

United States
Department of
Agriculture

Forest Service

**Technology &
Development
Program**

7700 Transportation Management
December 2000
0077 1804 SDTDC



Field Evaluation of the Long-Term Performance of Geocomposite Sheet Drains



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December 2000

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ACKNOWLEDGEMENTS

Funding for this project was provided by the U.S. Federal Highway Administration, Coordinated Technology Implementation Program (CTIP). The authors are grateful for the field assistance of Mark Leverton, Mark Truebe, and Richard Wischart from the United States Department of Agriculture (USDA) Forest Service (FS) and Mike Long from the Oregon Department of Transportation (DOT).

ABSTRACT

The long-term performance of geocomposite sheet drains were monitored at three sites by measuring the effect of the drains on site groundwater hydrology during peak groundwater events. The study is on-going with a maximum record of 14 years at one site in the southern Sierra Nevada Range, CA.

Over a 3-year period, the drain at one site produced as much as 100 liters per minute with no rise in the water table just down gradient from the drain. The peak hydraulic gradient toward this drain consistently reaches 0.66 to 0.73 during major rainstorms and returns to a “base level” of 0.45 to 0.50 within 10 days after a storm peak.

At a second site, the drain flowed up to 15 liters per minute with no water table rise in a retaining wall fill down gradient from the drain. Performance of this drain was consistently favorable over a 14-year period with no deterioration. Limited data suggest that the drain discharge (liters per minute) is proportional to about 13 times the hydraulic gradient toward the drain.

At a third site, drain performance is limited by construction problems. A collapsed trench wall during drain placement caused an uneven drain slope toward the outlet. This is a common problem of trench drains at sites with a high water table. The problem could be greatly mitigated by returning to one of the pioneering geocomposite drain designs, the Eljen Drain, in which vertical sections of the drain are completely independent units that can be immediately dropped into a trench behind the excavator. Despite the construction problems, the drain is partially dewatering the road prism just down gradient, as seen by approximately 1.2 meters of groundwater drawdown beneath the road.

INTRODUCTION

In the past 20 years, prefabricated geocomposite drains have become a standard method of groundwater drainage for a wide variety of purposes. In many cases these drains are cheaper, easier to construct, and require less space (as they are thinner) than conventional drains constructed using aggregate wrapped in a geotextile. Geocomposite drains are composed of a three-dimensional core surrounded by an appropriate geotextile. The core is usually either a geonet or a semirigid plastic sheet deformed or extruded with a pattern of cusps or small cylinders that project at a 90 degree angle to the plane of the drain. The geotextile may be stretched tight across the core and glued in place or placed loose around the core. The geotextile must span the gaps between the net strands or cusps in the drain core to keep them open for water flow. Some typical prefabricated geocomposite drains are shown in figure 1.



Figure 1—Typical geocomposite drains. The core can vary from a geonet (upper left), a plastic sheet that has been shaped to form cusps (lower left), cylinders (lower right), or mesh (upper right). The pen is provided for scale.

Drain core failure modes include short-term crushing of the core under a normal force, long-term creep compression of the plastic core, and rapid or long-term elongation of the fabric, allowing intrusion of the fabric into the pathways between the net strands or cusps. A drain may also fail due to soil, biological, or chemical clogging or blinding of the geotextile.

Early laboratory testing established that a lightweight plastic drain core could be made with enough compressive strength to resist short-term crushing under normal stresses encountered in typical civil engineering applications. However, these early tests were normally done by quickly applying force normal to the plane of the drain through a stiff platen in a procedure that only evaluated the short-term compressive strength of the drain

core. The current standard index test of geocomposite drains done according to the American Society of Testing Materials (ASTM) D4716 method (ASTM 1998) still uses a smooth platen to apply the normal load, and therefore does not evaluate the effects of elongation of the geotextile and intrusion into the flow pathways in the core. The test can be modified to evaluate quick intrusion into the core by placing a closed-cell foam rubber pad, or appropriate soil between the platen and the geotextile. ASTM D4716 is normally run for only 15 minutes, so long-term core creep, geotextile elongation and intrusion, and fabric clogging and blinding are not tested.

In other laboratory studies, Hwu et al. (1990) investigated intrusion of a fabric on one side of a geonet drain into the pathways between strands in the geonet core. They found short-term intrusion could reduce maximum flow capacity between 39 and 88 percent from the original.

The amount of intrusion was strongly related to the initial modulus of the geotextile and stiffening the fabric by resin treating, burnishing, and scrim reinforcing all increased flow capacity.

Stuart et al. (1991) conducted an extensive series of laboratory tests (periods of time as long as 500 days) evaluating geocomposite drain flow rates. These tests were done in a 0.15-meter-diameter triaxial cell with the drain surrounded by soil. The triaxial tests simply evaluated overall flow performance and did not try to explain the mechanisms of any flow reduction. The study found that fluted or cusped core drains had the greatest decline in flow over time and that most of this reduction occurred in the first few hours or days. While the net core drains had an overall lower flow capacity, the nets also suffered less decrease in flow from their initial flow capacity over time. The longest test in the series of the study was of a cusped core drain. The flow declined slowly, even after 500 days at a constant confining stress of 170 kilopascals.

Miura et al. (1998) used a test procedure similar to that of Stuart et al. (1991) to investigate the effects of fabric intrusion, fabric clogging by soil, trapped air bubbles, and core kinking on the discharge capacity of a geocomposite with a cusped core. The test found that single and double kinks in the core did not greatly decrease discharge, but instead trapped air bubbles lowered the discharge by about 20 percent. In a single long-term test lasting about 140 days, the combination of fabric intrusion and clogging reduced the drain discharge by 90 percent.

There are considerable difficulties and expenses in conducting controlled laboratory tests of drain performance over periods approaching the normal engineering design life of a drain. As Koerner (1994) discusses, extrapolation of laboratory results beyond approximately one order of magnitude is questionable. Thus, even the long-term flow rates reported by Stuart et al. (1991) and Miura et al. (1998) cannot be extrapolated to useful engineering design periods.

In the absence of suitable laboratory tests performed over appropriate time scales, it is critical to conduct insitu monitoring to determine if long-term drain performance matches design expectations. To date, few investigations have been made to the field hydraulic performance of geocomposite drains. Koerner et al. (1993) excavated 41 geocomposites installed as “edge drains” that were adjacent to highway pavements. Normally edge drains are constructed only to depths of less than 1 meter, but lateral loads on the drain core from heavy trucks can be up to 140 kilopascals (Koerner 1994). No hydraulic tests were conducted to quantify insitu drain performance and failure. Nonfailure was determined by visual inspection of overall appearance and measurement of the mass of soil lodged in the drain core. In all cases, the cores had not been deformed, but at eight sites excessive amounts of soil were judged to have moved through the geotextile and into the core (Koerner et al. 1993; Koerner et al. 1996). Koerner et al. (1993) also exhumed three geocomposite sheet drains behind retaining walls and all appeared to be performing acceptably.

Raymond et al. (1996) evaluated the performance of two geocomposite highway edge drains: one at a site with a clay subgrade and the other a sandy subgrade. At the clay-rich site, a 505-millimeter-deep drain with a cusplate core was exhumed after 1 year of service. The drain had failed or was failing due to core crushing, fine-grained soil in the core (with occasional complete core plugging), and migration of fines into the geotextile caused by water pumping. At the sandy site, a similar edge drain had been installed to a depth of 925 millimeters. After 2 years, the drain was examined and found to be clean and intact but without flowing water. Turbulent flow from the adjacent open-graded drainage layer beneath the pavement had deposited a layer of low hydraulic conductivity fine-grained soil adjacent to the geocomposite, preventing water from reaching the drain.

For 3 years, Chung et al. (1996) monitored the performance of geocomposite drains beneath three building raft foundations at a site with a high groundwater table. The drains were constructed of a geonet core with a geomembrane on one side and a geotextile on the other.

Piezometric data indicate the drains consistently lowered the pore water pressure by about 50 percent relative to adjacent undrained areas over the 3-year period with no change in drain performance.

Reported here are the initial results of an insitu monitoring program for the long-term hydraulic performance of three geocomposite sheet drains. Two of the drains were installed as vertical sheet drains along the inside edge of single-lane rural roads. One of these drains has a cusplate core and the other is a geonet. The third geocomposite also has a cusplate core and was constructed as a sheet drain behind a retaining wall.

FIELD MONITORING

The three drains are located in Oregon and northern California (figure 2) at sites on roads administered by the USDA FS. Monitoring of all three drains began when they were newly installed allowing performance changes over time to be referenced to their original condition. At all three test sites the hydraulic performance of the drains is being measured using monitoring wells fitted with recording piezometers. These systems (figure 3) measure the water level in each well once per hour and the individual readings are averaged for each 24-hour period. The wells are located up gradient and down gradient from the drains.

