THE EFFECTS OF TWO YEARS OF INTENSE MILITARY ACTIVITY ON THE SOURCE AREAS AND SOURCE-BASIN LENGTHS OF CHANNEL HEADS IN CAMP IRON MOUNTAIN OF THE U.S. ARMY'S FORMER DESERT TRAINING CENTER, MOJAVE DESERT, CALIFORNIA

A Thesis Presented

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Abstract

During World War II, the U.S. Army established twelve base camps that housed equipment and troops training at the Desert Training Center (DTC) in the Mojave and Sonoran Deserts of California and Arizona. After two years of intense use, during which over one million Americans filtered through the DTC, the camps were partially dismantled. Now, road berms and stone walkways are the most apparent remaining features of the camps.

At one of the base camps, Camp Iron Mountain, I show that the military has modified the landscape in at least two ways. First, road berms divert ephemeral streams away from the steepest gradient on the piedmont leaving areas (5 to 30 m) down slope of road berms un-channelized. Secondly, intense foot traffic in the living areas of the camp has smoothed and compacted the soil surface.

I quantify the military's modification of the landscape by comparing 6 control plots (60 x 60 m) to 6 road plots (containing road berms) and 6 walkway plots (containing heavily compacted soil). The mean source area (39.82 ± 42.45 m^2) and source-basin length (21.72 ± 10.76 m) for the control plot channel heads are smaller than the corresponding road plot channel head means (100.2 ± 117.9 m^2; 26.89 ± 11.49 m) and are larger than the means of the walkway plots ($18.27 + 9.83$ m^2; 26.89 ± 11.49 m).

Road plot channels may have larger source areas and source-basin lengths than the control plot channels, because the channel network has not had sufficient time to stabilize since the channels were destroyed by military training over fifty years ago. The channels are in the process of redeveloping since the camp was abandoned and have not yet reached equilibrium with slope and climate. The walkway plot channel heads have smaller source areas and source-basin lengths than the control plots because of the increased smoothness and compaction of the soil surface due to their location in the 'living areas' of the camp. Such modifications to the soil surface cause greater overland flow depths and velocities. Greater overland flow depths and velocities increase the ability of overland flow to erode the soil surface thus shortening source-basin lengths and allowing for smaller source areas in the walkway plots.

Acknowledgements

I wish to express my sincere appreciation to Professor P. R. Bierman and K. K. Nichols for advise, guidance, and input during this project. A special thanks goes to the Geology Critical Writing Class of 1999, S. Gran, K. Jennings, and A. Noren, for editorial remarks that increased the quality of this report. I wish to credit T. Trautz for help in conducting a check of experimental methods. Of course, I am indebted to my family, especially my parents, whose sacrifices and support have helped me attend UVM. Support for this project was provided by the Hawley Fund for undergraduate research in Geology.

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Introduction

1.1 *Arid Regions.*

As the world population grows, humans increasingly populate arid regions. The Mojave Desert of the southwestern United States is an arid region that has experienced a significant rise is human population and infrastructure in the last century (Nir and Gottlieb 1974; Gellis 1996). Interstate highways and structures like the Colorado River Aqueduct and several fossil fuel pipelines have been built on the Mojave Desert landscape in the last century (Wilshire 1992). Historically arid regions have been used in the United States for military training purposes (Prose 1986; Henley 1992). Twentynine Palms Marines Base and the National Training Center at Fort Irwin are examples of military bases currently in use in the arid southwest.

1.2 *Project Focus and Importance.*

I have studied the effects of two years of intense military activity on the source areas, source-basin lengths, and initiation of small (5 to 30 cm wide) ephemeral channel heads in a former U.S. Army training camp on a Mojave Desert piedmont. By comparing the mean values of source area and source-basin length for channel heads between experimental (affected by the military) and control plots (unaffected by military) on the piedmont. Camp Iron Mountain is located on a gently sloping piedmont (also know as an alluvial plain or bajada) which is abruptly separated, by a change in slope, from the Iron Mountains. This type of piedmont landscape is typical in the Mojave Desert and similar arid regions. Thus, Camp Iron Mountain may be used as an example of how military traffic and other similar human impacts have affected arid region surface hydrology.

1.3 *Terminology.*

A *channel head* is the farthest upslope extent of a channel (Fig. 1) defined by erosion and concentration of flow (ephemeral or perennial) that is delineated by well-defined and measurable banks (Montgomery and Dietrich 1989). *Channel head initiation* (or simply *channel initiation*) is the term used to describe the initial erosion of a channel head. Each channel head has an upslope contributing *source area* (Fig. 1) on the landscape where rainfall not infiltrating the soil collects and, via overland flow, enters the channel head. A *local drainage divide* delineates the boundary of the source area. The length between a channel head and the farthest point of the upslope local drainage divide is termed the *source-basin length* (Montgomery and Dietrich 1989).

1.4 *The Desert Training Center.*

The Desert Training Center (DTC), also known as the California-Arizona Maneuver Area (CAMA), is a former U.S. Army training area located in the Mojave and Sonoran Deserts of southern California, Nevada, and western Arizona (Fig. 2). The training area, initiated by General George S. Patton, Jr. in April of 1942, was used to prepare troops for battle in WWII (Henley 1992). Twelve base camps (tent cities), housing up to 15,000 soldiers each, were located at various locations in the 47,105 km^2 DTC (Prose 1986). Various maneuvers were conducted in the areas surrounding the base camps. The camps were used for two years and were dismantled and abandoned in May 1944 (Henley 1992). Over one million young Americans filtered through the DTC (Prose 1986)

The DTC is a unique location to study the effects of the military on the desert landscape, because it was heavily used for a discreet period of time (two years) over fifty years ago. Since abandonment 55 years ago, the DTC has remained mostly untouched due to the remote desert location (Prose 1986). Human activity has been limited to the occasional sight-seer, camper, and off-road vehicle, minimal impact in comparison to the

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Chapter 1

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The presence of the Camp Iron Mountain is still evident after 55 years of abandonment. The tents, structures, vehicles, and equipment were removed from the camps, but the roads and walkway networks were left intact and are still clearly visible. The roads were created in an orthogonal grid system (Fig. 3) and were constructed by grading two berms (20 to 50 cm high) adjacent to the roads. Walkways once connecting tents, buildings, and roads are present within the living areas of the camps. Troops outlined the walkways with clasts ranging in size from 10 to 20 cm. The rock alignments are in various states of deterioration throughout the camps.

Fifty-five years of fluvial activity has destroyed some of the walkways and road berms, but the roads and walkways have also altered the natural surface drainage hydrology in camps (Fig 4). Nichols and Bierman (in press) show that the surface drainage network inside the camps differs from the drainage network outside the camp, mostly due to the presence of the roads and walkways. I build upon the work of Nichols and Bierman (1998, in press) by showing that the military's modification of the landscape has altered the source areas, source-basin lengths, and initiation of channels inside Camp Iron Mountain.

1.5 *Site Location and Climate Setting.*

Camp Iron Mountain, located east of the Iron Mountains in southern California, is situated on a gently sloping piedmont that is drained by a system of shallow (1 to 30 cm), ephemeral streams (Fig. 3, 5). The Iron Mountains are Cretaceous granite and the piedmont sediment is comprised of mostly granitic sand and fine gravel (Prose 1985). Vegetation is sparse and is dominated by creosote bush [*Larrea tridentata*] (Schlesinger and Jones 1984).

The *normal mean* (computed over three consecutive decades) annual rainfall for the study area is 7.9 cm based on monthly precipitation values at the Iron Mountain

Climate Station [N 34° 08' W 115° 08', 922 m elevation] (NOAA 1982). The high, mean monthly precipitation value is 1.35 cm in January and the low is 0.08 cm in May (NOAA 1982).

In arid regions, the lack of vegetation, which decreases soil infiltration rates (Dunne 1980), coupled with rare, intense rain storms ensures that Horton overland flow is the dominant mechanism by which water flows down slopes and erodes the landscape (Cooke and Warren 1973). Rainfall intensities and infiltration rates are not well documented in arid regions; therefore, the occurrence of runoff (Horton overland flow) in the Mojave Desert is hard to estimate. However, Iverson et al. (1981) postulate that runoff occurs approximately once every decade under natural conditions and possibly more often in anthropogenically affected areas. Mojave Desert soil surfaces impacted by off-road vehicle (ORV) use experience overland flow more frequently due to the soils having lower infiltration rates (Iverson et al. 1981).

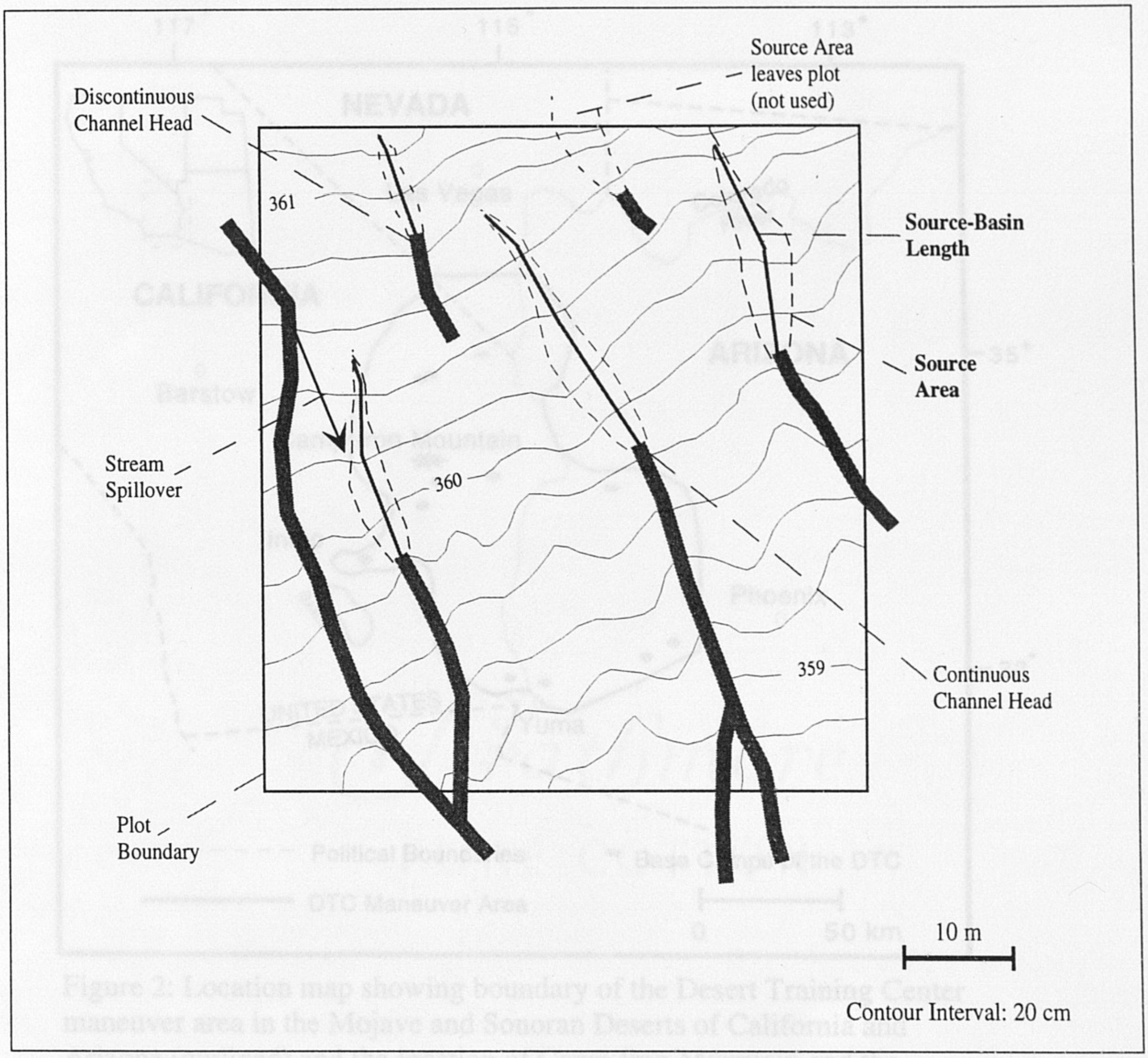


Figure 1. Schematic drawing depicting channels on a landscape similar to the Iron Mountain piedmont. Some channels start within the plot boundaries, others travel through the plot. Channel heads are the farthest upslope point of a channel. Source areas represent the area above a channel head where all overland flow is focused, by topography, to the channel head (delineated by drawing boundary lines perpendicular to contours). Boundaries of the source areas are termed local drainage divides. Source-basin lengths represent the distance from the channel head to the farthest upslope point in the source area. Stream spillover to a source area, which represents an additional input of water besides rainfall, is displayed with the black arrow. Source areas crossing the plot boundaries are not used in the study.

