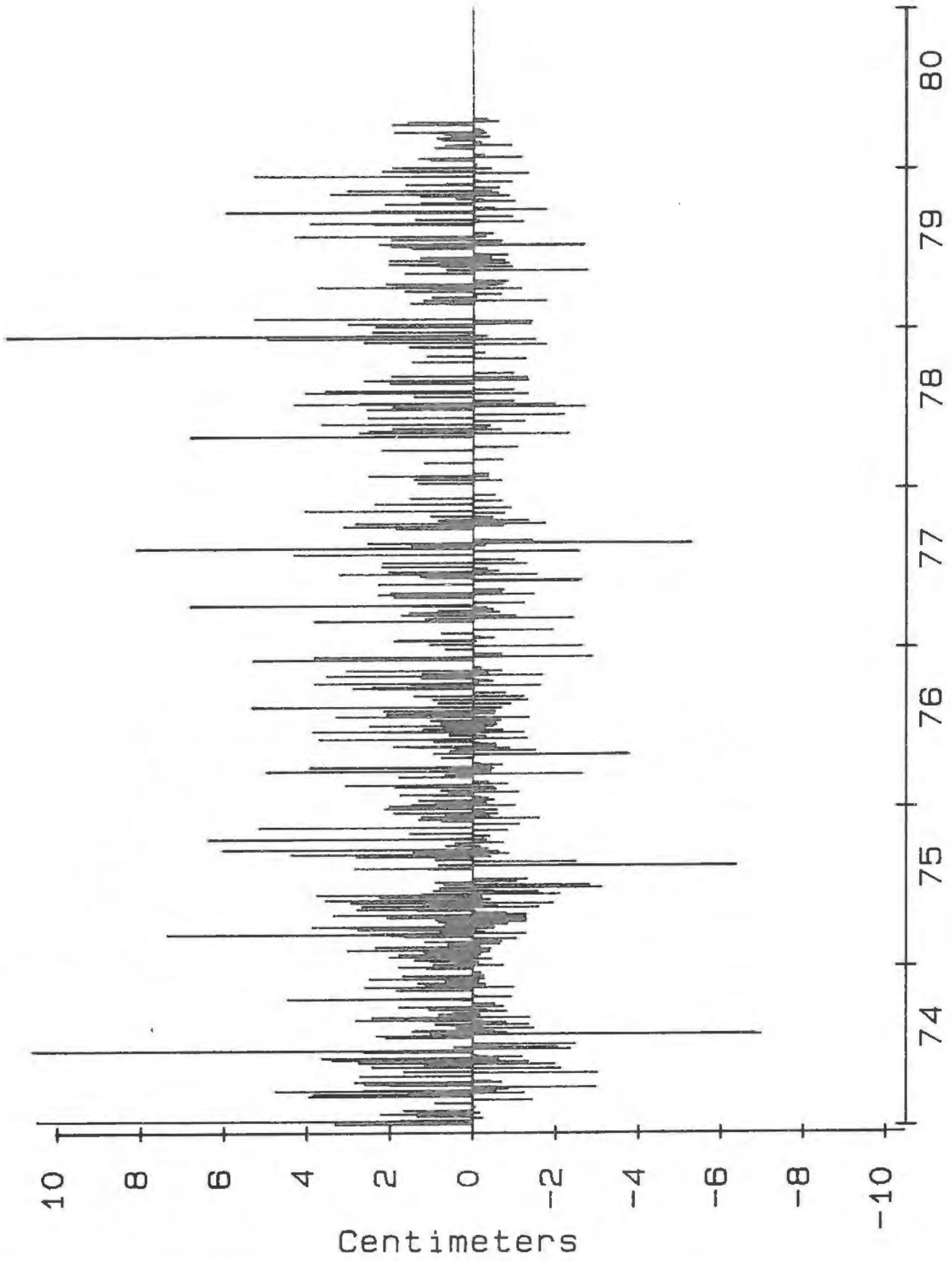

Figure 6. Total precipitation on the Spicewood pond drainage area and losses from pond storage over a 7-year period, in area centimeters.