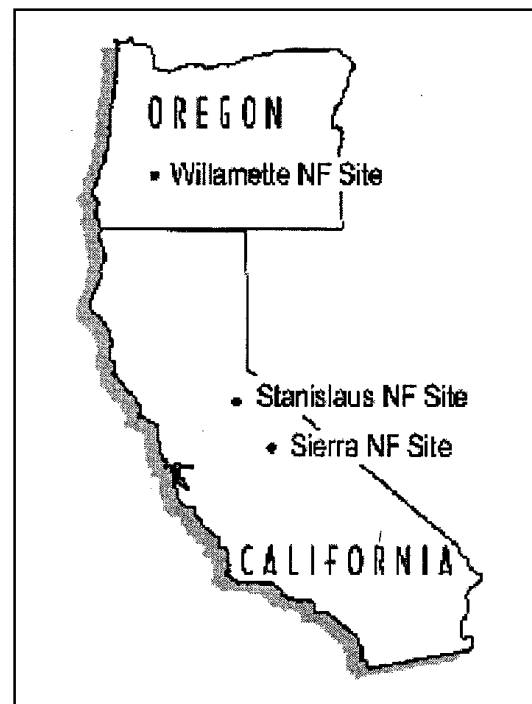


Figure 2—General locations of test sites.



Figure 3—Groundwater level measuring equipment. The piezometer (white cylinder at the end of the cable) measures the water pressure, the datapod (small black box) records the data, and the large outer box powers the piezometer and conditions the electrical signal.

Willamette National Forest Site

At the Willamette National Forest (NF) site, the geocomposite is Hitek Stripdrain 75, installed in a vertical trench 2.4-meters deep along the inside edge of a single-lane aggregate surfaced road (figures 4 and 5). The site was chosen for study because the local water table is high during each 6-month winter period and the road has sagged vertically several meters over the years in a slow creeping movement. Apparently this is caused by seasonal elevated pore water pressures. Precipitation is dominantly rainfall from November through April and no sustained snow pack. The site is shown in figure 6.

The drain did not extend to bedrock but is entirely within a colluvial soil. The upper portion of the soil (1 meter) is a clay-like gravel (GC in USC system). From a depth of 1 to 2.3 meters the soil is clay (CH) and deeper than 2.3 meters; the bottom of the trench penetrates a silty sand (SM). The maximum sustained normal stress on the bottom of the drain is estimated to be approximately 26 kilopascals.

Locally, hillslope drainage is from the west to the east and the road has a gradient of approximately 6 percent from the south toward the north. As seen in figure 4, there is a 0.60-meter-diameter culvert just south of the site. This culvert has separated under the road and the culvert inlet was buried to relevel the vertical sag in the road. Consequently, surface water flowing from the south in the ditch line on the inside edge of the road bypasses the culvert and contributes to road fill saturation. The geocomposite drains both groundwater from the hillslope to the west and the infiltrating water from the ditch line to the south.

The Stripdrain 75 has a high-density polyethylene (HDPE) cusped core, 19-millimeters thick, surrounded by a needle-punched nonwoven geotextile that is not glued to the core. The distributor-supplied performance specifications of Stripdrain 75 are indicated in table 1. To custom fabricate the drain for this site, two of the 1.1-meter-wide rolls of the drain were wired together side-by-side. A 102-millimeter-diameter perforated plastic pipe was pulled through the bottom roll so that it directly contacted the core inside the nonwoven geotextile. The two joined rolls and collector pipe were then lowered into the trench to form a continuous sheet drain. The perforated collector pipe leads into a solid pipe of the same diameter that takes water from the drain under the road to an outlet at the northeast edge of the site (figure 4).

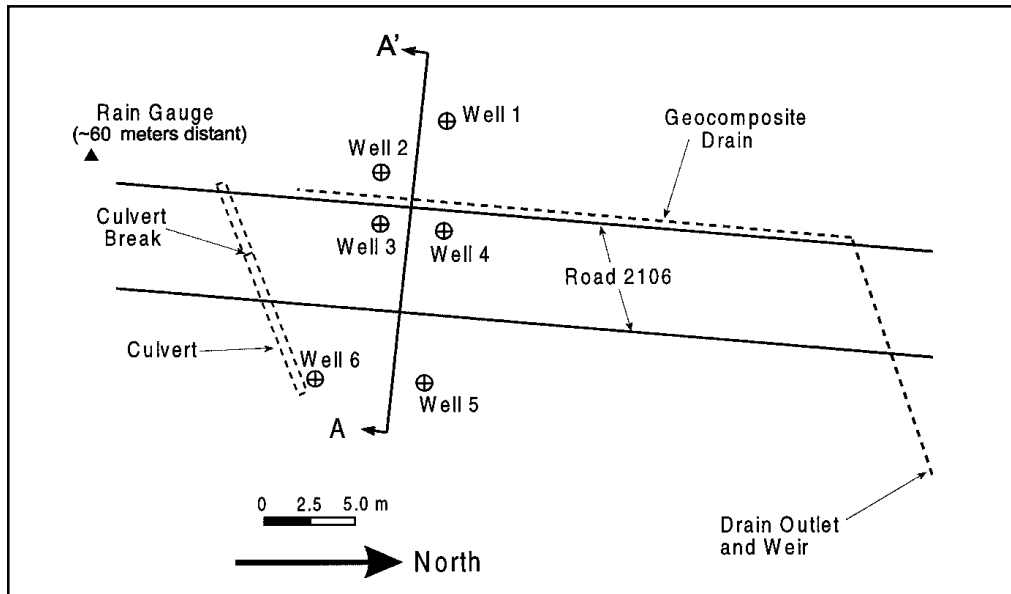


Figure 4—Willamette National Forest site plan. Wells are open observation with recording piezometers. A'-A is shown in figure 5.

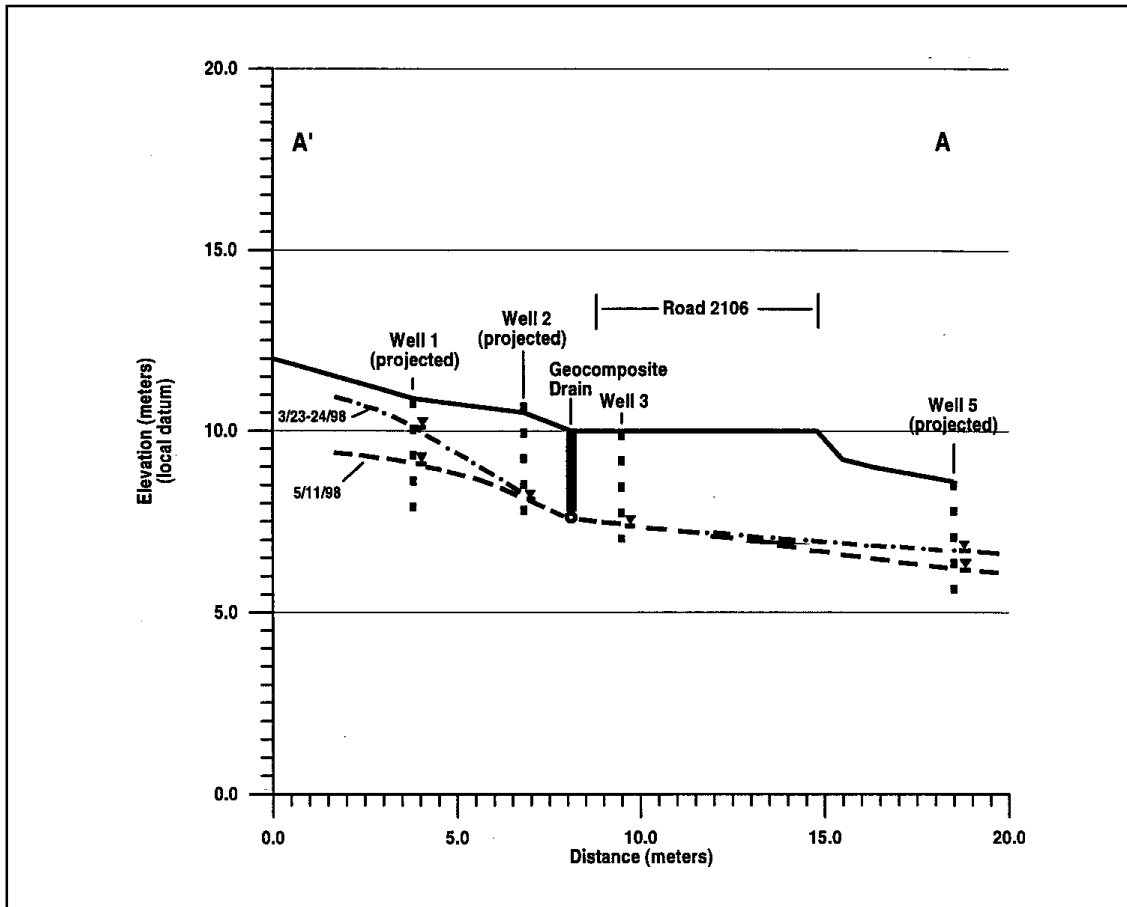


Figure 5—Section A'-A elevation view of the Willamette National Forest site. Two typical water table conditions are shown: 5/11/98 is during a period of little rain; 3/23-24/98 is the peak groundwater response to a major storm.