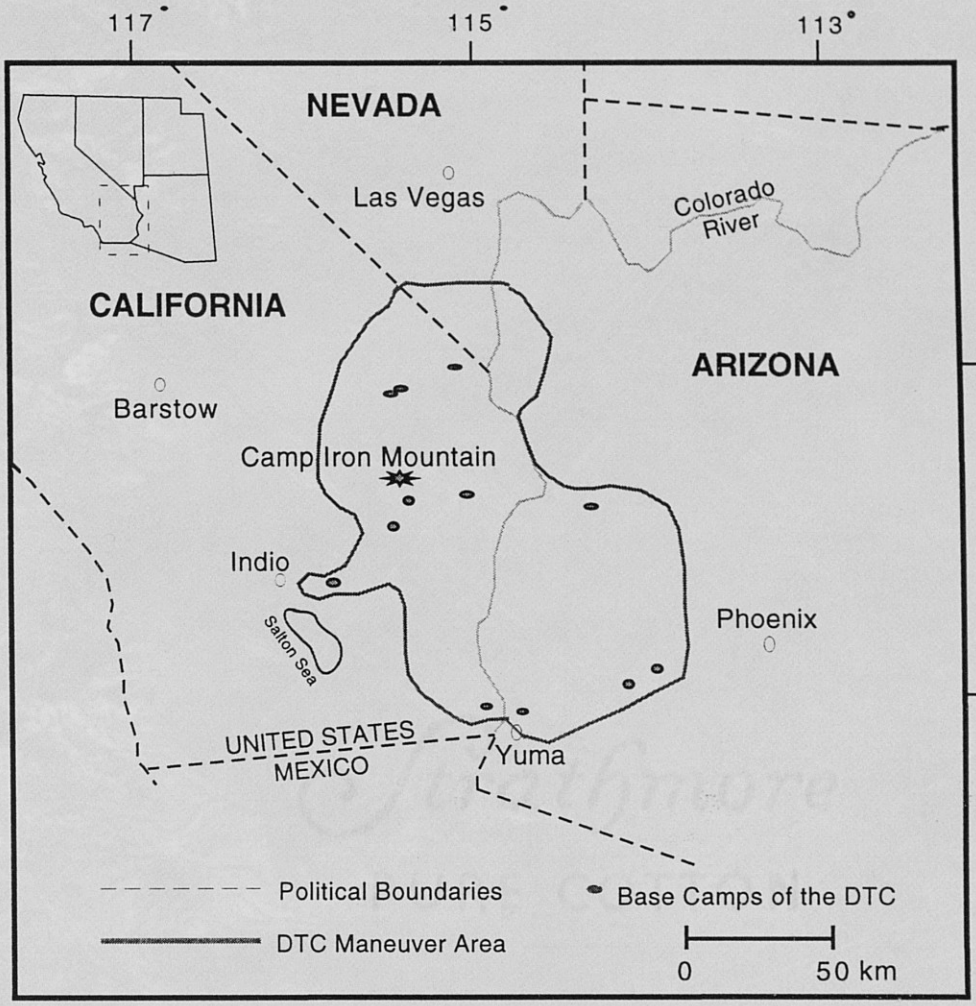


Figure 2: Location map showing boundary of the Desert Training Center maneuver area in the Mojave and Sonoran Deserts of California and Arizona (outlined) and the location of Camp Iron Mountain and the other base camps of the DTC. (Modified after Henley 1992 and Prose 1985)

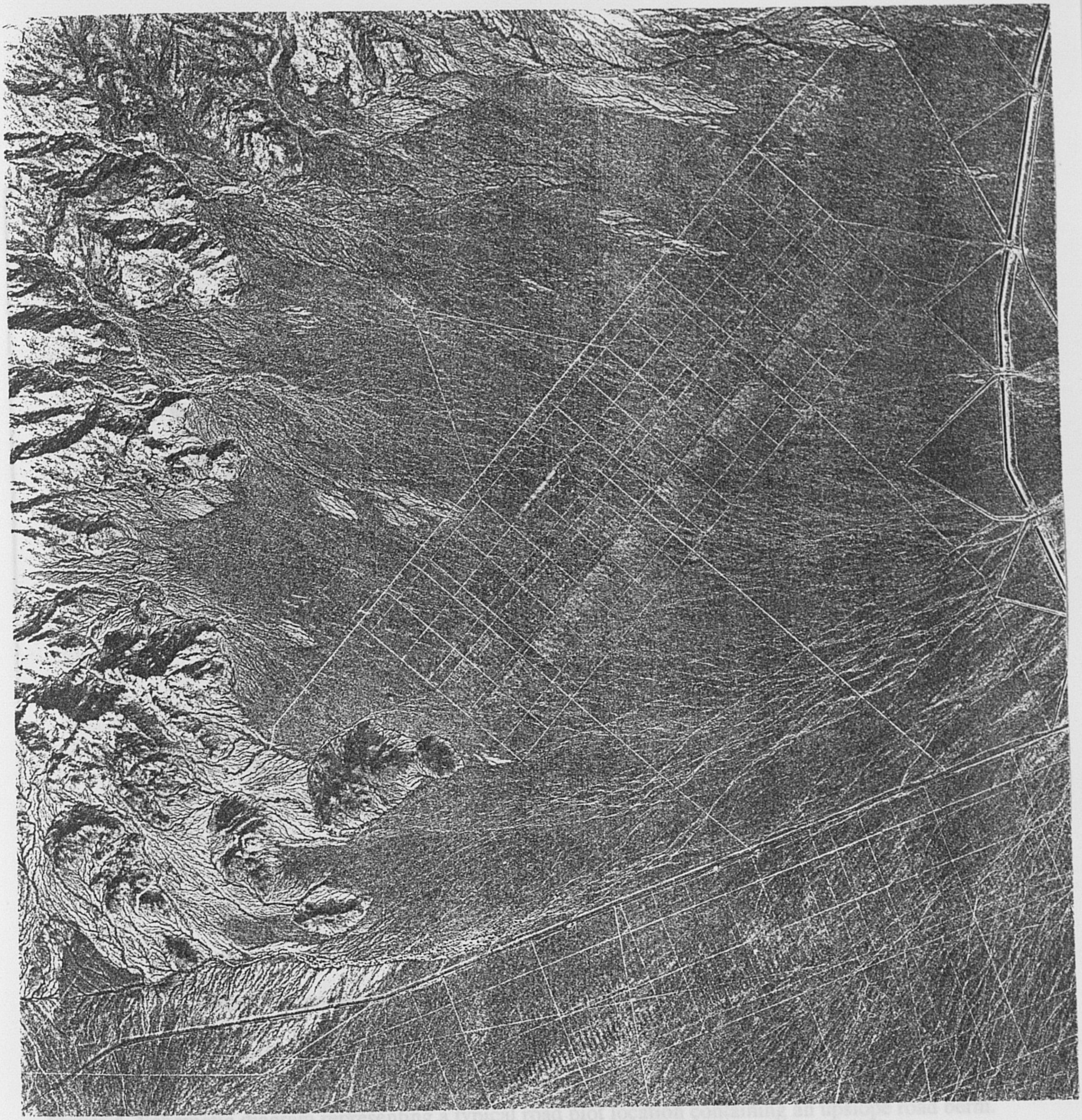


Figure 3. Aerial photo of Camp Iron Mountain taken in October of 1995. Iron Mountains are to the west and northwest. Camp Granite (another DTC base camp) is shown at the bottom of the picture below south of California Highway 62. The dark linear feature in the upper right hand corner is the Colorado River Aqueduct. The roads of the base camps were created in an orthogonal grid system. Each road is bounded by a set of road berms.

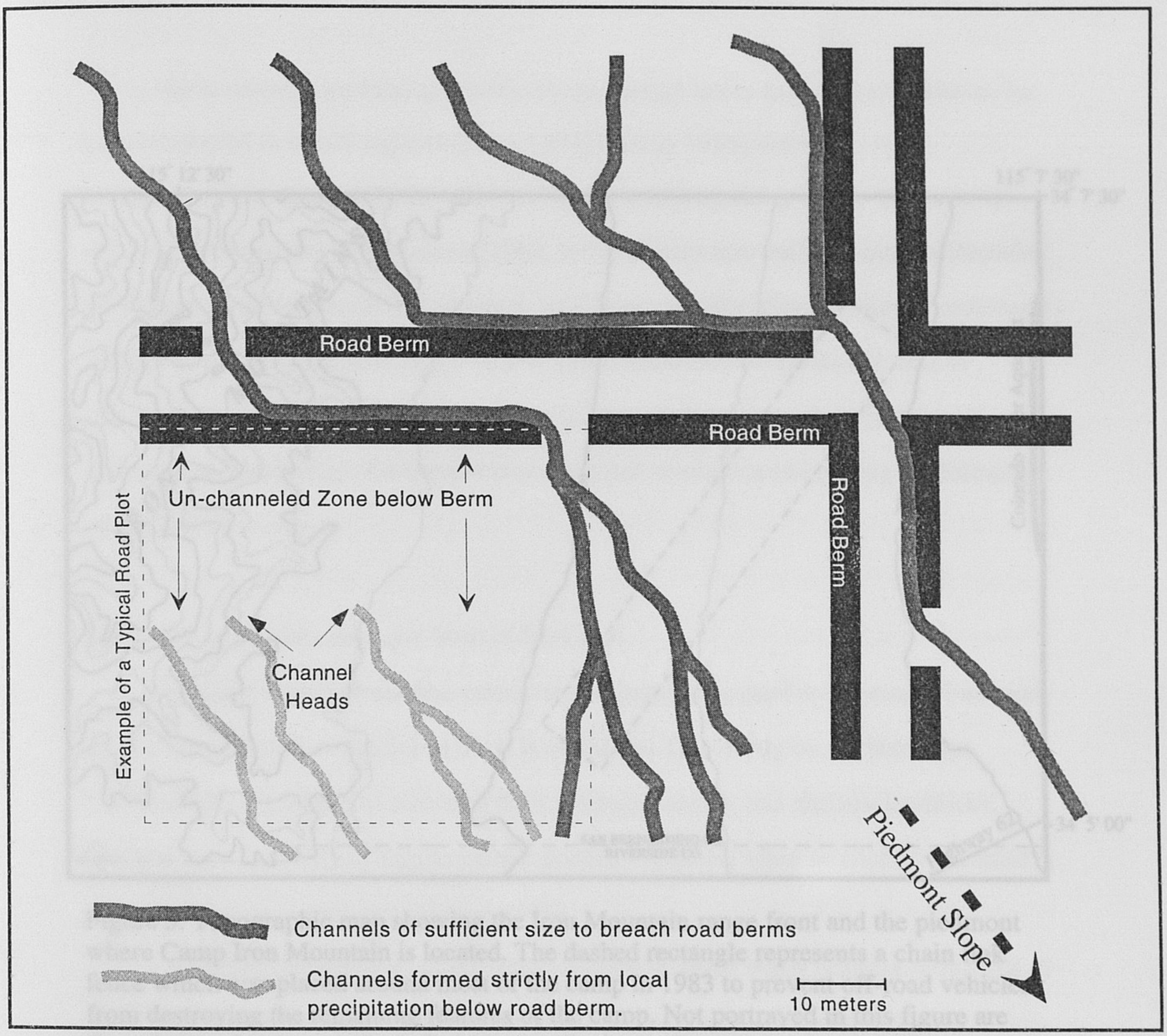


Figure 4. Schematic diagram representing a typical road plot location containing an upslope road berm. Roads are bounded by berms (>20 cm high), which can divert channels flowing down the natural gradient of the piedmont. Down-slope of the road berms is an un-channeled zone where new channels have initiated. Some channels carry enough flow to breach the road berms.

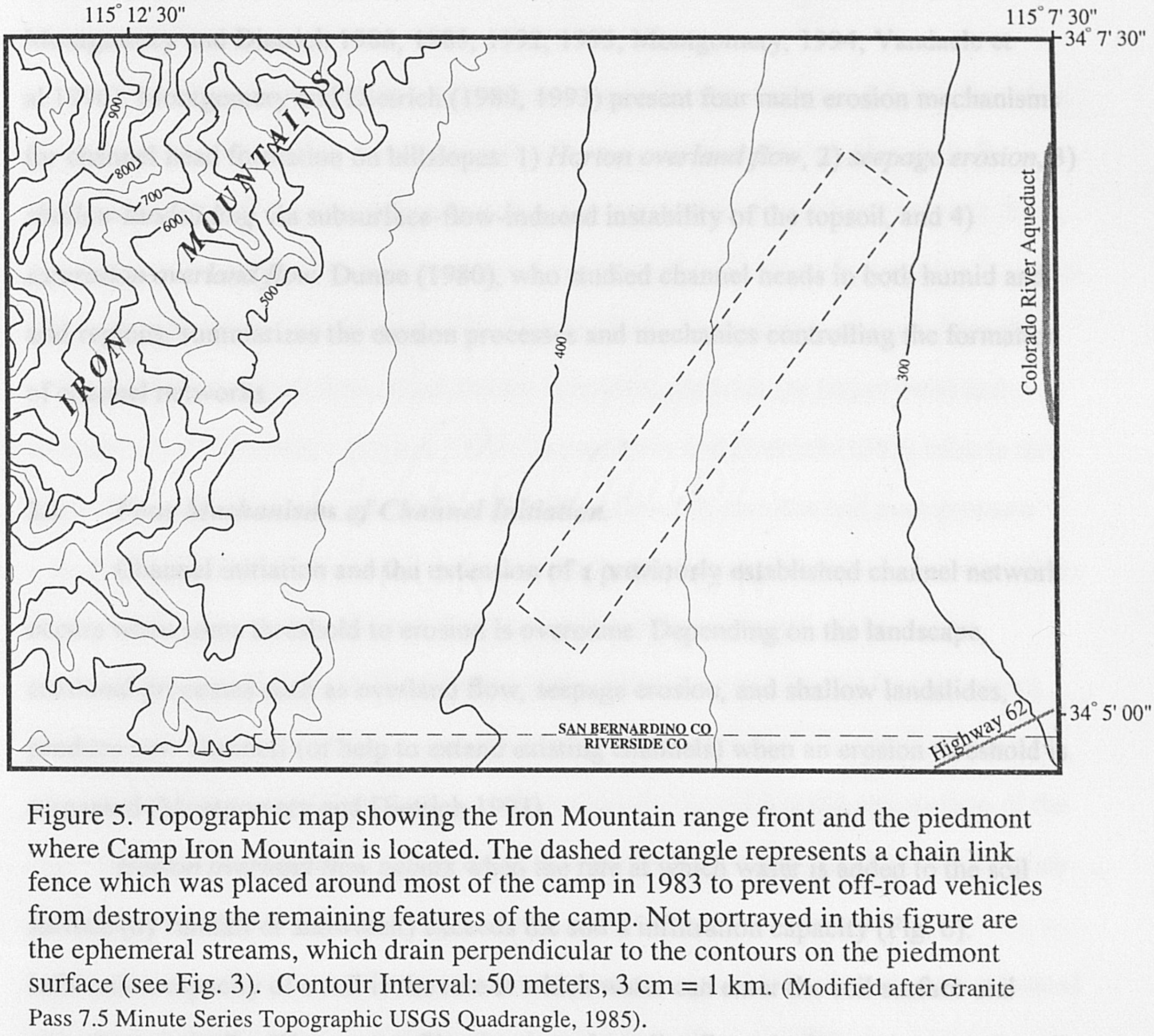


Figure 5. Topographic map showing the Iron Mountain range front and the piedmont where Camp Iron Mountain is located. The dashed rectangle represents a chain link fence which was placed around most of the camp in 1983 to prevent off-road vehicles from destroying the remaining features of the camp. Not portrayed in this figure are the ephemeral streams, which drain perpendicular to the contours on the piedmont surface (see Fig. 3). Contour Interval: 50 meters, 3 cm = 1 km. (Modified after Granite Pass 7.5 Minute Series Topographic USGS Quadrangle, 1985).