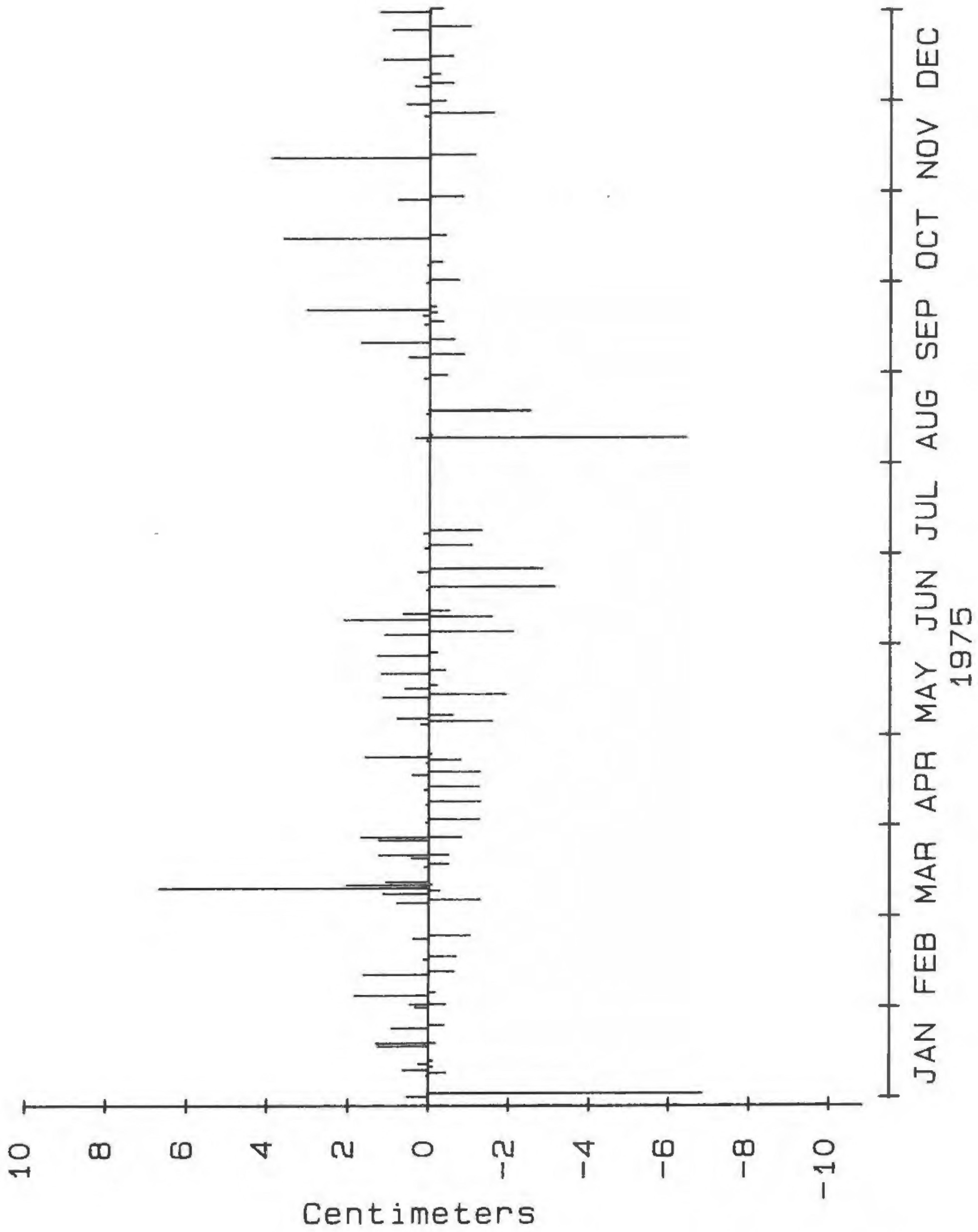

Figure 7. Gains and losses in pond storage. Values are equivalent to centimeters of depth over entire drainage area.