Figure 6—At the Willamette National Forest site, seasonal elevated pore water pressure has caused the road to sag several meters.

Table 1—Hitek Stripdrain 75 properties.

Core Min. Flow Capacity @ 69 kPa l/min/m	Confining Stress, $i = 1.0$ kPa	Geotextile Grab Elongation %	Geotextile A.O.S.	Geotextile Water Flow Rate l/min/m ²	Geotextile Coeff. of Perm. m/sec	Drain Standard Roll Width m	Drain Standard Roll Length m
149	275	50	70–100	7	2	1.1	55

The drain and six monitoring wells were installed in September 1995. One of the wells is approximately 6 meters upslope from the drain, three wells are within 2 meters of the drain, and two wells are approximately 10 meters down slope from the drain, just below the outside edge of the road. Flow from the drain is automatically recorded on an hourly basis at a flume at the pipe outlet using a submerged echo-ranging sensor on the weir (figure 7). Rainfall is recorded with a precision of 2 millimeters at a tipping bucket gauge approximately 60 meters south of the drain.



Figure 7—Flume at drain outlet. The water level in the stilling basin on the left side of the flume is measured and converted to a flow volume.

Sierra National Forest Site

An Eljen Drain was constructed at the back of an excavation site, as a reinforced soil type retaining wall on the Sierra National Forest in 1984 (figures 8 and 9). This wall is the repair of a landslide that destroyed the two-lane paved road during the winter of 1983. The wall height ranges from 4.6 to 6.8 meters. The local geology is granodiorite bedrock, that weathers to a grus, overlain by a colluvial soil. The grus still retains much of the bedrock structure and both the grus and the colluvium classify as SM materials. The back of the excavation for this wall extends through the colluvium and well into the saprolite. The climate at the site is Mediterranean with essentially all of the annual precipitation occurring during the winter months (between November and May) as either snow or rain. Groundwater at the site drains from the hillslope south of the road. The site and retaining wall are shown in figures 10 and 11.

The Eljen Drain (which is no longer produced) has a styrene cusped core with channels between the cusps that are at least 18-millimeters deep and between 15- and 20-millimeters wide. The drain is protected on the up-flow side by a monofilament woven geotextile and on the down-flow side by a nonwoven geotextile. The manufacturer-supplied performance specifications of the Eljen Drain are included in table 2.

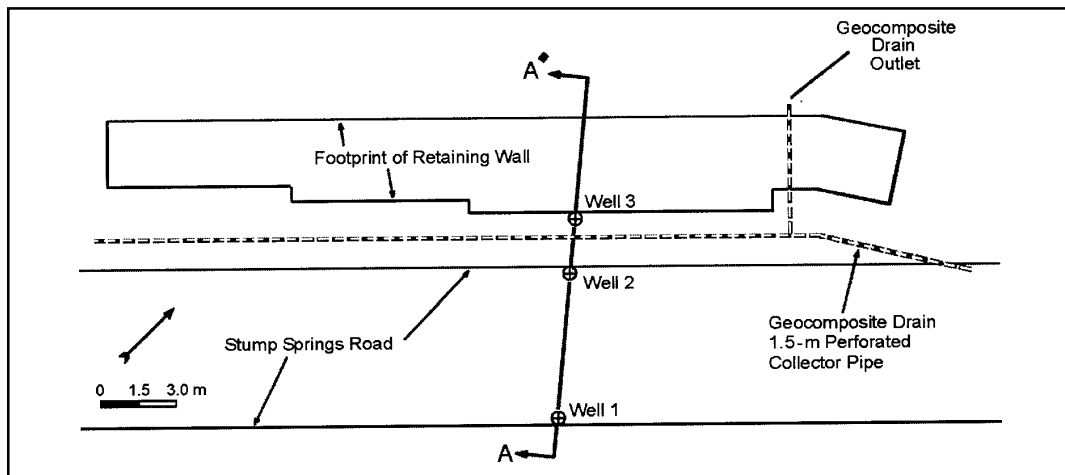


Figure 8—Sierra National Forest site plan. Wells are open observation with recording piezometers. A'-A is shown in figure 9.

During repair, the site was excavated for access to build. The retaining wall and the cut at the back of the excavation was made at an angle of approximately 1.1:1 (horizontal to vertical). The Eljen Drain was in sections 3.3-meters wide, with each section as tall as the customer specified. Each section of the drain is an independent component completely surrounded by geotextile. The individual drain sections were arranged side-by-side and nailed into place on the back slope of the excavation through strips of

geotextile that were sewn to the top of each section for this purpose. The bottom, or toe, of each drain section was supplied with a loop of geotextile sewn to it and a continuous 1.5-meter-diameter perforated plastic collector pipe was inserted through these loops. The perforated pipe was led into a nonperforated pipe to carry water beneath the wall. The reinforced soil wall was then built in front of the drain (figure 9). The maximum normal stress on the bottom of the drain is approximately 90 kilopascals.

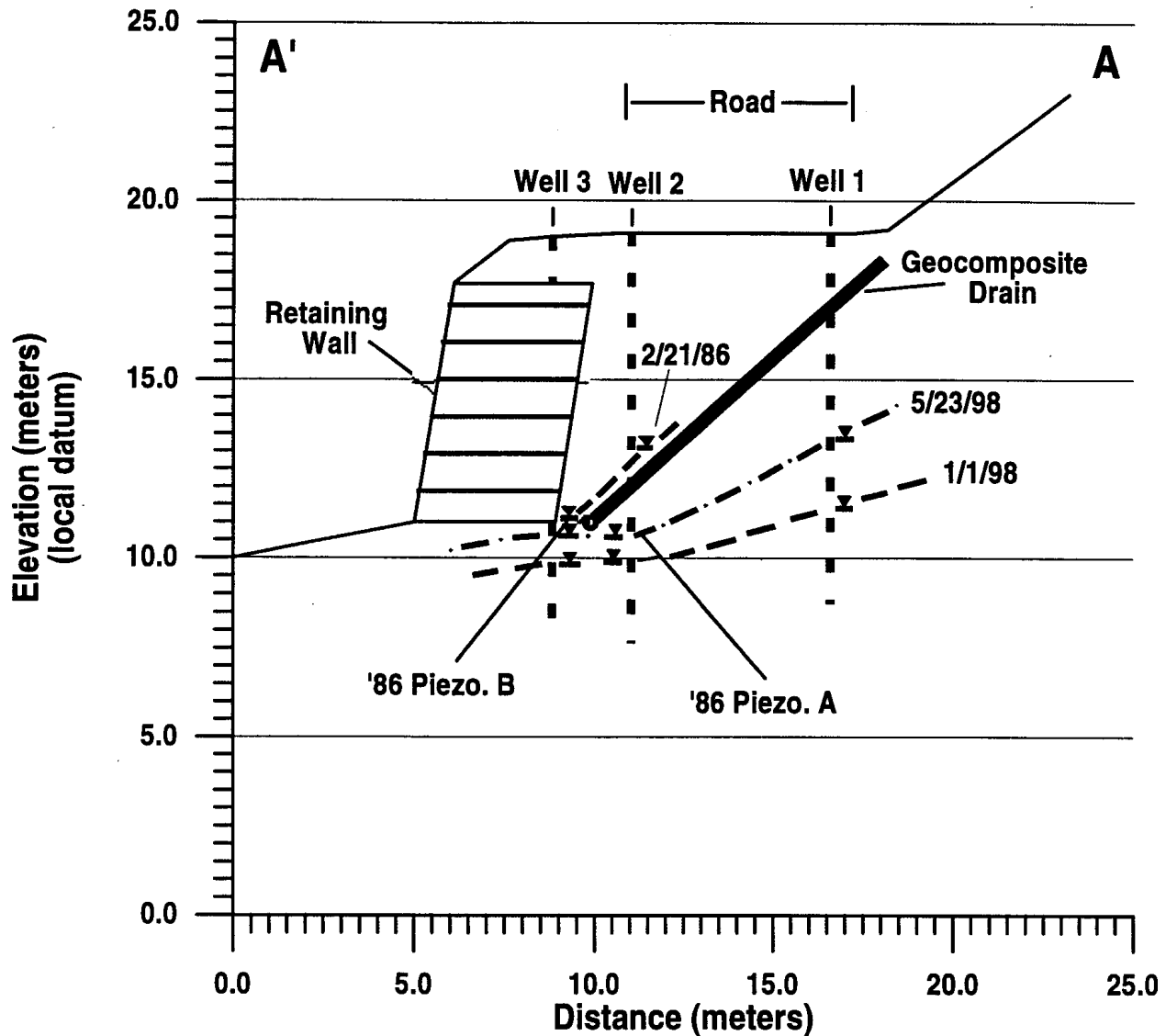


Figure 9—Section A'-A elevation view of Sierra National Forest site. Three typical water table conditions are shown: 1/1/98 is during a period of little rain; 5/23/98 is the peak groundwater response to seasonal snowmelt; 2/21/86 is the peak response to an intense "rain on snow" event. Piezometers A and B were sealed in place and operational only during 1985 through 1987.