Chapter 2

Previous Work and Theory

Most research pertaining specifically to channel heads and channel initiation has been conducted in humid regions (Jones 1971; Marcus 1980; Abrahams 1984; Montgomery and Dietrich 1988, 1989, 1992, 1993; Montgomery, 1994; Vandaele et al.1996). Montgomery and Dietrich (1989, 1993) present four main erosion mechanisms for channel head formation on hillslopes: 1) *Horton overland flow*, 2) *seepage erosion*, 3) *shallow landsliding* via subsurface-flow-induced instability of the topsoil, and 4) *saturation overland flow*. Dunne (1980), who studied channel heads in both humid and arid regions, summarizes the erosion processes and mechanics controlling the formation of channel networks.

2.1 *Four Mechanisms of Channel Initiation.*

Channel initiation and the extension of a previously established channel network occurs when some threshold to erosion is overcome. Depending on the landscape, erosional processes such as overland flow, seepage erosion, and shallow landslides, produce new channels (or help to extend existing channels) when an erosion threshold is surpassed (Montgomery and Dietrich 1993).

Horton overland flow occurs when the rate at which water is added to the soil surface (by rainfall or snowmelt) exceeds the soil's infiltration capacity (Fig. 6). Infiltration capacity of a soil is the rate at which water can enter the soil surface and percolate vertically. Water not infiltrating into the soil collects in depressions on the soil surface and is known as surface detention (Dunne and Leopold 1978). Water fills the depressions and eventually spills out, flowing down-slope as an irregular sheet of water (Horton 1945; Dunne and Leopold 1978; Dunne 1980). This flowing sheet of water exerts a shear stress on the soil surface capable of eroding the soil when the shear stress exceeds the soil's resistance to erosion (Dunne and Leopold 1978; Dunne 1980). The eroded areas are often referred to as rills. For rill formation to occur, the overland flow must reach a sufficient depth to dissipate raindrop energy and prevent raindrop-induced obliteration of incipient rills (Dunne 1980). As erosion continues, the small rills will develop observable banks, becoming channel heads that focus the overland flow into channelized flow.

Subsurface flow (Fig. 6) occurs when water infiltrates the topsoil, but is forced to move down-slope by a less permeable soil horizon (such as an eluvial, clay-rich, B-horizon) or bedrock contact. Subsurface flow can act to erode the soil in two ways. First, laterally moving subsurface flow encountering saturated soil is forced to emerge from the soil becoming return flow (Dunne 1978; Dunne 1980). As the water emerges from the soil to become overland flow, it can entrain individual particles (or larger peds) and transport them down slope (Dunne 1990). Montgomery and Dietrich (1989) refer to this process as *seepage erosion*. Secondly, subsurface flow can increase soil pore pressure and induce small, *shallow landslides* in localized areas (Montgomery and Dietrich 1989). Greater soil pore pressure reduces the resisting force/shear strength of the soil by reducing the normal force on the failure surface. When the total driving force/shearing stress exceeds the resisting force then the slope will fail or slide (Selby 1993). Seepage erosion and shallow landsliding create hollows (much like rills) in the soil surface. If the hollows subsequently focus overland flow or subsurface flow into the channel, then they are referred to as channel heads.

Saturation overland flow (Fig. 6) occurs when rainfall falls directly onto saturated soil, can not infiltrate and thus, becomes overland flow (Dunne 1978). In addition to rainfall on saturated soil, subsurface flow emerging from saturated soil (as mentioned previously, see *seepage erosion*) is also converted to overland flow [also known as return flow (Dunne and Leopold 1978)]. The importance of saturation overland flow as an erosion mechanism is not in its emergence from the soil (this is important for the seepage erosion mechanism), but rather by its movement down-slope as an irregular sheet on top of the soil. Saturation overland flow erodes the soil surface by the same mechanism as Horton overland flow.

2.2 *Research on humid region channel heads and channel initiation.*

In humid regions, Horton overland flow, saturation overland flow, seepage erosion, and shallow landsliding all contribute to the initiation of channels. Until recently, Horton overland flow was considered to be the dominant mechanism forming channel heads (Dunne 1980; Montgomery and Dietrich 1989). Chorley (1978) and Dunne and Leopold (1978) suggest that Horton overland flow is rare in most humid areas because of the presence of dense vegetation and a humus layer on the soil surface, both of which increase soil infiltration capacities in turn hindering Horton overland flow. In lieu of Horton overland flow as a channel initiation mechanism, saturation overland flow, seepage erosion, and shallow landsliding are postulated as the processes leading to channel initiation in humid regions (Dunne 1980; Montgomery and Dietrich 1989; 1993). Since arid regions lack a significant vegetated cover, Horton overland flow and subsequent rilling are probably the dominant mechanism of channel initiation (Cooke and Warren 1973).

On the basis of research conducted in grassland valleys near San Francisco, Montgomery and Dietrich (1989) conclude that there are two forms of channel heads: *gradual* and *abrupt*. The morphology of the two different channel heads results from the specific location of the channel head on the landscape and the hydrologic mechanisms of its formation. *Gradual* channel heads lack a distinct head-cut or scarp because they are formed by (saturation) overland flow. *Abrupt* channel heads, formed by shallow landsliding or seepage erosion (caused by subsurface flow), have a distinct scarp making them easier to define than gradual channel heads. As subsurface flow exits the soil through the channel head it can entrain sediment from below the soil surface (Higgins

1990). Continued erosion by subsurface flow will undercut the scarp of a channel head maintaining its abrupt morphology.

Montgomery and Dietrich (1989) suggest that gentle slopes in humid regions have both gradual channel heads (caused by saturation overland flow) and abrupt channel heads (caused by seepage erosion). They conclude that steep slopes in humid regions contain mostly abrupt channel heads where shallow landsliding is the dominant channel initiation mechanism. On gentle slopes, abrupt channel heads will be formed by seepage erosion, because shallow landsliding is rare.

Montgomery and Dietrich (1988, 1989, 1993) demonstrate that local slope is inversely related to both source area and source-basin length. The relationship suggests that on steep landscapes, the source areas and source-basin lengths of channel heads will be smaller than on gently sloping landscapes. The slope vs. source area, source-basin length relationships provide insight into the conditions affecting channel initiation and can be compared with existing channel head location data to predict how landscapes will respond to disturbance and environmental change (Montgomery and Dietrich 1993).

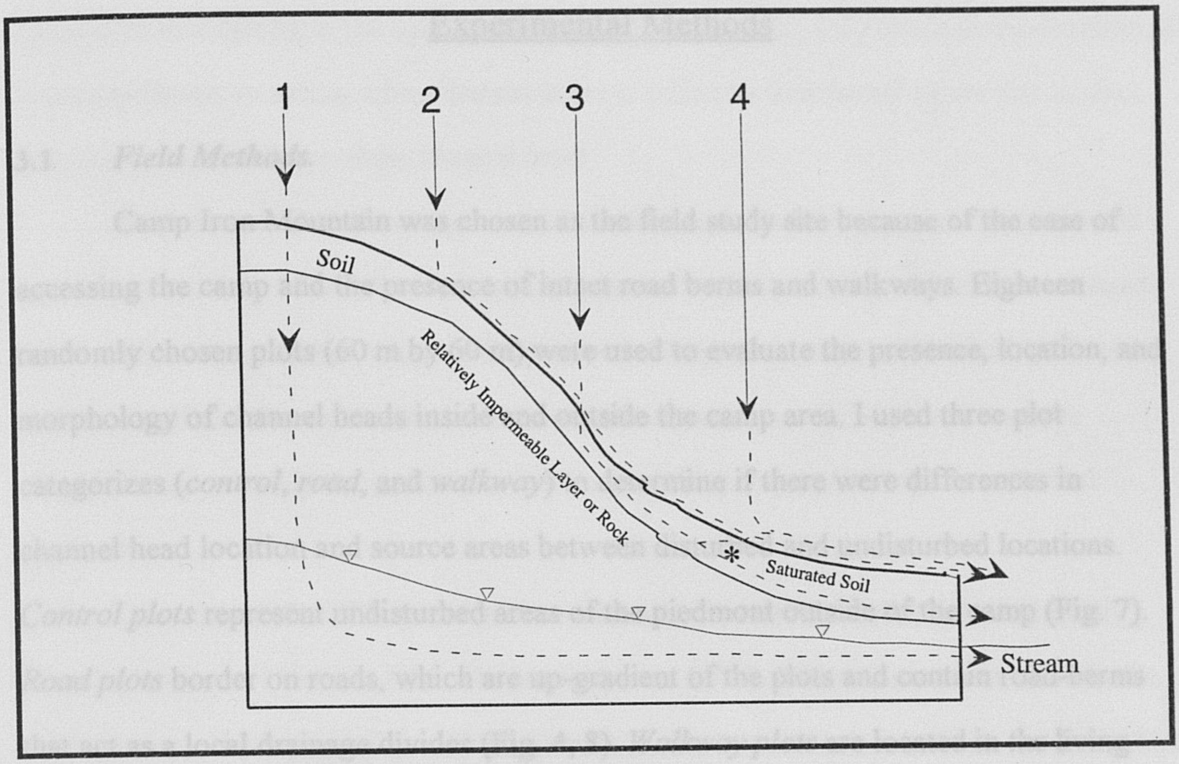


Figure 6: Schematic diagram showing the various flow paths rainfall can travel down a hillslope. (Dunne (1980), and Dunne and Leopold (1978)).

1. Rainfall infiltrates the ground and percolates through the topsoil and the relatively impermeable layer or bedrock and enters the groundwater system.

2. Horton Overland Flow : rainfall flows downslope on top of the soil surface when the rainfall intensity is greater than the soil's infiltration capacity

3. Subsurface Flow: rainfall infiltrates the topsoil, but is forced downslope on top of the impermeable layer. Subsurface flow can erode the soil surface in two ways: i) by <u>shallow landsliding</u> which occurs when subsurface flow through the topsoil increases soil pore pressures and liquifies the soil allowing small portions of soil to move downslope, or ii) by <u>seepage erosion</u> when subsurface flow is forced to emerge from the topsoil by saturated conditions (noted by *, see Saturation Overland flow below) and entrains sediment particles transporting them downslope.

4. Saturation Overland Flow: rainfall flows down-slope when i) saturated conditions in the topsoil convert rainfall directly to overland flow and ii) subsurface flow is forced to emerge from the topsoil (noted by *) by saturated conditions and continue downslope as overland flow.

Chapter 3

Experimental Methods

3.1 *Field Methods.*

Camp Iron Mountain was chosen as the field study site because of the ease of accessing the camp and the presence of intact road berms and walkways. Eighteen randomly chosen plots (60 m by 60 m) were used to evaluate the presence, location, and morphology of channel heads inside and outside the camp area. I used three plot categorizes (*control*, *road*, and *walkway*) to determine if there were differences in channel head location and source areas between disturbed and undisturbed locations. *Control plots* represent undisturbed areas of the piedmont outside of the camp (Fig. 7). *Road plots* border on roads, which are up-gradient of the plots and contain road-berms that act as a local drainage divides (Fig. 4, 8). *Walkway plots* are located in the living areas of the camp and contain rock alignments that outline walkways (Fig. 9); soil in walkway plots was heavily compacted by human foot traffic. The locations of the plots were randomized, but had to fall within their particular grouping (i.e. walkway plots in living areas, road plots adjacent to a road berm, control plots outside of the camps).

A Pentax PCS-2 Total Station was used to determine the boundaries of most plots; tape and compass was used for control plot 3. I marked channels and channel heads in each plot by placing a small flag at the measurable/observable bank edge. I surveyed the topography and delineated the channel and channel head boundaries within each plot using a Trimble 4400 real time kinematic differential Global Positioning System (~1 cm precision). The rock alignments were also surveyed in the walkway plots. Initially, the topography was surveyed by taking a point at 5-meter grid intervals within the orthogonal plots. Once the topographic points were collected, the rock alignment, channel, and channel head points were surveyed.

Observations made in the field suggest that some channel heads include an additional input of water, which 'spilled over' from up-gradient channel banks, in addition to rain falling in the source area (Fig. 1). In the field, I determined the location of stream spillover by noting where stream-bottom sediment was found on the soil surface directed towards a down-slope channel head.