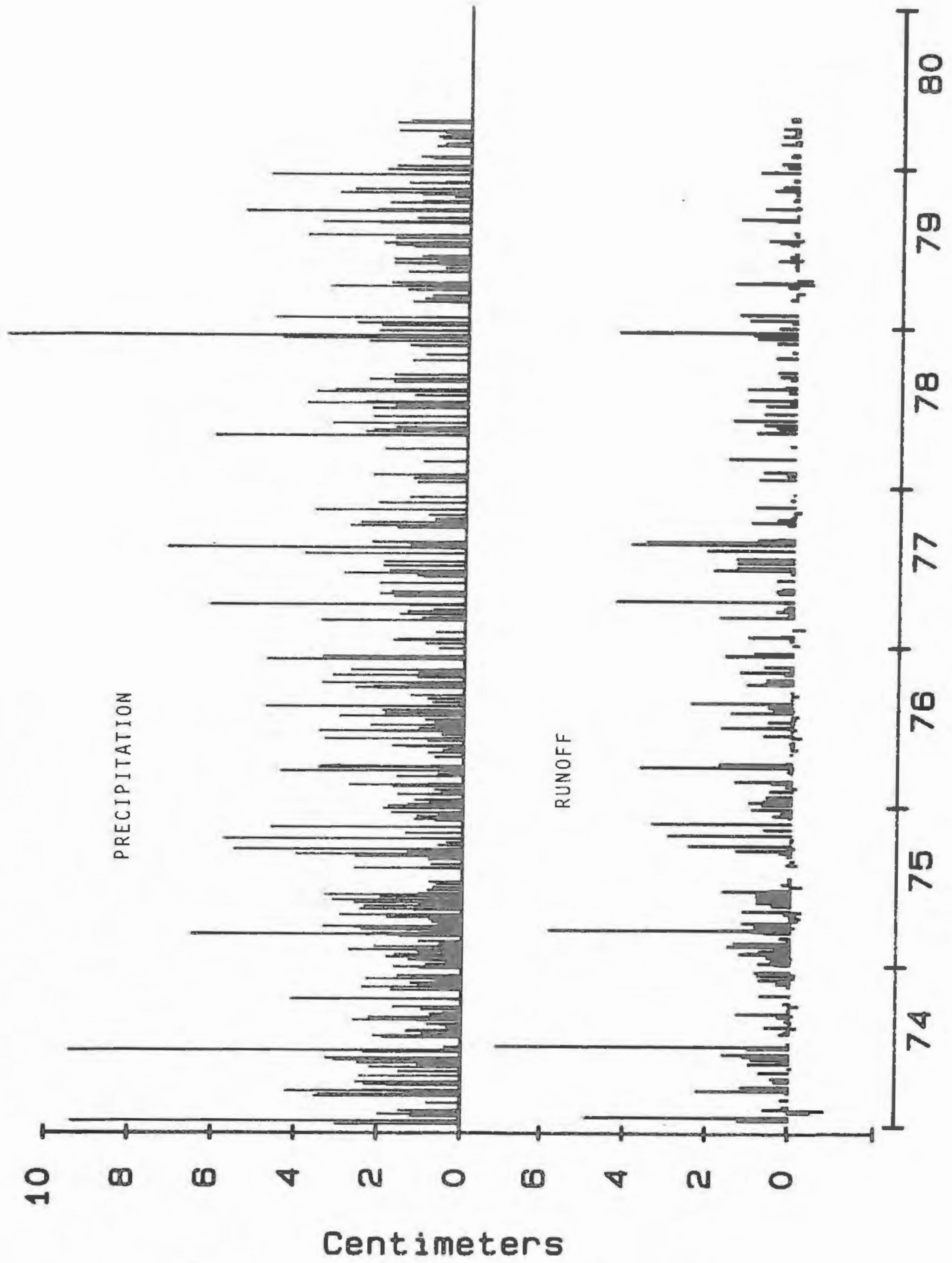

Figure 8. Precipitation on Spicewood watershed and runoff into the pond, in area centimeters.