Figure 10—Sierra National Forest site. The drain is installed along the inside edge of the road.



Figure 11—Retaining wall at the Sierra National Forest site.

Placement of the drain at the back of the excavation kept it out of the way of the wall construction and minimized construction damage to the drain. Fill compaction within a horizontal distance of 0.5 meters from the drain was done with a hand compactor. The remainder of the wall and fill were built with standard machine-controlled compaction. The local groundwater flow is from the south and the Eljen Drain intercepts it before reaching the wall. As others have noted (e.g., Terzaghi 1936), an inclined drain with this geometry is also beneficial in eliminating horizontal seepage forces on the back of the wall by directing it just behind the wall vertically downward to the drain.

During the construction of the wall, one piezometer was sealed approximately 1 meter in front of the drain (down gradient) and another about 1.2 meters horizontally behind the drain (up gradient). These piezometers were monitored for 2 years before they were abandoned. Three additional open monitoring wells were then drilled in April and May 1997. Two of these were up gradient and one down gradient from the drain (figure 9). From 1985 to 1987, the discharge from the drain collector pipe was monitored at its outlet by a large tipping bucket recorder. Area rainfall is recorded at Huntington Lake, approximately 8 kilometers south, with an elevation approximately 600 meters higher than the test site.

Table 2—Eljen Drain properties.

Core Compress. Strength kPa	Core Min. Flow Capacity @96 kPa Confin. Stress, $i=1.0$ l/min/m	Geotextile Grab Tensile Strength (ASTM 1682) N	Geotextile Open Area	Geotextile Pore Sizes	Geotextile Transmissibility @ 50 mm Head mm/sec	Drain Dimensions
96	25	>266	>10%	All <0.8 mm and <10% >0.2mm	>30	User Specified

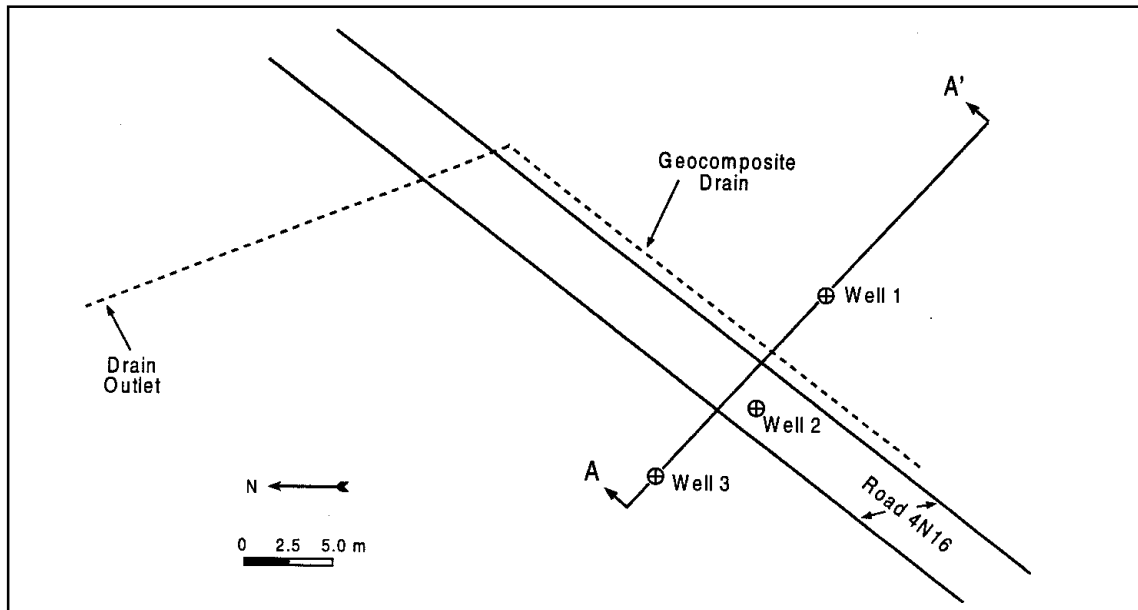


Figure 12—Stanislaus National Forest site plan. Wells are open observation. A'-A is shown in figure 7.

Stanislaus National Forest Site

In July 1996 at the Stanislaus National Forest site, a drain constructed from a single layer of Tensar DN1 geonet was installed in a vertical trench on the inside edge of a single-lane, unsurfaced road (figures 12, 13, and 14). At this site a regolith 5- to 10-meters-thick covers the underlying granitic bedrock. The overburden is a silty-sand that classifies as an SM-SC material. Precipitation is concentrated as rain and snow from November through April. Some years a snowpack develops, which melts during the late spring. This site has a perennial high groundwater table and installation of the drain was difficult due to rapid collapse of trench walls. The depth of the trench ranged from 1.2 to 3 meters and averaged 2.4 meters. It did not extend to bedrock. The maximum normal stress on the bottom of the drain is estimated to be 27 kilopascals.

The Tensar DN1 geonet drain core has a heat-bonded nonwoven geotextile glued to one side of the geonet. A second layer of nonwoven geotextile was placed against the other side of the geonet during field installation. The DN1 is 6.3-millimeters thick and made of foamed low-density polyethylene strands. Two sets of parallel strands are crossed at an angle and joined at all the junction points to form a net structure. The openings between strands in the net are approximately 7.6-millimeters wide. A 1.02-meter-diameter perforated plastic collector pipe was placed at the bottom of the net, inside another piece of geotextile that was joined to the prefabricated geonet drain. The perforated pipe is led into a solid pipe that moves water from the drain to the discharge point at the north end of the site. The manufacturer-supplied performance specifications of the geonet are shown in table 3.

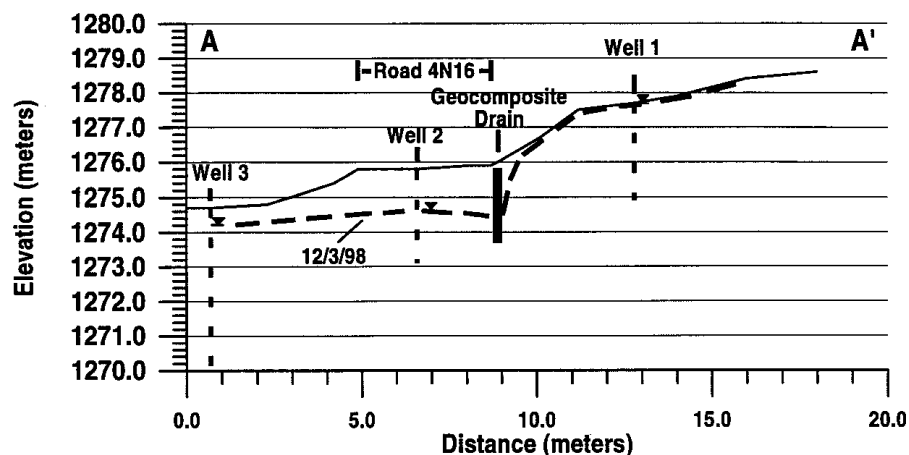


Figure 13—Section A-A' elevation view of the Stanislaus National Forest site. The typical year-round water table condition is shown.



*Figure 14—Stanislaus National Forest site.
View is downslope to the north.
Well 1 is to the left of the large tree.*

The local groundwater flow is downslope from the east to the west. Three monitoring wells were installed: one well up gradient and two wells down gradient from the drain (figures 12 and 13). A tipping bucket, recording rain gauge with a precision of 2 millimeters was also installed at this site. All of the instrumentation was completed in September 1996.

RESULTS

The objectives of this project are to monitor changes in hydraulic performance of geocomposite drains as a result of any drain core collapse and core or geotextile clogging. However, as discussed by Koerner et al. (1994), it is not appropriate to use transmissivity as the performance measure because flow in the drains is turbulent. Instead, drain performance is evaluated by monitoring the effects of the drain on the local hillslope hydrology. From a users perspective, this is the most important measure of performance. In applications of this type it is critical that a drain draws down the groundwater to keep the retaining wall or road fill dry. The drain must control even peak groundwater flows during large storms. Another useful measure is the rate at which the geocomposite can drain the local hillslope after peak flow events. Of course this depends on the rock and soil hydraulic conductivities as well as drain performance, but the former are probably reasonably constant over time, so progressively slower drainage of the slope may indicate gradual geocomposite failure.

Table 3—Tensar Drain properties.

Net Compression @ 24 kPa Confining Stress %	Net Transmissivity @ 10-100 kPa Confining Stress, $i=1.0$ l/min/m	Net Standard Roll Width m	Net Standard Roll Length m
3	84	1.9	30

Willamette National Forest Site

As previously noted at this site, the water entering the geocomposite drain comes from both groundwater flowing down the hillslope from the west and water flowing from the south in the ditchline on the inside edge of the road (figures 5 and 6). Figure 15 shows rainfall, drain outflow, and groundwater response, from March 5 through June 9, 1998. These data are typical of winter to spring conditions, which are the most adverse at this site. Figure 5 shows the locations of the monitoring wells. The data are included in figure 15. Results from Wells 4 and 6 were not reliable over this period due to equipment failures and also because they have not been used.