Field observation also suggests that some channel heads may have been formed by seepage erosion. I identified this type of channel head by noting which channel heads had significantly undercut scarps and contained collapsed portions of the soil surface in the bottom of the channel head. Animal burrows were associated with some of the channel heads possibly formed in this fashion and this observation was noted when applicable.

I contoured the GPS data at ten-centimeter intervals for each plot using *Surfer* mapping software (Version 6.04, Golden Software 1997). The maps were created in the field allowing the topography, rock alignments, and channel locations to be field checked for accuracy. I made observations of each channel head (including its source area, morphology, presence of stream spillover, and location within the plot) and took photographs of important features inside the plots.

3.2 *Determining Source Areas and Source-Basin Lengths.*

I determined source areas for each channel head by hand-drawing boundary lines perpendicular to contours on the plot maps (Fig. 1; Appendix 1). The boundary lines represent the local drainage divides enclosing the source area for each channel head. Drainage divides are road berms and local changes in topography. This method of determining source areas relies heavily on the accuracy of the maps created by the GPS survey data and subsequent interpolation of the *Surfer* program. Observations made in the field at each plot after the maps were created support the accuracy of computer interpolated topography (on a 10-cm contour interval). Source areas that did not fall completely within the plots or crossed walkways were not used for the study (Fig. 1).

I calculated source areas using a digitizer. The distance from each channel head to its particular upslope drainage divide (the source-basin length) was determined by measuring the line up-the-axis of the source area hollow (Montgomery and Dietrich 1989) using the digitizer (Fig. 1). Local slope was determined by measuring the distance (in meters) between the upslope and down-slope contour lines surrounding each channel head and dividing by the contour interval.

Since the method of hand-drawing the source areas can be subjective, two plots from each category were randomly chosen (road plots 2,5; walkway plots 2,4; and control plots 3,5) so source areas could be drawn on a separate set of new maps (Appendix 2). To check for bias created by only myself drawing the source areas, three randomly chosen plots (road plots 1, 4; and control plot 1) were selected for a second outside person to construct source areas on a separate set of maps (Appendix 2). These seperately drawn source areas demonstrate the repeatability/reproducibility of the hand drawing methods.

I draw conclusions about the differences in the source areas and source-basin lengths of the experimental and control plots using the means of the source areas and source-basin lengths of the entire population of channel heads from each plot category. In order to substantiate my conclusions concerning the differences between the control plot and experimental plot means, I organized a set of *Student's t-tests* (Devore and Peck 1986). The one-tailed t-tests compare (at a 0.05, or 95% significance level) the road plot channel heads means and walkway plot channel head means separately to the control plot means using the *Minitab* statistical software package (Release 12.1, Minitab 1998). The full set of statistical analyses, procedures, and *Minitab* outputs is listed in Appendix 3.

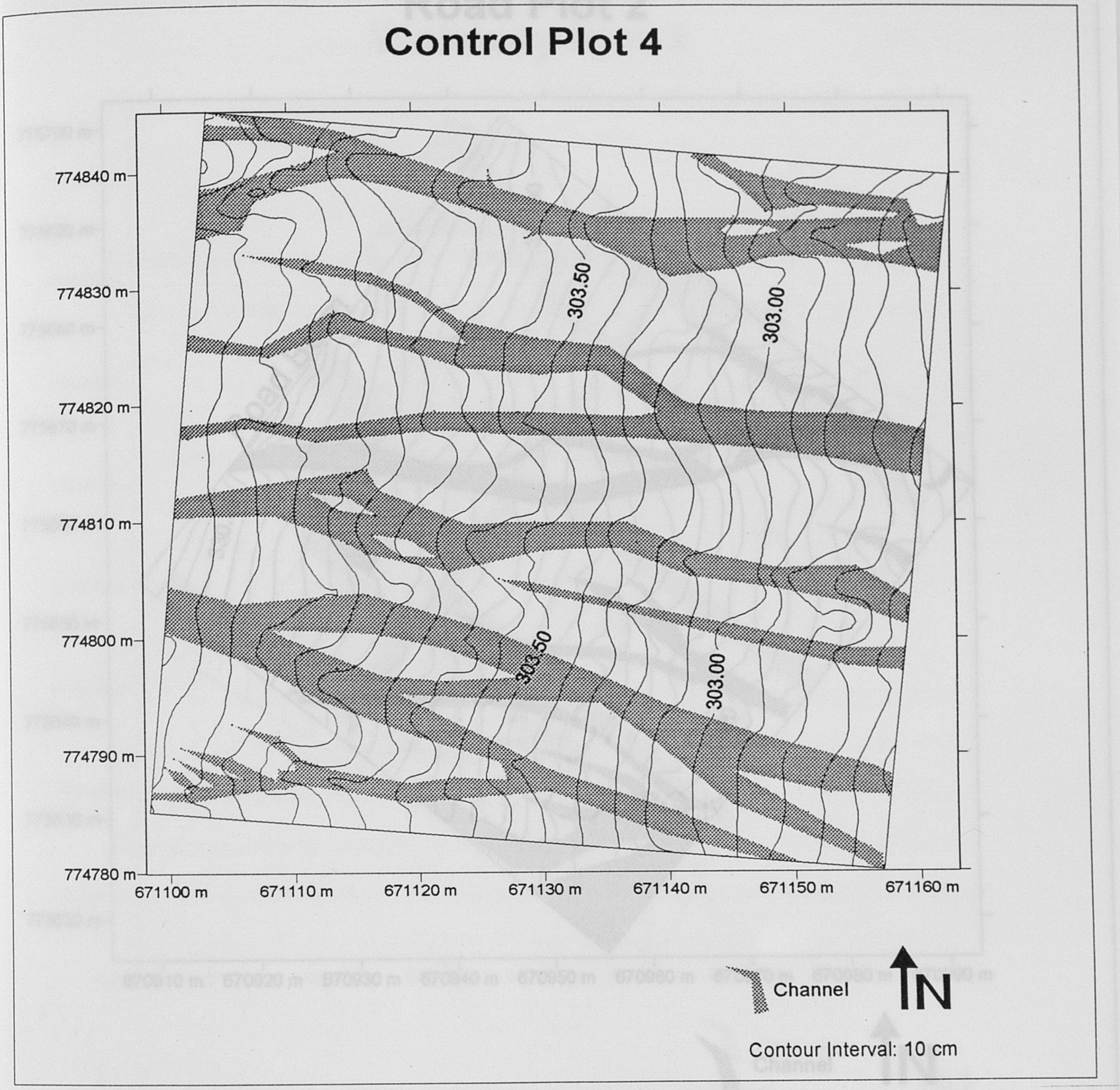

Control Plot 4

Figure 7. Example control plot. Control plots represent areas outside of Camp Iron Mountain that have soil surfaces not disturbed by the military. The source areas and source-basin lengths obtained from control plots should reflect 'natural' conditions on the piedmont.

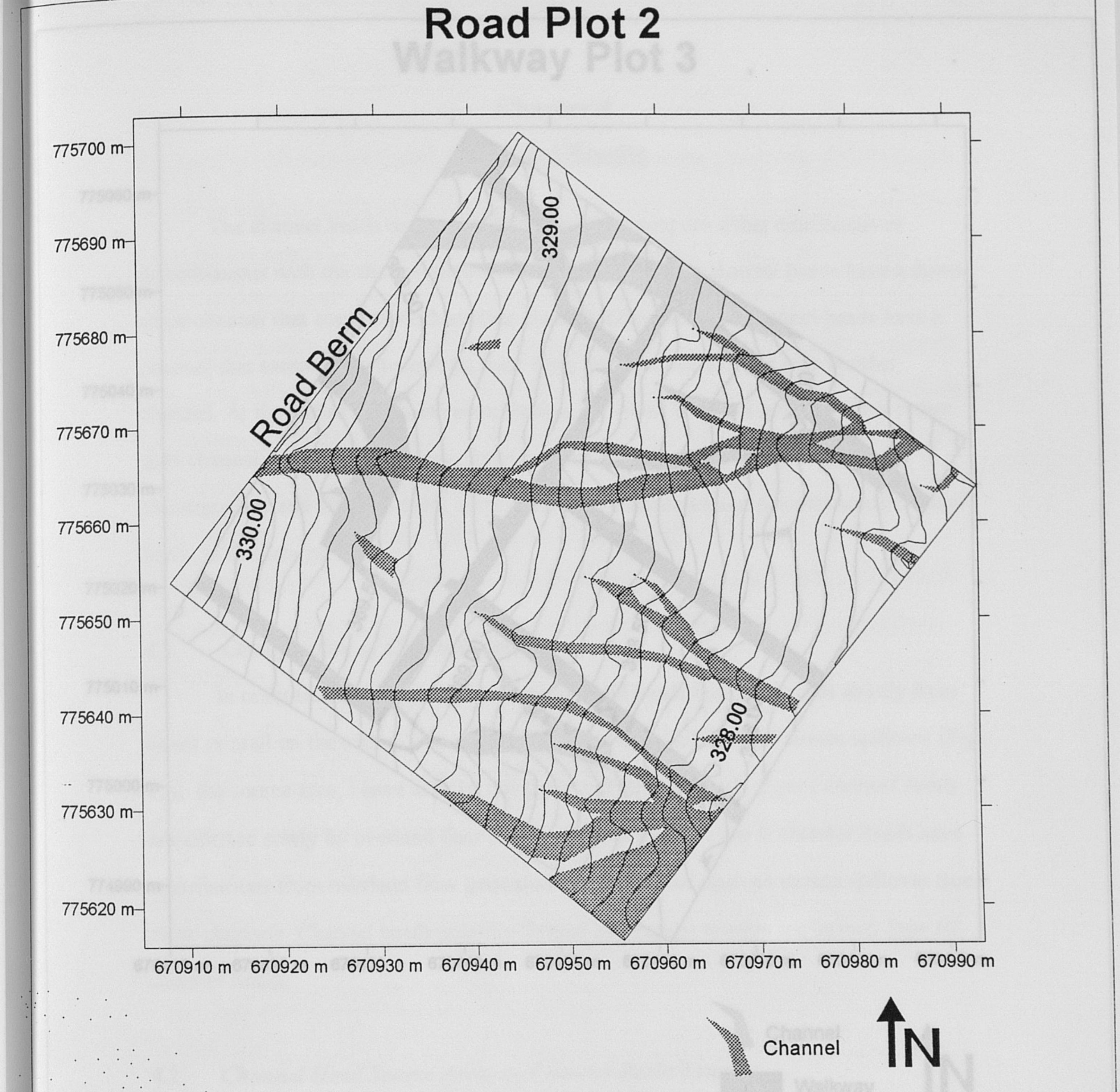


Figure 8. Example road plot. Road plots represent areas inside Camp Iron Mountain bounded by an upslope road berm. These berms act as local drainage divides diverting channels away from the natural piedmont gradient and leaving areas (5 to 30 m) unchannelized. Some channels carry enough flow to breach the road berms.

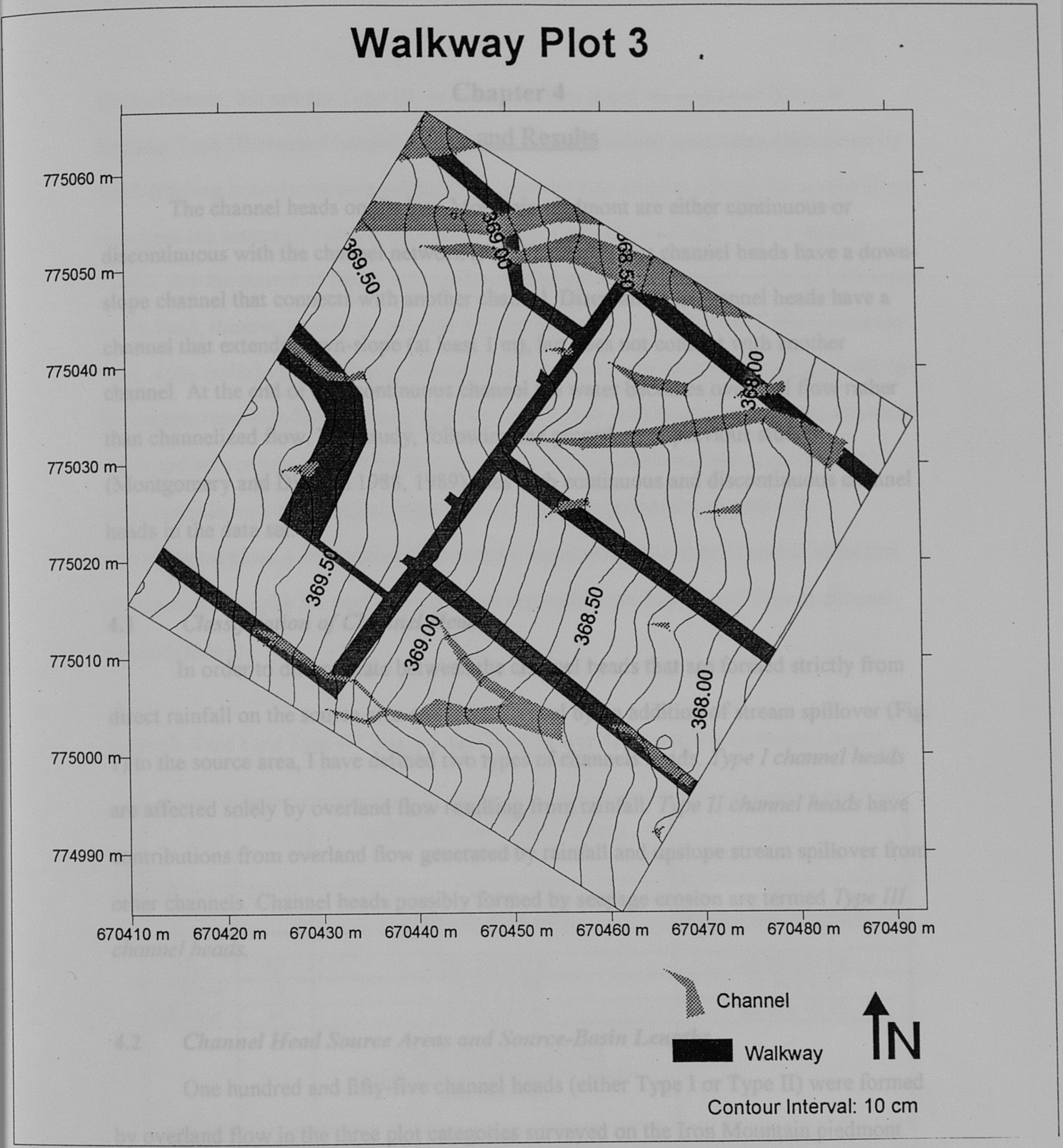


Figure 9. Example walkway plot. Walkway plots are located in areas of the camp containing rock walkway alignments. The walkways once connected tents and other structures. The walkways probably represent the 'living areas' of the camp and, therefore, the soil surface has been highly compacted and smoothed due to two years of intense foot traffic.