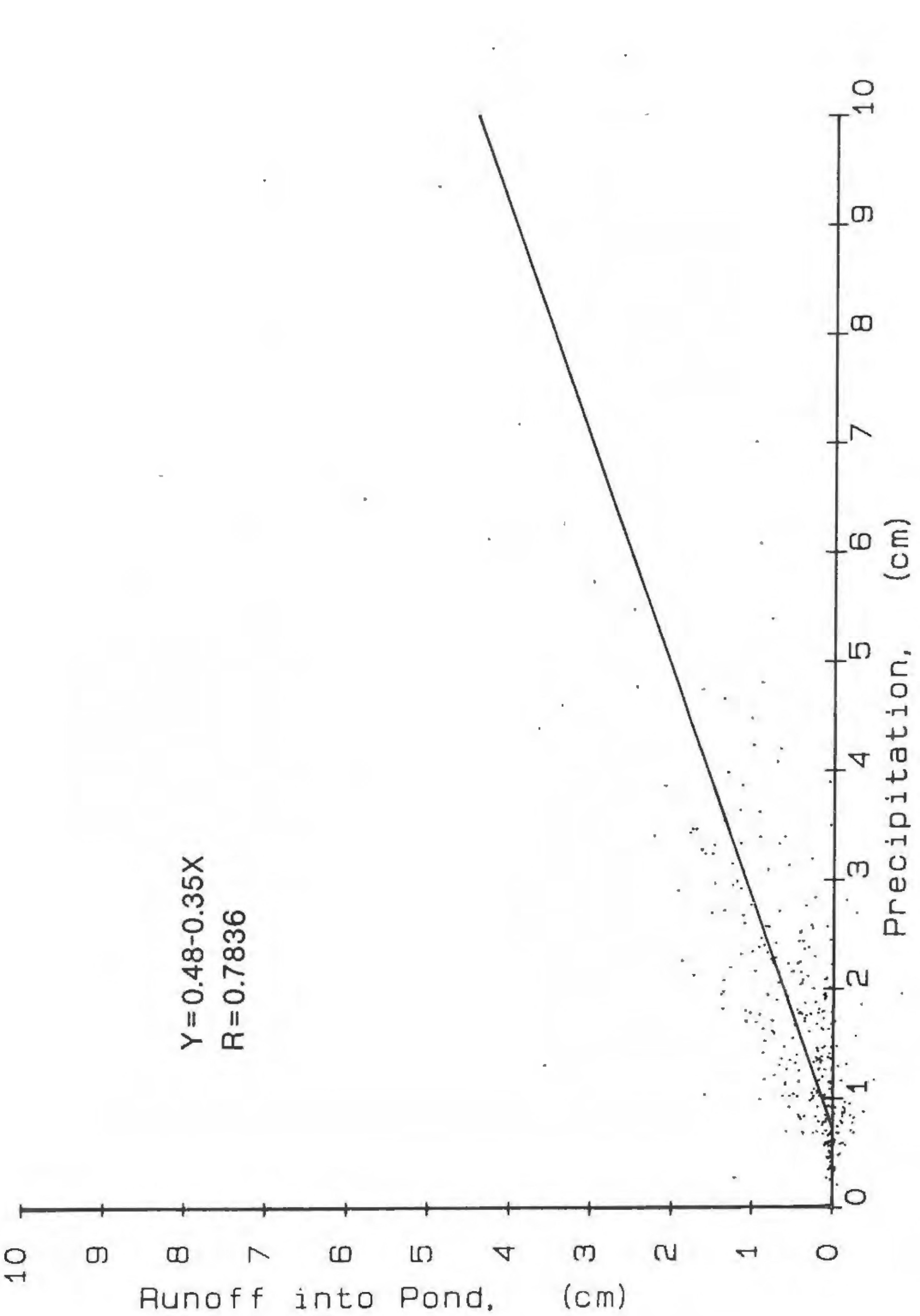

Figure 9. Relationship of increase in pond volume to watershed precipitation, in area centimeters.