This drain has very high peak flows with an approximately 24-hour lag after large storm peak rainfall. Occasionally as a result of isolated brief rainstorms, the drain flow increases somewhat 4 to 5 days after the storm, while the groundwater does not respond in any of the monitoring wells (e.g., storms on April 23 and May 1 and 2, 1998). At all times the flow from this drain is slightly turbid, not appearing to increase with flow volume.

Well 1 is approximately 9 meters up gradient from the drain and near the uphill edge of the zone of influence (see figure 6 for typical drawdown curves during and between storms). This well most closely represents the natural hillslope response to rainfall. Piezometric peaks in Well 1 lag behind storm peaks by one to a few days depending on the rainfall pattern. The greatest response is to short duration, high intensity storms. Well 2 is approximately 2 meters uphill from the drain and is within the zone of influence of the geocomposite. It never responds to groundwater flow either from the hillslope or the ditchline. Well 3 is sited approximately 2 meters down gradient from the drain and is located in the inside wheel track of the road. Generally, the water table here is about 0.5 meters lower than in Well 2. Well 5 is located 16 meters down gradient from the drain, on a fillslope below the road. Piezometric response in Well 5 is similar to Well 1 but more subdued. It is not known if the water reaching Well 5 is groundwater traveling under the drain and the road, or if it is surface water moving off the road and then re-infiltrating.

The hydraulic gradient between Well 1 and the drain during the peak and falling limb portions of large storm hydrographs is being used as a primary measure of drain performance. An example of this gradient at the peak of a storm during March 23 and 24, 1996 is shown in figure 6. The gradient in the early portion of a storm (the rising hydrograph limb) is strongly influenced by antecedent moisture conditions, and is not useful as a performance standard. As seen in figure 16, the peak gradient in 12 large storms between December 20, 1996 and June 10, 1998 is consistent with 7 events having a peak gradient between 0.66 and 0.73 (two of the curves plot on top of each other in figure 16) and 4 events with peaks between 0.52 and 0.57. All of the storms occurred during the winter to spring months (November to June) and produced greater than 15 millimeters of rain in 24 hours. The single storm in November 1997 that produced a peak gradient of 0.36 is explained as the first large seasonal rain with dry antecedent conditions. There are occasional large storms during the summer dry season at this site, but these do not produce the same piezometric rise because of the dry antecedent conditions. If the drain begins to fail over time, the zone of influence during large winter storms will shrink. The groundwater levels in Well 2 and possibly the drain will rise, causing the peak gradient to decline. During the 1996 through 1998 period, there is no evidence of such a decline in peak hydraulic gradient.

The slope of the hydrograph falling limb, as measured by the change in hydraulic gradient (i) over time after the peak occurrence, is extremely consistent (figure 16). During the 1996 through 1998 period, the change in gradient with time; ($\log di/\log dt$) was -0.15 ± 0.06 (1s). If the drain begins to fail, the slope of the falling limb will decrease, taking longer for the geocomposite to remove the groundwater from the hillslope.

Between storms, the mid-winter hydraulic gradient consistently returns to a value between 0.45 and 0.50. This happens within 10 days after the peak gradient occurred, unless another storm occurs during that period. If the drain begins to fail in the future, a lower between storm “base level” gradient may become evident.

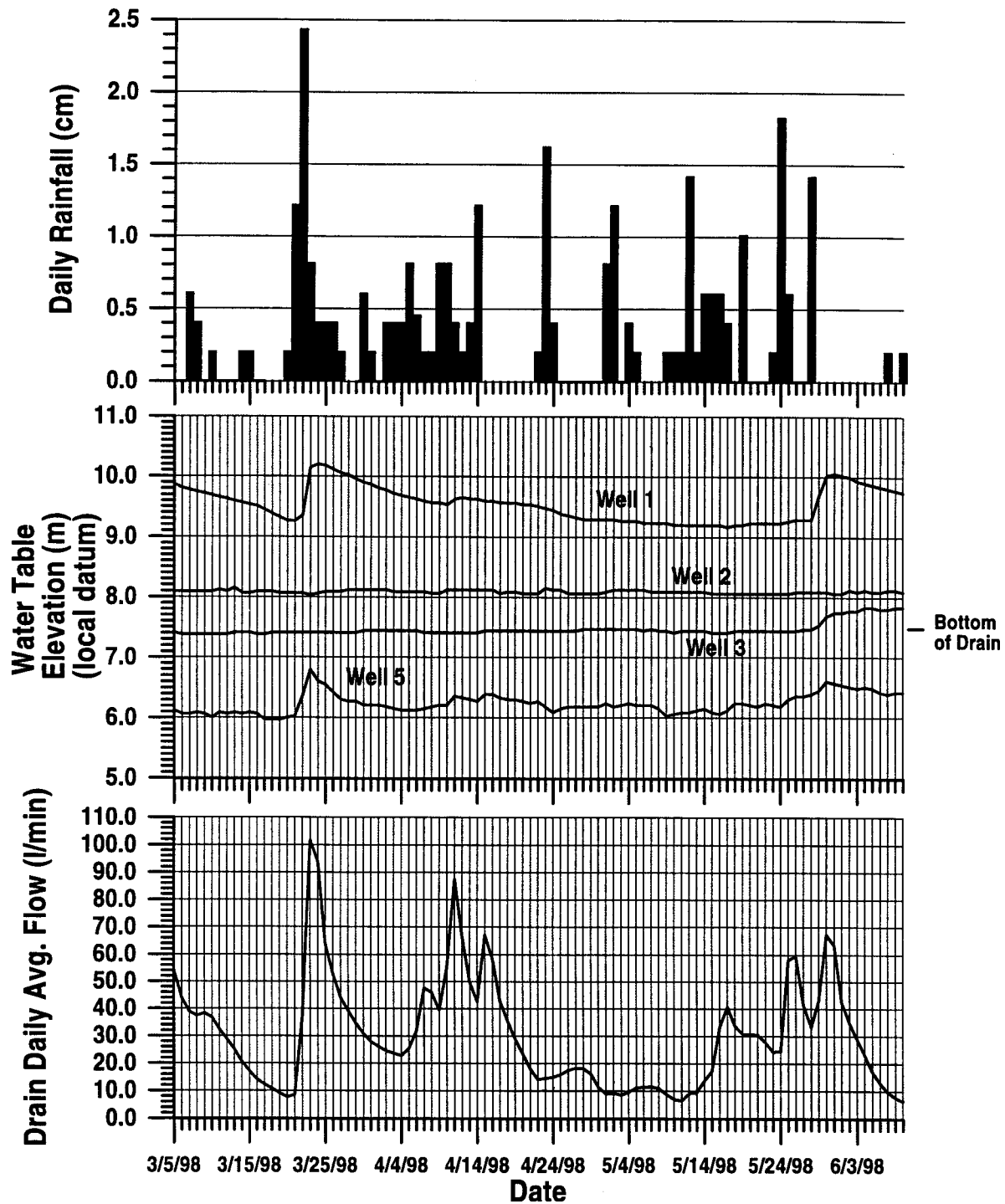


Figure 15—Willamette National Forest site daily geocomposite drain performance. Rainfall, drain outflow, and groundwater response are shown for a variety of rainstorms from March 5 through June 9, 1998.