Chapter 4

Data and Results

The channel heads on the Iron Mountain piedmont are either continuous or discontinuous with the channel network (Fig. 1). Continuous channel heads have a down-slope channel that connects with another channel. Discontinuous channel heads have a channel that extends down-slope (at least 1 m), but does not connect with another channel. At the end of a discontinuous channel the water becomes overland flow rather than channelized flow. This study, following the procedure of previous studies (Montgomery and Dietrich 1988, 1989) uses both continuous and discontinuous channel heads in the data set.

4.1 *Classification of Channel Heads.*

In order to differentiate between the channel heads that are formed strictly from direct rainfall on the source area and those formed by an addition of stream spillover (Fig. 1) to the source area, I have defined two types of channels heads. *Type I channel heads* are affected solely by overland flow resulting from rainfall. *Type II channel heads* have contributions from overland flow generated by rainfall and upslope stream spillover from other channels. Channel heads possibly formed by seepage erosion are termed *Type III channel heads.*

4.2 *Channel Head Source Areas and Source-Basin Lengths.*

One hundred and fifty-five channel heads (either Type I or Type II) were formed by overland flow in the three plot categories surveyed on the Iron Mountain piedmont. There are only 14 Type III channel heads (evidence suggesting formation due to seepage erosion) and they occurred in only the walkway and control plots.

The source area and source-basin lengths were determined for Type I and Type II channel heads, but not for Type III, as overland flow is not the dominant factor in forming Type III channel heads (Appendix 4). Type II source areas were determined by hand-drawing boundaries perpendicular to contours (see section 3.2), so the source areas represent the source of rainfall for overland flow (as is the case with Type I channel heads), not the source of the stream spillover. The presence of stream spillover was noted in the field, there is no way to quantify the amount of stream spillover. I determined the local slope (m/m) of each Type I channel head located in the control plots (Appendix 5) for comparison with Montgomery and Dierich's (1989, 1993) relationship between local slope and source area/source-basin length. In order to make conclusions about the differences in source areas and source-basin lengths between the control and experimental plots, I determined the mean (± one standard deviation) source areas and source-basin lengths for each plot category separated into Type I and Type II channel heads (Table I).

Table I: Type I and Type II Channel Head Mean Source Areas and Source Basins Lengths.

		TYPE I CHANNEL HEADS (OVERLAND LAND FLOW STRICTLY FROM RAINFALL)	
PLOT	Count	**Mean Source Area** (m^2)	**Mean Source-Basin Length** (m)
Road	52	100.2 ± 117.9	26.89 ± 11.49
Walkway	18	18.27 ± 9.83	15.49 ± 5.27
Control	16	39.82 ± 42.45	21.72 ± 10.76
		TYPE II CHANNEL HEADS (OVERLAND FLOW FROM SPILL-OVER AND RAINFALL)	
PLOT	Count	**Mean Source Area** (m^2)	**Mean Source-Basin Length** (m)
Road	20	21.94 ± 23.85	13.96 ± 5.93
Walkway	20	6.57 ± 3.06	7.61 ± 2.61
Control	29	8.41 ± 6.71	8.40 ± 3.54

4.3 *Tests to Check for Reproducibility of Hand-Drawing Source Areas.*

Source areas can be reproduced, by myself or another person, using the method of hand-drawing boundaries perpendicular to the contour lines. The 'check' source areas drawn by myself differ from the originally produced source areas by an average (± one standard deviation) of 1.8% ± 61.38% (70 channel heads checked). The average difference of the source areas drawn by an outside person are 7.89% ± 61.02% less than the corresponding original (41 channel heads checked) source areas (Appendix 6). The percent differences for each check of reproducibility are low, but the standard deviations are considerably higher. Since large populations (i.e. mean source areas and mean source-basin lengths for each plot category) are compared in this study rather than individual source areas or source-basin lengths, it is more important that the average percent differences in reproducibility of the check population are smaller than the individual percent differences.

4.4 *Statistical Analyses of Source Area and Source-Basin Length Data.*

The road plot channels exhibit the largest mean source areas and source-basin lengths for both Type I and Type II channel heads (Table 1). The walkway plot channel heads have the smallest mean source areas and source-basin lengths for both Type I and Type II channel heads. Regardless of plot category, Type I channel heads (channel heads formed by overland flow as a result of rainfall only) have larger source areas and source-basin lengths than Type II channel heads (channel heads formed by overland flow as a result of rainfall and stream spill over).

The t-tests (Appendix 3) support the observation that the experimental plot source areas and source-basin lengths are significantly different at a 95%, significance level (Appendix 7) except for the Type II walkway plot mean source-basin length vs. the Type II control plot mean source-basin length. At a 90% significance level, however, the Type

II walkway mean source-basin length is statistically different from the control plot mean (Appendix 3).

4.5 *Relationship of Source Area and Source-Basin Length to Local Slope*.

As previously mentioned, Montgomery and Dietrich (1989), show an inverse relationship between local slope and both source area and source-basin length in humid regions. The Iron Mountain piedmont source areas and source-basin lengths for the Type I control plots show a similar inverse relationship with local gradient, although the two data sets plot in different areas of the graphs (Fig. 10). Only Type I control plot channels heads were used for comparison because they represent the naturally occurring channel network on the Iron Mountain piedmont without modification (by the military or input from stream spillover).

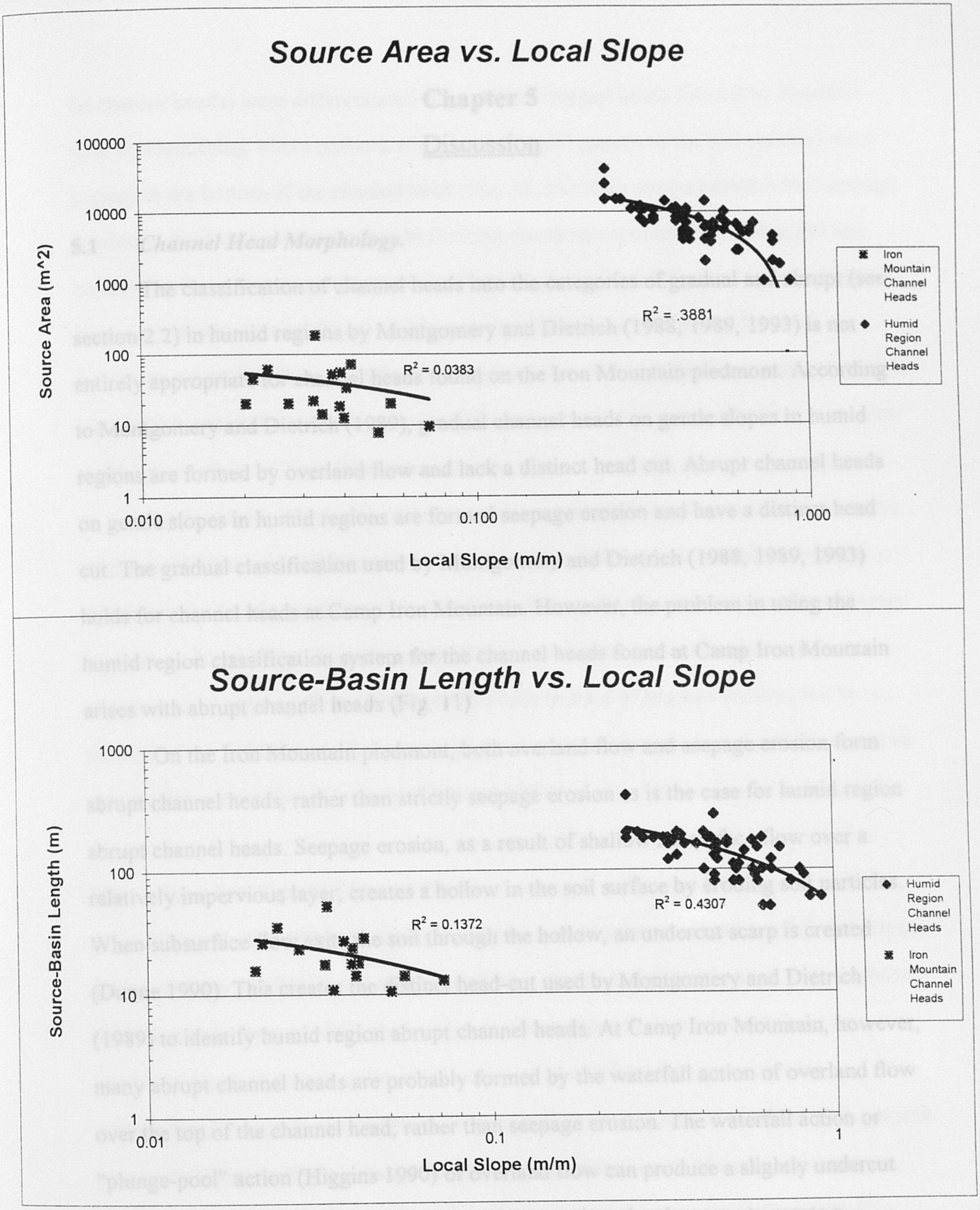


Figure 10. Log-log graphs of the inverse relationship of slope vs. source area and source-basin length. Diamonds represent Montgomery and Dietrich's (1989) humid region channel heads data. Squares represent the control plot, Type I, channel heads on the Iron Mountain piedmont. The humid region data have a larger r^2 value than the Iron Mountain data, however, neither the humid region data nor the Iron Mountain data have strong inverse relationships.

Chapter 5

Discussion

5.1 *Channel Head Morphology.*

The classification of channel heads into the categories of gradual and abrupt (see section 2.2) in humid regions by Montgomery and Dietrich (1988, 1989, 1993) is not entirely appropriate for channel heads found on the Iron Mountain piedmont. According to Montgomery and Dietrich (1989), gradual channel heads on gentle slopes in humid regions are formed by overland flow and lack a distinct head cut. Abrupt channel heads on gentle slopes in humid regions are formed seepage erosion and have a distinct head cut. The gradual classification used by Montgomery and Dietrich (1988, 1989, 1993) holds for channel heads at Camp Iron Mountain. However, the problem in using the humid region classification system for the channel heads found at Camp Iron Mountain arises with abrupt channel heads (Fig. 11).

On the Iron Mountain piedmont, both overland flow and seepage erosion form abrupt channel heads, rather than strictly seepage erosion as is the case for humid region abrupt channel heads. Seepage erosion, as a result of shallow subsurface flow over a relatively impervious layer, creates a hollow in the soil surface by eroding soil particles. When subsurface flow exits the soil through the hollow, an undercut scarp is created (Dunne 1990). This creates the distinct head-cut used by Montgomery and Dietrich (1989) to identify humid region abrupt channel heads. At Camp Iron Mountain, however, many abrupt channel heads are probably formed by the waterfall action of overland flow over the top of the channel head, rather than seepage erosion. The waterfall action or "plunge-pool" action (Higgins 1990) of overland flow can produce a slightly undercut scarp or head-cut, but it does not excavate far enough under the scarp to create a significant overhang (Fig. 12).

Abrupt channel heads formed by seepage erosion at Camp Iron Mountain (Type

III channel heads) were differentiated from abrupt channel heads formed by overland flow by identifying where portions of collapsed 'roof' (pieces of the soil surface) were present in the bottom of the channel head (Fig. 12, 13). This method assures that seepage erosion is the dominant mechanism in forming the abrupt channel head, since the soil surface overhang is present. Some of the Type III channel heads had evidence of animal burrows in the scarp area (Fig. 13). The presence of sub-surface animal burrows facilitates subsurface flow and allows seepage erosion. Without further investigation, it is not possible to tell if animal burrows or differences in soil horizon infiltration capacities are the main cause of Type III channels heads.

Interestingly, Higgins (1990) asserts that overland flow must contribute, at some extent, to all channel head formation and that overland flow could actually work to destroy evidence of seepage erosion as a formation mechanism by transporting collapsed roof pieces down-slope. This may mean that some abrupt channel heads were misinterpreted as being formed by overland flow instead of seepage erosion, but in defense of my field observations, seepage erosion in arid regions is not well documented as a erosion mechanism (Cooke and Warren 1973).