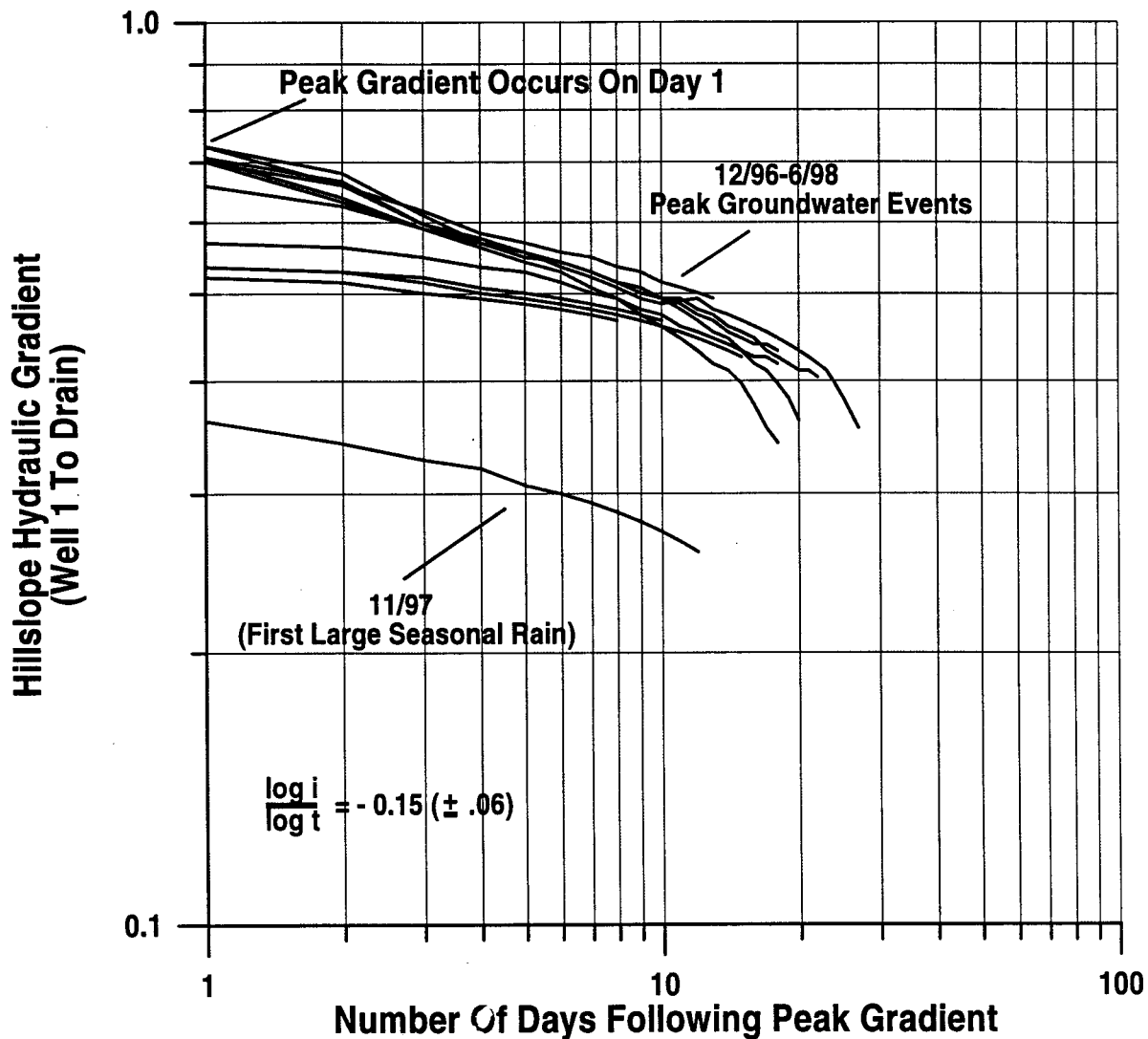


Figure 16—Willamette National Forest site groundwater drawdown rates following peak events. All mid-winter rates are extremely consistent.

Sierra National Forest Site

The regolith at this site is coarse, silty-sand with a relatively high hydraulic conductivity. Consequently, large water inputs are required to cause a change in the water table. This location is near the edge of the seasonal snow cover in this portion of the Sierra Nevada Mountain Range where the extent and thickness of the local snow pack can vary dramatically from year to year. The most severe hydrologic events are “rain on snow,” which heavy rain melts at least part of the snow pack, and thus the amount of water generated in the storm is greater than the rainfall itself. In contrast, other rainstorms of nearly equal magnitude that occur when there is no snow cover will cause a much reduced groundwater response. In addition to being sensitive to large individual storms, the

groundwater also responds each spring to the snowmelt between April and June.

Figure 17 shows the performance of this geocomposite when it was new during a large rainstorm from February 12 through 20, 1986. Rain fell 50.5 centimeters over the 9-day period and this total was augmented by an unknown amount of snowmelt in a classic rain on snow event. By February 21, the water table had risen nearly 2 meters at Piezometer A, up gradient from the drain (figures 9 and 17). The drain outflow also peaked on that day at almost 15 liters per minute. The water table appears to have risen just above the drain, but the retaining wall remained dry revealing no change in hydraulic head at Piezometer B, just down gradient from the drain (figures 9 and 17).

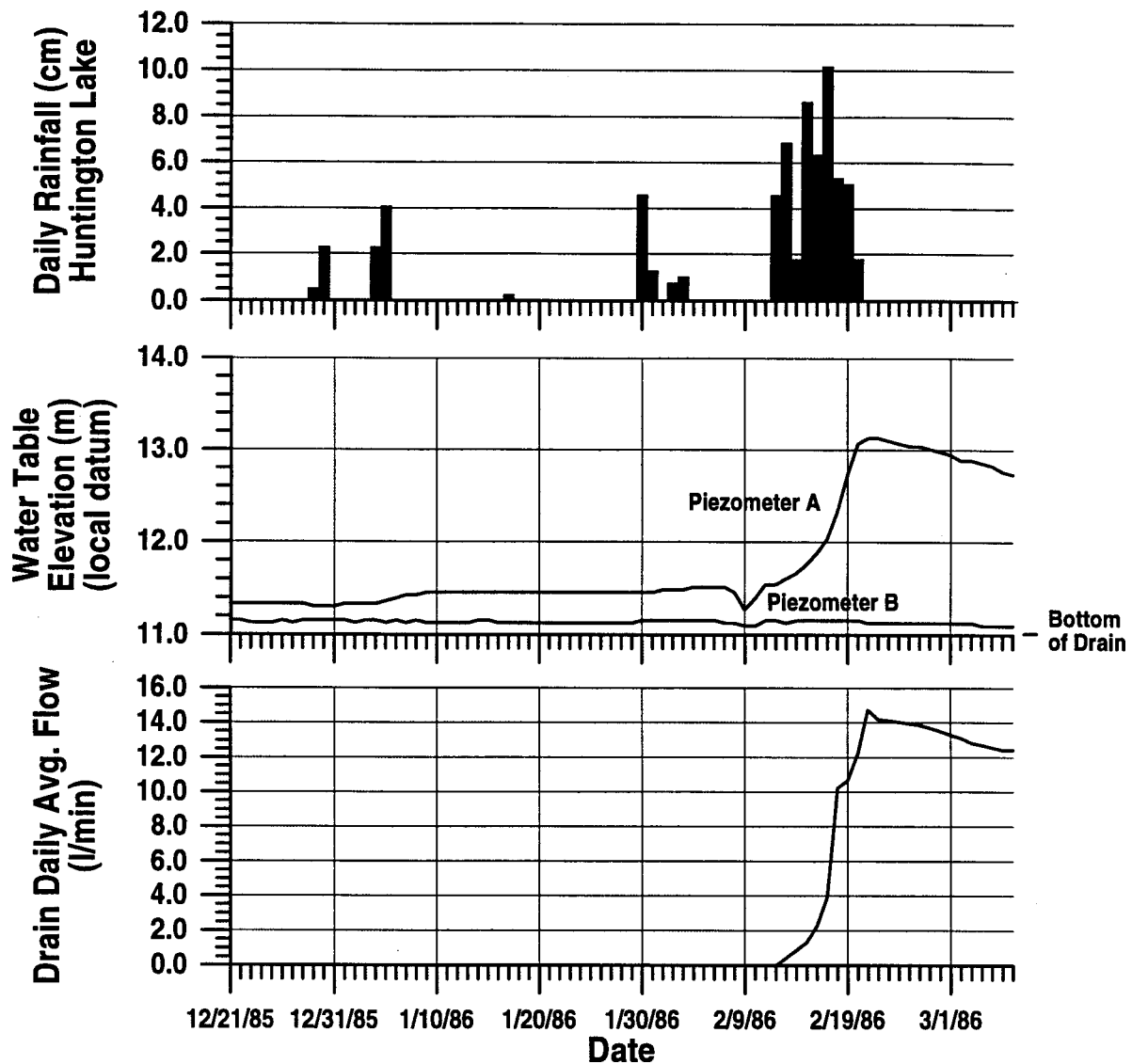


Figure 17—Sierra National Forest site geocomposite drain performance during a large “rain on snow” event.

Although the available data are limited to three events in 1985 and 1986, the relationship between hydraulic gradient toward the drain and drain flow is consistent (figure 18). The ratio of drain flow to gradient is 12.7 ± 5.6 (1s). The recording weir was removed after 1986 but will be reinstalled at this site to compare future drain performance with figure 18.

The combination of water inputs from rainstorms, rain on snow, and snowmelt complicates the groundwater response and consequently peak groundwater gradients toward the drain are not consistent. For example, in February 1986, the large rain on snow generated a peak gradient of 1.52 (figure 18), while in contrast the seasonal response to melting a heavy snow pack in 1998 generated a peak gradient of only approximately 0.5 (figure 19).

Therefore, consistency of the peak gradient over time does not adequately predict the drain performance. Similarly, the complexity of water inputs complicates the decline of the hydraulic gradient over time after some peak gradient occurs.

Figure 12 also illustrates that after 14 years of service, the Eljen Drain is still functioning well. The groundwater in Well 1 peaked on May 23, 1998, during the spring snowmelt. However, the water levels in Wells 2 and 3 rose only to the elevation of the bottom of the drain. As in 1986, the retaining wall was kept completely dry by the geocomposite drain during the 1997 through 1998 water year.

Stanislaus National Forest Site

Experience from this site illustrates the problems of installing geocomposites in vertical trenches at locations where the groundwater table is constantly high. This geocomposite was made of a net with a geotextile glued only to the up gradient side of the drain. During installation, a second geotextile was placed on the down gradient side and around the collector pipe at the bottom of the drain. To the extent possible, the drain was preassembled on the ground surface, then lowered into the trench. Trench excavation proceeded from the outlet end so it would drain during construction. However, the trench would not stand open long enough to complete the geocomposite assembly and installation. Caving of the walls during installation resulted in an uneven trench floor and drain bottom. Generally, it is not economical to brace the trench walls in geocomposite installations of this kind in remote areas.

Performance of this drain is only considered partly successful, probably due to the construction problems rather than drain core collapse or geotextile intrusion or clogging. Typical site groundwater conditions are shown in figures 13 and 20. Up gradient from the drain, the water table is perennially at or near the ground surface. However, the drain does appear to draw down the water table under the road, just down gradient from the drain. At Well 2 on December 3, 1998 (figure 13), the groundwater was approximately 1.2 meters below the road surface, but the drain was installed at least 2 meters deep. The 0.8 meters of head in the drain is probably the result of the uneven trench floor with water ponding in a low spot of the trench floor profile. Excavation will be required to confirm this. The groundwater remained relatively constant during the winter and spring of 1999 with the only slight fluctuations occurring in the fill slope

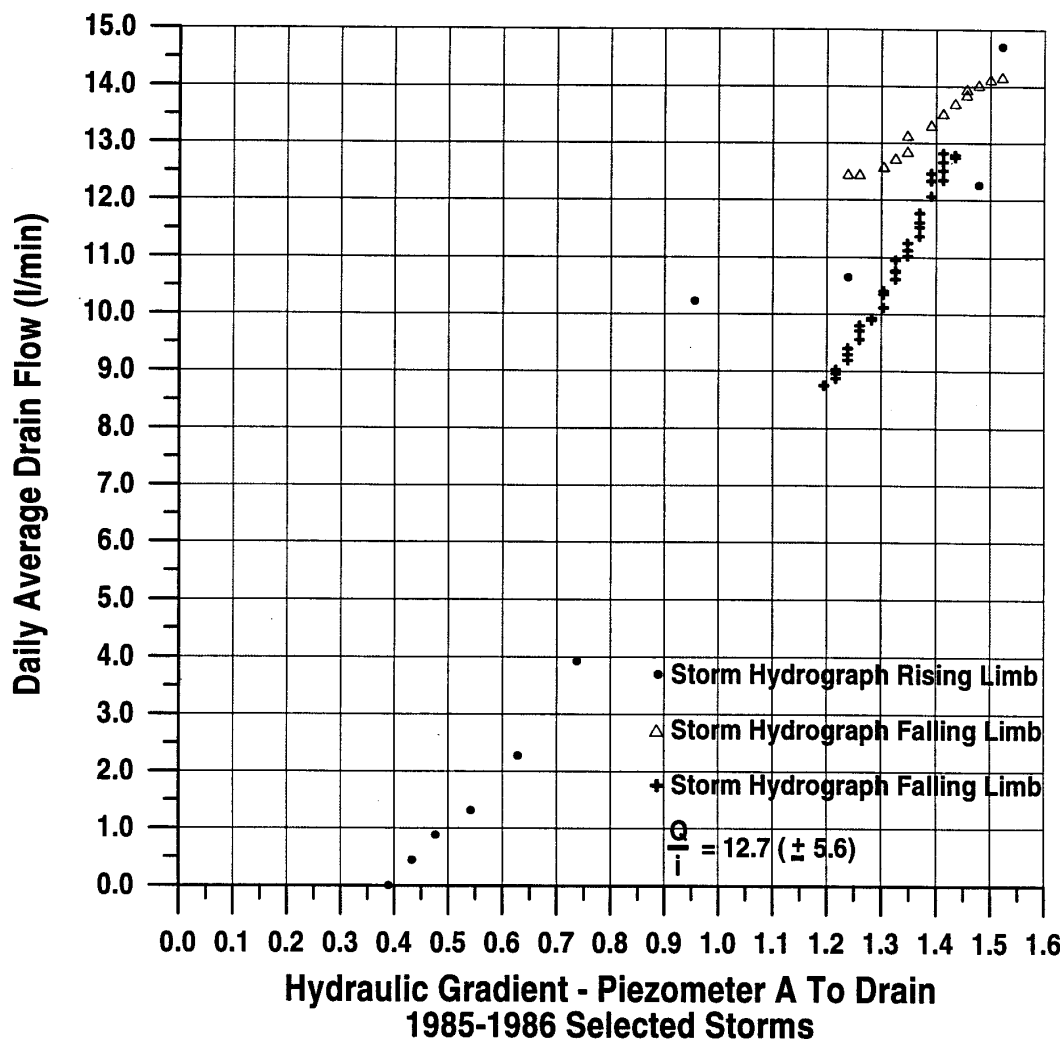


Figure 18—Sierra National Forest site linear relationship between the local hydraulic gradient toward the geocomposite drain and the drain outflow rate.

below the road at Well 3 (figure 20). Even during major storms, such as the one from February 16 through 21, 1999, when nearly 0.11 meters of rain fell, the water level in Well 2 did not rise. This indicates that despite the construction problems, the drain continues to partially dewater the road prism.

Drain outflow is measured manually whenever the monitoring equipment is serviced. Discharge is low and

fairly constant over time, ranging from 3 to 6 liters per minute. This is much lower than the drain capacity (see table 3) and low for a geocomposite at a site with silty-sand soils.

In summary, the drain is partially drawing down the water table under the road, even during periods of major storms. However, this draw down is not as great as designed. The drain has no effect on the water table in the cutbank above the road, and the flow rate from the drain is low.

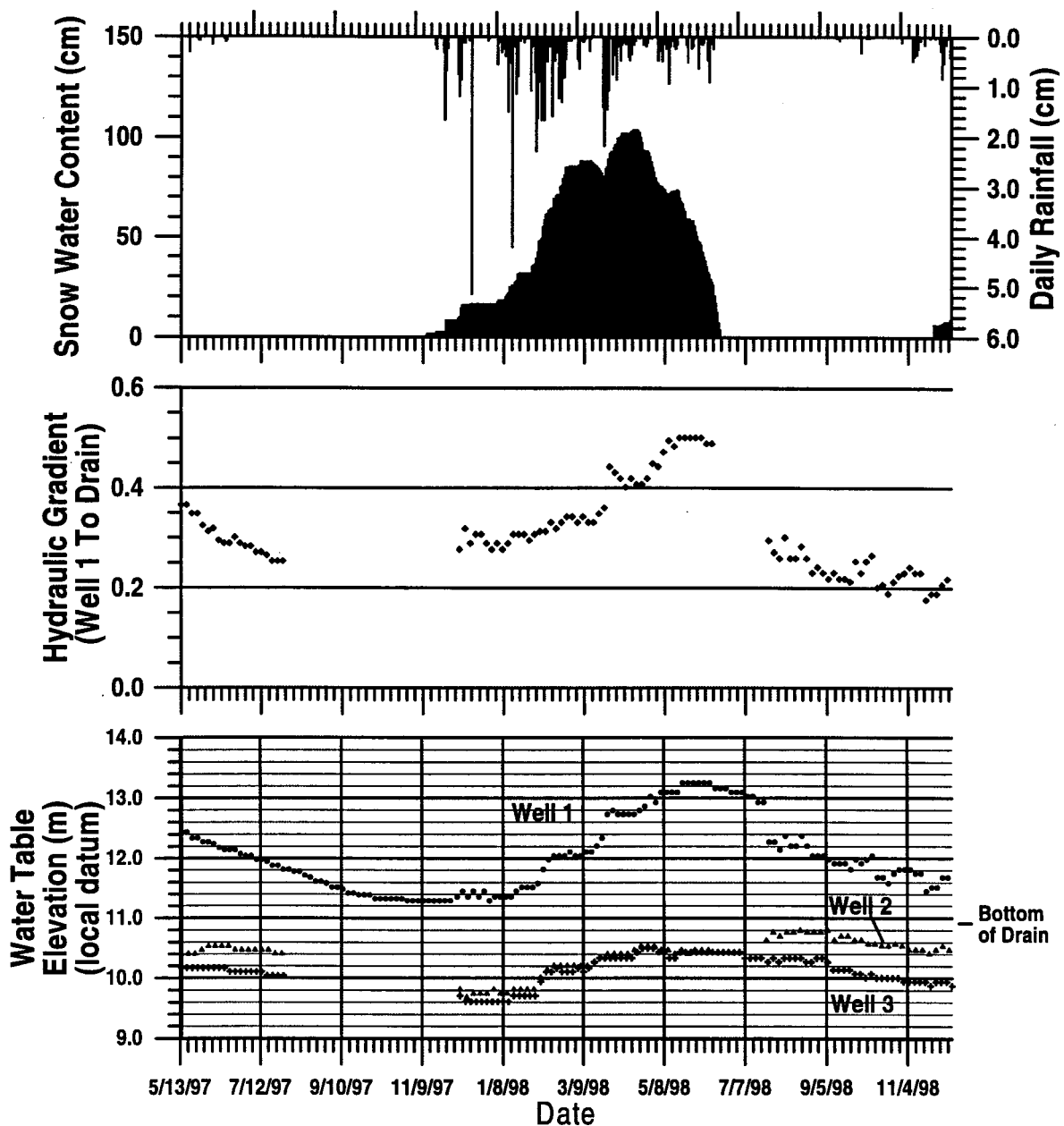


Figure 19—Sierra National Forest site geocomposite drain performance during annual spring season snowmelt.