5.2 *Type I vs. Type II Channel Heads.*

Type II channel heads (those formed by a combination of both rainfall and stream spillover) have smaller source areas and shorter source-basin lengths than Type I (those formed strictly from rainfall) channel heads. Since Type II channel heads have an additional input of stream spillover, the amount of overland flow per unit area contributing to Type II channel heads is greater than the amount of overland flow per unit area contributing to Type I channel heads. The additional input of water via stream spillover to Type II channel heads, increases the depth of the overland flow, which increases shear stress on the soil surface in turn allowing for smaller source areas and shorter source-basin lengths (Montgomery and Dietrich 1993) compared to Type I channel heads.

5.3 *Differences between Control and Experimental Plots.*

I assume that the data collected from the control plots represents the natural the piedmont surface. Assuming the control plot data are representative of the natural landscape, then the military's modification of the piedmont surface in Camp Iron Mountain (by the destruction of pre-existing channels, placement of road berms, and compaction of soil) explains why road plot and walkway plot channel head locations differ from those occurring naturally. Nichols and Bierman (in press) show that the military's modification of the landscape in Camp Iron Mountain has altered the channel depths, widths, areas, orientations, and drainage densities as compared to the natural landscape. Nichols and Bierman (in press) attribute the differences between control plots and impacted plots to the two years of intense military training in the camp 55 years ago. They postulate that the differences are caused by: 1) the presence of rock alignments and road berms inside the camp, which divert overland flow away from the natural drainage direction of the piedmont, and 2) smoothing and compaction of the soil surface, which decreases infiltration capacities and increases overland flow velocities and the erosive force (shear stress) of overland flow. The conclusions of Nichols and Bierman (in press) pertaining to soil surface compaction and smoothing by military activity in Camp Iron Mountain support earlier observations made Iverson (1980) and Iverson et al. (1981) concerning the hydrologic impact of ORV use in the Mojave Desert.

5.4 *Walkway Plots vs. Control Plots.*

The conclusions of Nichols and Bierman (in press) and Iverson (1980) offer a reasonable explanation for the discrepancies between the control plot and walkway plot source areas and source-basin lengths. The mean source areas and source-basin lengths for walkway plot channels are smaller and shorter than the corresponding control plot data (Table 1). The discrepancies could be attributed to the smoothing and compaction of the soil surface in the walkway plots. The walkway plots are located in the 'living areas' of the camps (Fig. 14) and, therefore, the soil was heavily impacted by foot traffic. A smoother soil surface has decreased surface roughness (a lower *Mannings n* roughness coefficient value), which yields increased flow velocities of overland flow (Iverson et al. 1980; Iverson 1981). Moreover, highly compacted soil surfaces have reduced infiltration capacities due to the closing of soil pore spaces at the surface (Dunne and Leopold 1978). Decreased infiltration capacity increases the volume of overland flow and thus shear stress on the soil surface. A decrease in infiltration capacity or an increase in shear stress created by overland flow will result in smaller source areas (Montgomery and Dietrich 1993). Smaller source areas and shorter source-basin lengths as compared to the control plot data are the expression of decreased surface roughness and infiltration capacities inside the walkway plots.

5.5 *Road Plots vs. Control Plots*.

In contrast to the walkway plots, the road plot channels have larger source areas and source-basin lengths than the control plot channels (Table 1). The discrepancy between the road plot and control plot channel source areas and source-basin lengths could be a result of the recent destruction of the channel network inside the camp. When the military abandoned Camp Iron Mountain the channel network was most likely completely destroyed by foot and vehicle traffic. Photographs of various base camps of the DTC, during its active use, depict a soil surface void of vegetation and channels (Fig. 14). The road plot channel network may not have had sufficient time to adjust (or in this case re-develop in the fifty-five years since the camp was abandoned) to the alteration of the landscape. Overland flow events have produced the channel network pattern that is present inside the camp and these events are rare (~ once a decade). The channel heads occurring naturally on the piedmont (represented by control plot channel source area and source-basin length) are assumed to be in equilibrium with climate and slope and, therefore, channel network growth or retreat outside of the camp has probably stabilized. Conversely, the channel network inside the camp has experienced only those overland flow events that have occurred since the camp was abandoned. Therefore, road plot channels will experience headward development of the channels (by the shrinking of source areas and source-basin lengths) with each overland flow event until the channel heads are in equilibrium with slope and climate (and the source areas and source-basin lengths are similar to those in the control plots).

Furthermore, Nichols and Bierman (in press) show that the drainage densities in the road plots (0.067 ± 0.023 m/m^2) are smaller than those occurring under natural conditions (0.096 ± 0.036 m/m^2). The observation of smaller drainage densities in the road plots also supports the hypothesis that the channel network in the road plots has not equilibrated in the fifty-five years since the camp was abandoned.

5.6 *Recovery of Road Plot Channels.*

Channel head location can vary significantly on the landscape when large-scale environmental changes occur (Dunne 1980; Montgomery and Dietrich 1993). For example, when a landscape is altered by a base level lowering or an increase in slope, the channel network will respond by extending closer to the drainage divide (i.e. 'headward development', the source-basin length and source area will decrease); the response usually stabilizes quickly in geologic time (Dunne 1980). Or, if the climate of a landscape was to become arid, vegetation would be reduced and infiltration rates would decrease forcing channel head source areas to decrease (Montgomery and Dietrich 1993). In the case of Camp Iron Mountain, two years of intense military activity destroyed the channel network and the road plot source areas and source-basin lengths have yet to stabilize with slope and climate. The channel network inside the road plots should expand, by channel head extension towards the drainage divide, with each additional overland flow event. Over time, the source areas and source-basin lengths of the road plots should stabilize (by shrinking) and become equivalent to those of the control plots as the road plots experience more overland flow events.

5.7 *Recovery of Walkway Plot Channels.*

Compaction and smoothing of the soil surface has decreased the source areas and source-basin lengths of channel heads in the walkway plots. Until the smoothing and compaction of the soil is reversed, the soil roughness and infiltration capacity will remain lower in the living areas of the camp than in the control plots. These factors will continue to result in increased overland flow velocities, which will in turn decrease source areas and source-basin lengths.

After the soils in 'the living areas' of the camp (as expressed by the walkway plot data) have recovered from smoothing and compaction, than the source areas and source-basin lengths will likely become equivalent of the natural landscape. Webb et al. (1986) suggest that Mojave Desert soil densities can take as long as a century to recover from human impact.

5.8 *Local Slope vs. Source Area and Source-Basin Length.*

Montgomery and Dietrich (1988, 1989, 1993) show a inverse relationship between local slope and both source area and source-basin length in humid regions (Fig. 10). Although Montgomery and Dietrich's relationship is stronger and the two data sets plot in different areas of the graphs, the Type I control plot channel heads at Camp Iron Mountain show a similar inverse relationship. Montgomery and Dietrich (1989) sampled source areas (from 1000 m^2 to 40,000 m^2) and source-basin lengths (from 60 m to 400 m) over slopes ranging from 0.1 to 1.0 in humid regions. I sampled source areas (from 5 m^2 to 180 m^2) and source-basin lengths (from 10 m to 50 m) on a uniformly sloping desert piedmont yielding a more limited range of slopes (0.02 to 0.08).

The location of the separate data sets in different areas of the graphs attests to the differences between humid and arid region surface hydrology. Channel heads are usually restricted to hillslopes in humid regions (Montgomery and Dietrich 1989, 1992), while in arid regions channel heads are found mainly on the alluvial piedmonts, since the hillslopes are bare rock. Humid regions are dominated by soil-mantled hillslopes and valleys containing a thick vegetative cover. These properties allow channel heads in humid regions to form on wider range of steep slopes with larger source areas and source-basin lengths than arid region channel heads. Conversely, arid regions are dominated by uniformly sloping piedmonts and bare rock hillslopes, which lack significant vegetative covers. These properties allow arid region channel heads, with smaller source areas and source-basin lengths, to form on smaller range of gentler slopes.

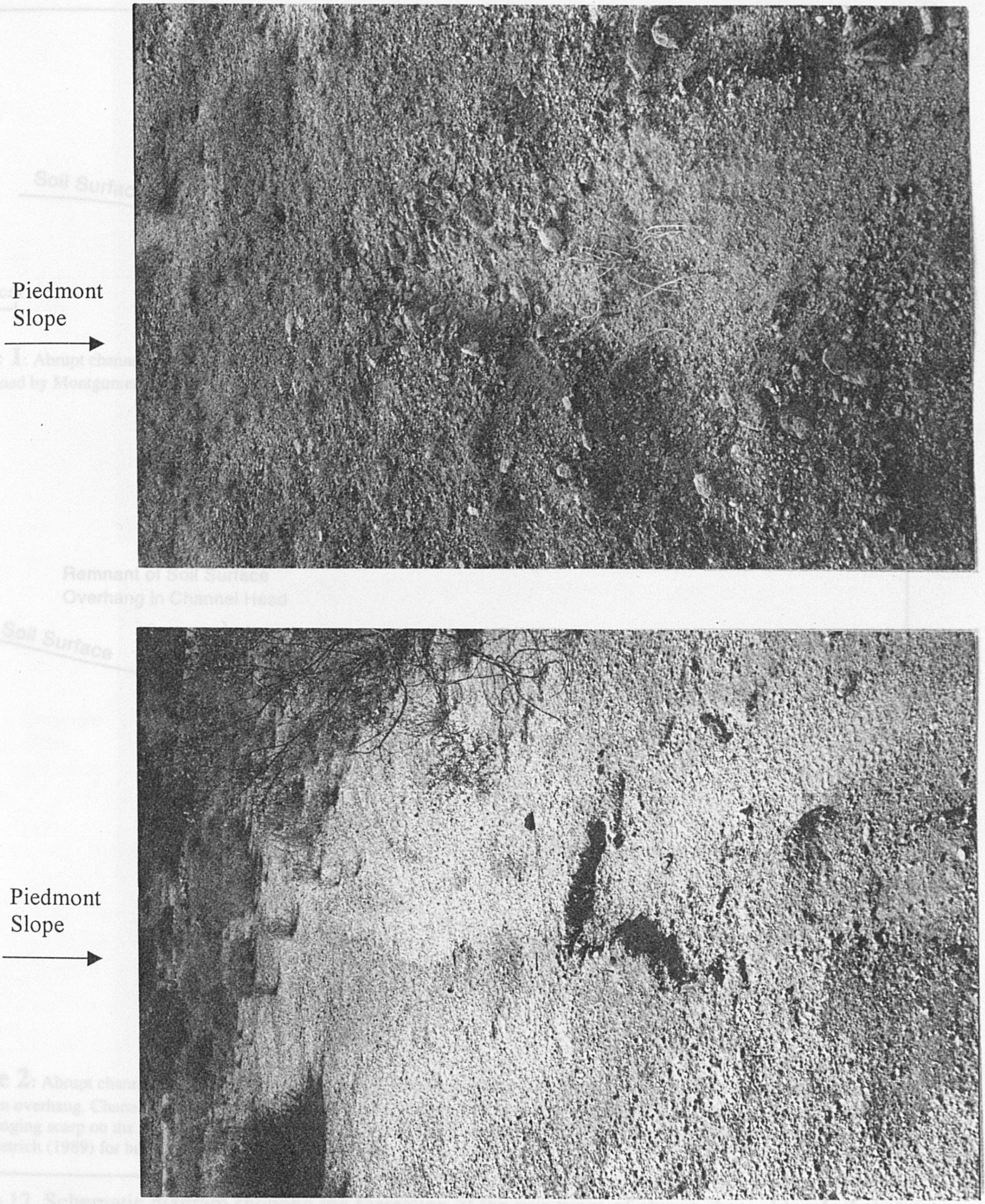
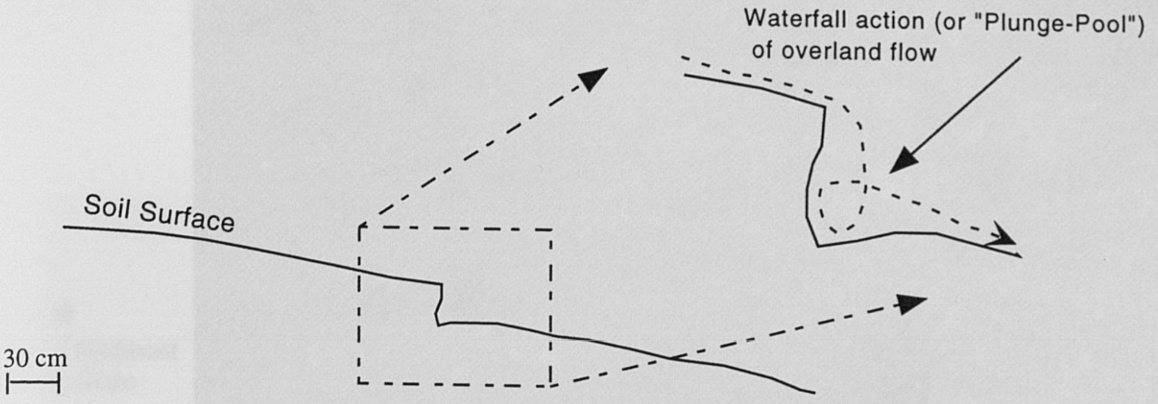
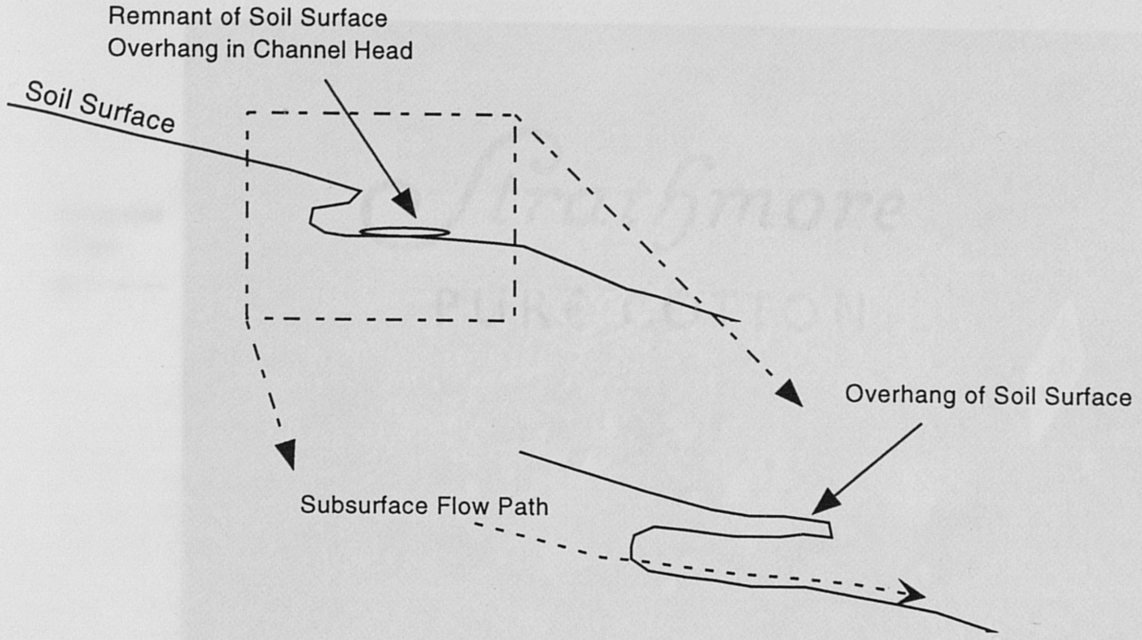


Figure 11. Gradual and abrupt channel heads. Upper photo is of a typical gradual channel head found at on the Iron Mountain piedmont. Note the lighter sand in the channel. Lower photo is of an abrupt channel head. Note the easily definable abrupt scarp.