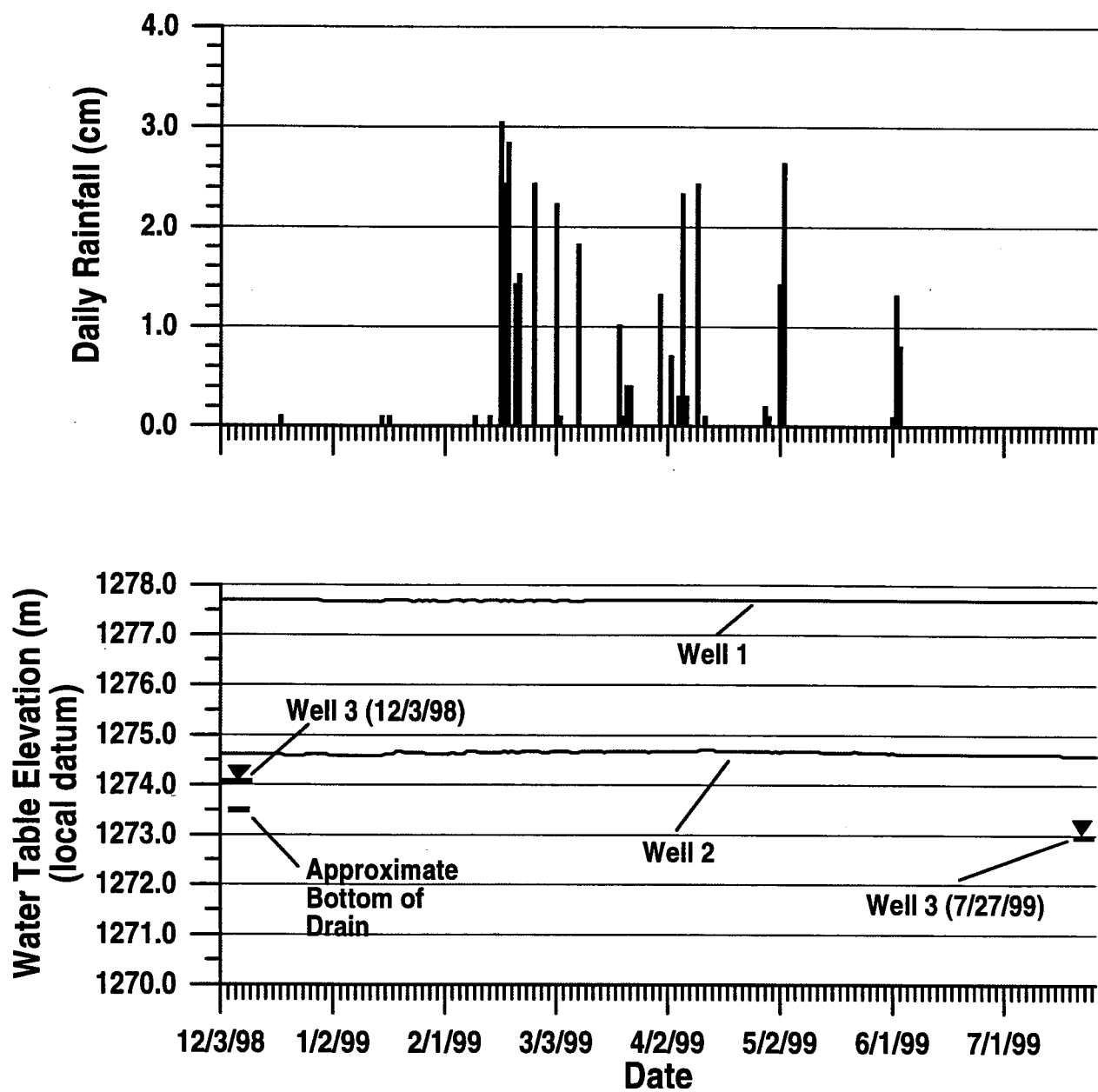


Figure 20—Stanislaus National Forest site geocomposite drain performance during a winter and spring season. Well 3 data are available only at the beginning and end of the period due to equipment problems.

CONCLUSIONS

The geocomposite drain at the Willamette National Forest site appears to be functioning consistently well in the first 4 years in operation. Piezometers near the drain have never shown a water table rise, even during large storms. The peak hydraulic gradient toward the drain is reproducible and the decline of the gradient after major storms is consistent. Discharge from the drain has been as great as 100 liters per minute without a rise in the water table beneath the road, just down gradient from the drain. Both the rising and falling limbs of the discharge curve are steep during storms, also suggesting the drain is efficiently dewatering the slope. The only concern thus far is the slight turbidity of the discharging water. The source of the sediment is not known but will be monitored closely. If it gets worse, a portion of the drain will be excavated to examine the geotextile and core for evidence of clogging.

At the Sierra National Forest site, the combination of water inputs from rain, rain on snow, and seasonal snowmelt complicate using peak hydraulic gradients and drawdown times to measure the hydraulic performance of the drain. Limited data suggest there may be a consistent relationship between hydraulic gradient and drain outflow. In its 14 years of operation, the drain has continued to keep the retaining wall completely dry during such extreme water events such as the rainstorm of February 1986 and the spring 1998 snowmelt.

The typical problems of installing geocomposite drains in vertical trenches at remote construction sites were encountered at the Stanislaus National Forest site. Project economics normally mean the trenches cannot be braced during construction; therefore if the water table is high, the trench walls are often unstable and the drain must be rapidly installed from the ground surface without personnel entering the trench.

Normally current geocomposite sheet drains are produced in rolls that have a width of approximately 1 meter with a geotextile on one or both sides. No provision is made for connecting a perforated collector pipe to the geocomposite. To assemble a sheet drain from the rolls for installation in a vertical trench more than 1 meter deep, two or more rolls must be laid out and somehow attached together side-by-side. Then an extra piece of geotextile must be fashioned into a loop surrounding a perforated collector pipe at the bottom edge of the roll. This will be on the bottom of the trench. The loop and pipe must be securely fastened to the geocomposite. Then, the whole handcrafted assemblage is lowered into the trench, hopefully without damage. In a 3-meter-deep, unbraced

trench, avoiding damage is nearly impossible. At many sites with high water tables, trench walls often collapse.

For this type of application, the earlier design of the Eljen Drain, which is apparently no longer available, was preferable. The Eljen Drain was ordered in sections that were fabricated to the design dimensions required for each job. A typical section would be 1- to 2-meters-wide and as tall as the trench was deep. Each vertical section was an independent unit completely encased in a geotextile and which had a geotextile loop already sewn to its bottom edge for a flexible perforated collector pipe. During installation in a vertical trench, the sections were simply laid out side-by-side on the ground and a perforated pipe (prewrapped in its own geotextile) was threaded into the pre-sewn loop in each section. The sections were then lowered rapidly into the trench and the drain was finished. The individual vertical sections and the continuous collector pipe could be lowered into a trench directly behind the excavator as it worked, so only a few meters of the trench wall were ever exposed to collapse before drain installation. For most applications, it is not important that each section directly abuts its neighbors. Small gaps between sections do not normally affect performance. The top of each section could also be cut to the height desired if the final trench depth is less than originally planned. It is unfortunate this geocomposite style is no longer available and manufacturers are encouraged to reintroduce this design for use in vertical trench drains, possibly with modification.

In the original Eljen Drain, the geotextile was loose on both sides of the core. This offered a greater opportunity for intrusion of the fabric into the drain core flow channels than if the fabric were stretched tight and glued to the core. However, a geocomposite with fabric glued to both sides of the core is stiff and can not be easily rolled for transport. Also, it won't conform well to irregularities in a trench wall or other surface against which it may be placed. An appropriate compromise for cases of unidirectional flow is to glue the fabric on one side of the core and leave it loose on the other side. This would provide flexibility to roll the product for shipping and handling. During installation, the glued side would be placed on the up gradient side of the drain where intrusion and closure of the drainage channels is most critical.

It is our intention to continue to monitor the geocomposite drains at the Willamette and Sierra National Forest sites. At 3 to 5 year intervals, we will reinstrument the sites and compare the drain hydraulic performance. If the performance begins to deteriorate, we will excavate the

drain to determine the cause(s) of failure. The drain at the Stanislaus National Forest site will also be excavated to investigate possible causes of its marginal performance. The drain will be examined for soil clogging of the fabric, the core, and geotextile intrusion into the core. The possibility of construction-related problems, such as kinking of the drain, collapse of the outlet pipe, or an uneven grade on the bottom of the drain will also be evaluated.

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