Case 1: Abrupt channel head formed by erosion due to the water fall (or plunge-pool) of overland flow. Abrupt channel heads are defined by Montgomery and Dietrich (1989) as being formed strictly by seepage erosion in humid regions.



Case 2: Abrupt channel head formed by seepage erosion removing soil particles and undercutting below the soil surface creating an overhang. Channel heads formed by seepage erosion in Camp Iron Mountain were identified by finding remnants of the overhanging scarp on the floor of the channel head. This type of abrupt channel head fits the definition given by Montgomery and Dietrich (1989) for humid region abrupt channel heads.

Figure 12. Schematic diagram showing the formation of the two types of abrupt channel heads that form at Camp Iron Mountain (see Fig. 13 for photographs of the two types of abrupt channel heads). Case 1 shows abrupt channel heads formed by overland flow. Case 2 shows abrupt channel heads formed by seepage erosion. In each case, the inset cartoon displays how each channel head was formed.

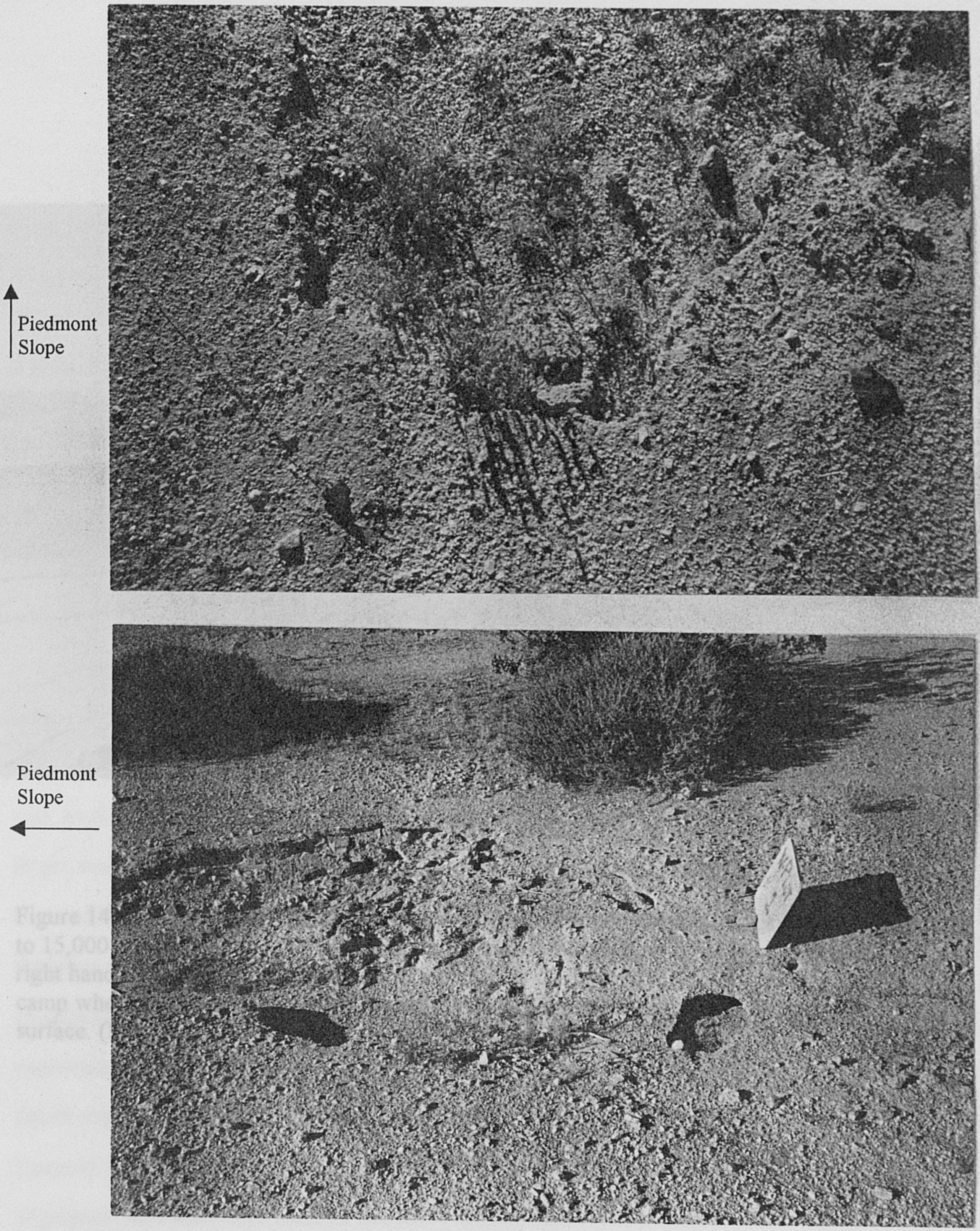


Figure 13. Examples of Type III channel heads found on the Iron Mountain piedmont formed by seepage erosion (see Fig. 11 for example of abrupt channel head formed by the waterfall of overland flow). The upper photo is an example of a Type III channel head with evidence of collapsed 'roof' pieces. The bottom picture is an example of a Type III channel head with evidence of an animal burrow near the scarp. Not the circular hole in the soil below the placard. There is significant evidence of collapsed roof in this channel head. The animal burrow facilities seepage erosion.

Figure 14. Photograph of a DTC base camp. The base camps were tent cities housing up to 15,000 troops each at one time. Note the intense concentration of tents in the upper right hand corner of the photo. This was most likely the barracks or 'living area' of the camp where the troops lived. Also, note the lack of vegetation and channels on the soil surface. (Photo from Henley 1992).

Chapter 6

Implications of Experimental Findings

Two years of intense military training and the persistence of road berms on the piedmont surface may increase erosion rates in localized areas of Camp Iron Mountain. Areas of the camp that experienced intensified smoothing and compaction of the soil surface (expressed by the walkway plots) due to heavy foot and vehicle traffic have channel heads with smaller source areas and source-basin lengths as well as higher drainage densities (Nichols and Bierman, in press). An increase in drainage density implies that more of the landscape surface area is channelized and thus has yielded more sediment than a less channelized landscape. Prose (1985) has also suggested that compacted soil in Camp Iron Mountain and other various DTC base camps experience accelerated rates of erosion.

The road berms left in place when Camp Iron Mountain was abandoned 55 years ago, have acted to divert channels and create large unchannelized areas (expressed by the larger source areas and source-basin lengths of the road plots) on the piedmont down-slope of the berms. Moreover, Nichols and Bierman (in press) show that drainage densities are smaller in road plots than in control plots. Areas of the Mojave Desert containing local drainage divides similar to road berms experience decreases in vegetation cover due to the diversion of channelized water, a significant water source for desert vegetation (Schlesinger and Jones 1984). It is widely accepted (Dunne and Leopold 1978; Dunne 1980; Montgomery and Dietrich 1993) that a reduction in vegetation on a landscape leads to increased erosion rates. These implications may be used as examples of possible environmental consequences in similarly impacted areas of the Mojave Desert and possibly other arid regions.

Chapter 7

Summary

I have determined the military's impact to channel head source areas and source-basin lengths inside Camp Iron Mountain by comparing at the differences between natural (control plots) and experimental (road and walkway plots) soil surface conditions on the Iron Mountain piedmont. Roads berms left intact on the piedmont when the camp was abandoned have increased the source areas and source-basin lengths of channel heads in road plots. The mean road plot channel source area (100.19 ± 117.89 m^2, n=52) and source-basin length (26.89 ± 11.49 m, n=52) are larger than those source areas (39.8 ± 42.45 m^2, n=16) and source-basin lengths (21.72 ± 10.76 m, n=16) occurring naturally. This discrepancy may suggest that the road plot channel network has not yet stabilized on the recently altered landscape of Camp Iron Mountain due to the low frequency of overland flow in the 55 years since abandonment.

Heavily compacted and smoothed soil surfaces noted by Nichols and Bierman (in press) and Iverson (1980), due to increased rates of foot traffic, in the walkway plots have decreased the source areas and source-basin lengths. The mean walkway plot source area (18.27 ± 9.83 m^2, n=18) and source-basin length (15.49 ± 5.27 m, n=18) are smaller than those occurring naturally. The source areas and source-basin lengths of the experimental plot channels will not become equivalent to natural conditions until the road berms are compromised and soil compaction and smoothing is reversed. Statistical analyses have substantiated the differences in the means of the control and experimental plot populations at a 95% significance level (90% significance for Type II walkway mean source-basin length vs. control plot mean).

The classification by Montgomery and Dietrich (1989) of humid region channel heads into the categories of *gradual* and *abrupt* is not completely appropriate for channel heads on the Iron Mountain piedmont. According to Montgomery and Dietrich (1989) for gentle humid region slopes, gradual channel heads are formed by overland flow; this conclusion holds true for gradual channel heads on the Iron Mountain piedmont. Abrupt channel heads on gentle slopes in humid regions are formed strictly by seepage erosion (Montgomery and Dietrich 1989); however, at Camp Iron Mountain overland flow or seepage erosion both form abrupt channel heads.

An inverse relationship between source area/source-basin length vs. local slope (Montgomery and Dietrich 1989) is seen for the Camp Iron Mountain channels. However, the data set plots in a different location on log-log graphs than Montgomery and Dietrich's (1989) humid region data set. The separate locations of the data sets on the graphs arise from the differences in humid and arid region surface hydrology. Montgomery and Dietrich (1989) sampled channel heads from a large range of humid vegetated hillslopes (0.1 to 1), whereas I sampled channel heads on a gently sloping (0.02 to 0.08), unvegetated desert piedmont.

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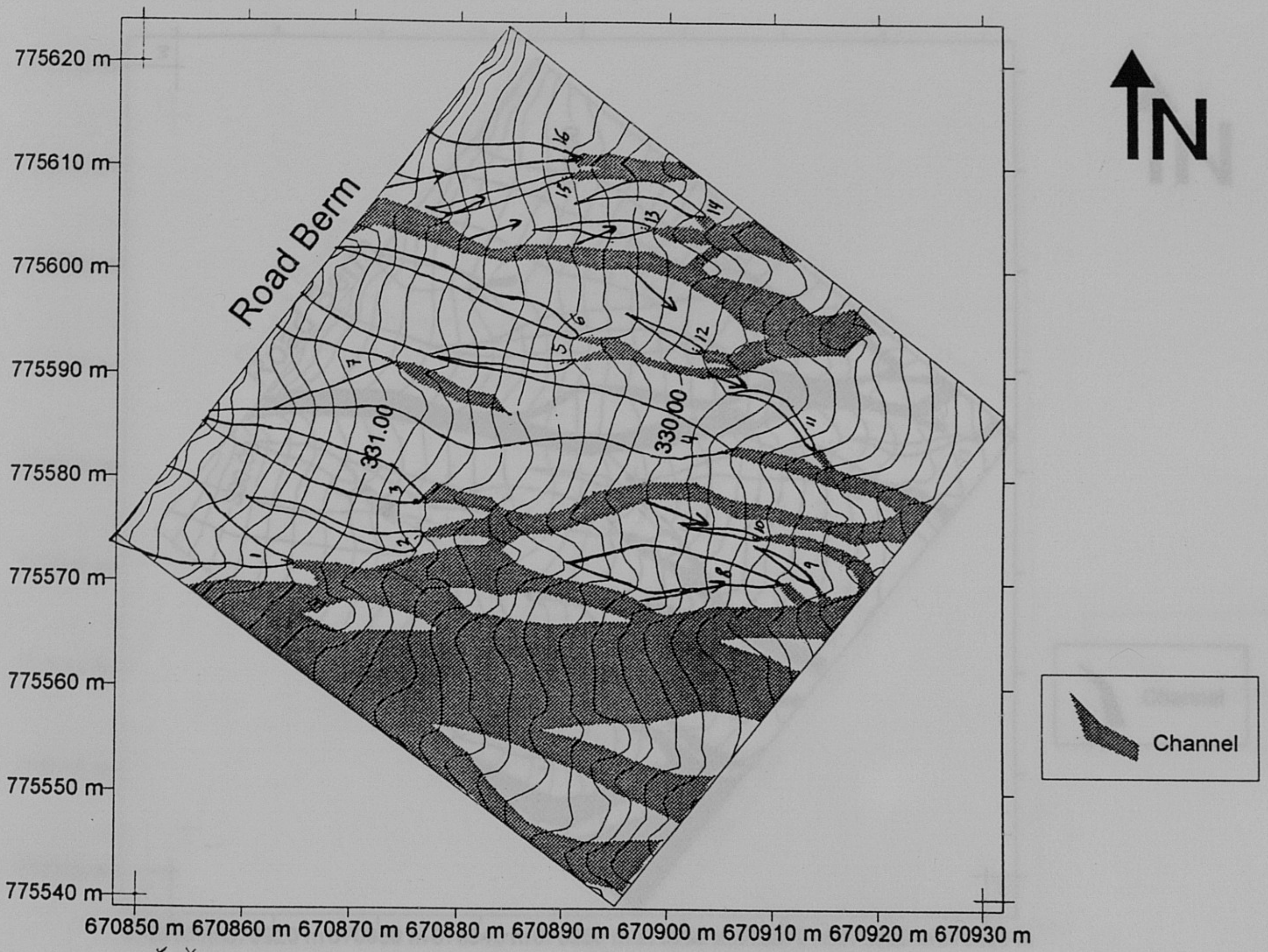
Appendix 1

Plot maps (6 road plots, 6 walkway, 6 control plots) used to determine source area and source-basin length (reproductions of 11x17 maps used for digitizing). Locations of stream spillover were transferred from field maps/notes and are noted with arrows.

Road Plot 1



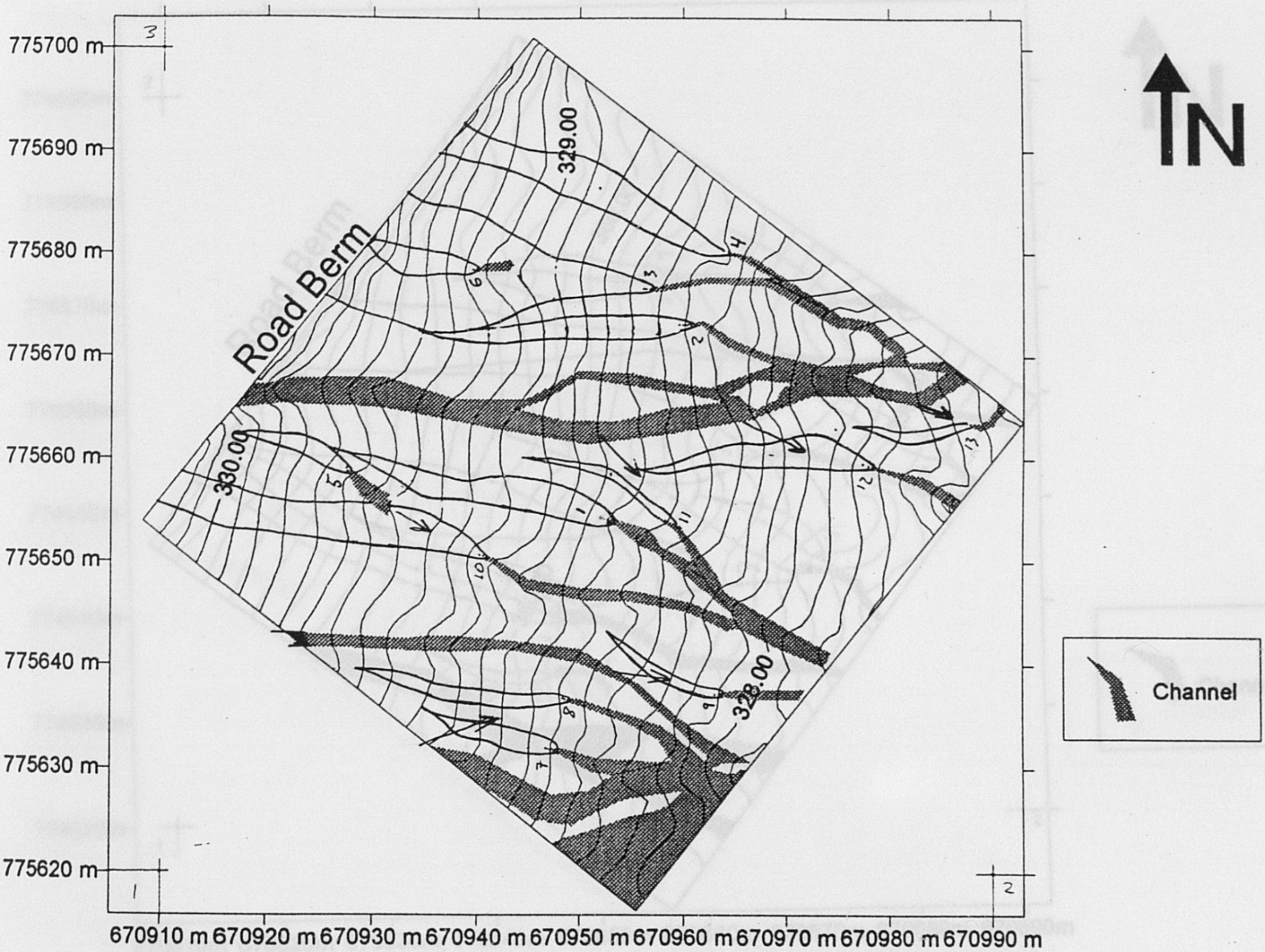
X, Y

1. 850, 540

2. 930 540

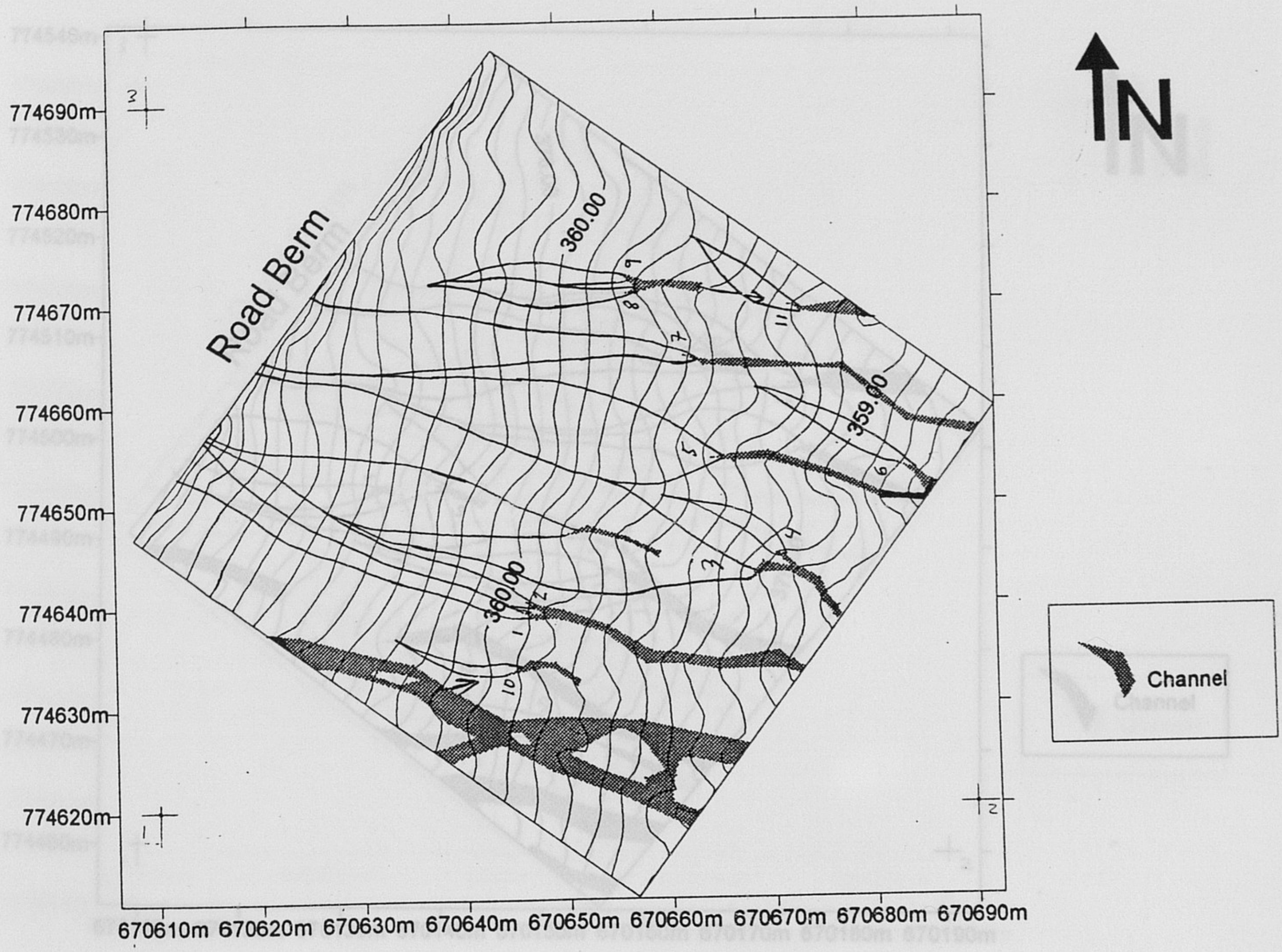
3. 850, 620

Road Plot 2



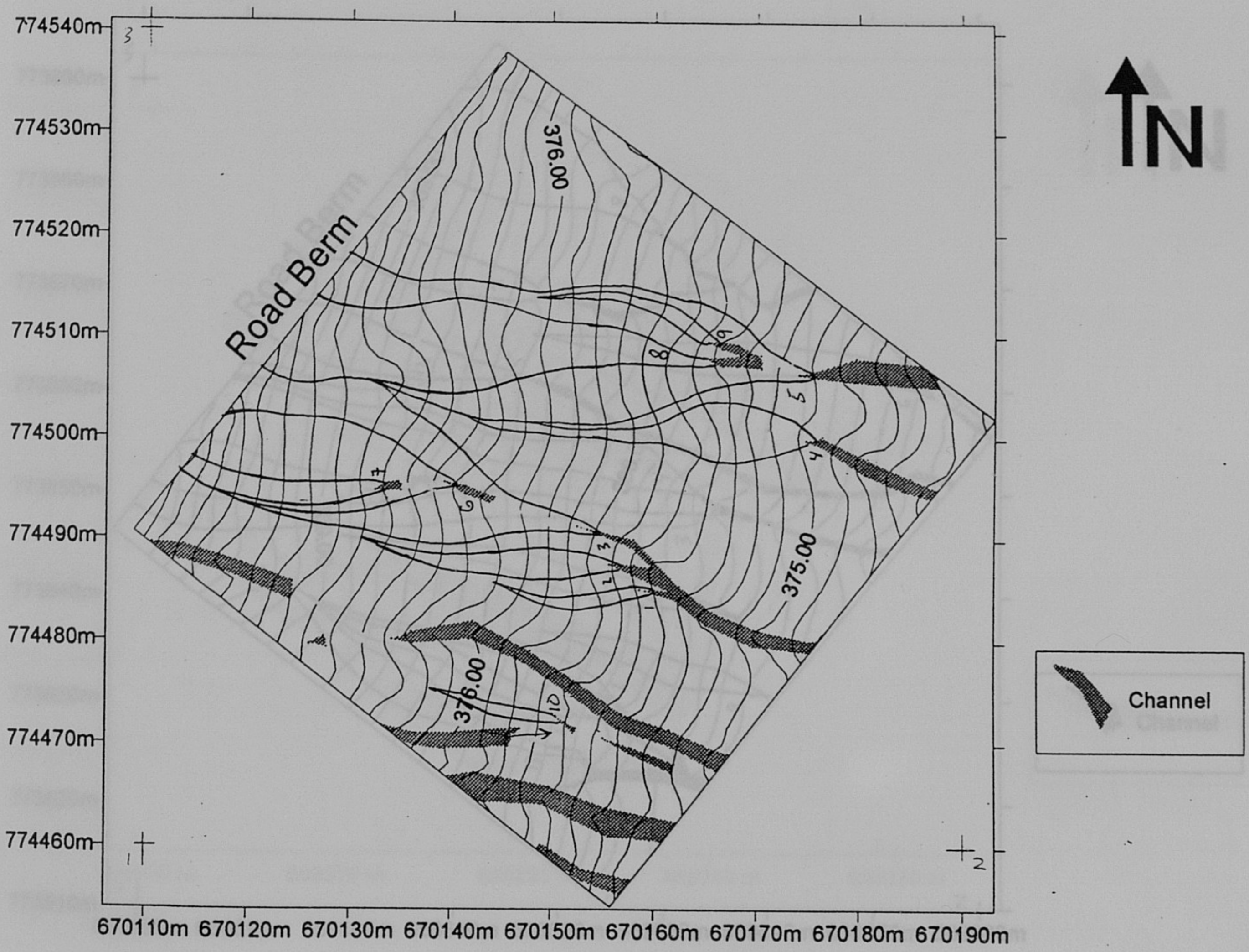
1) 910, 620
2) 990, 620
3) 910, 700

Road Plot 3



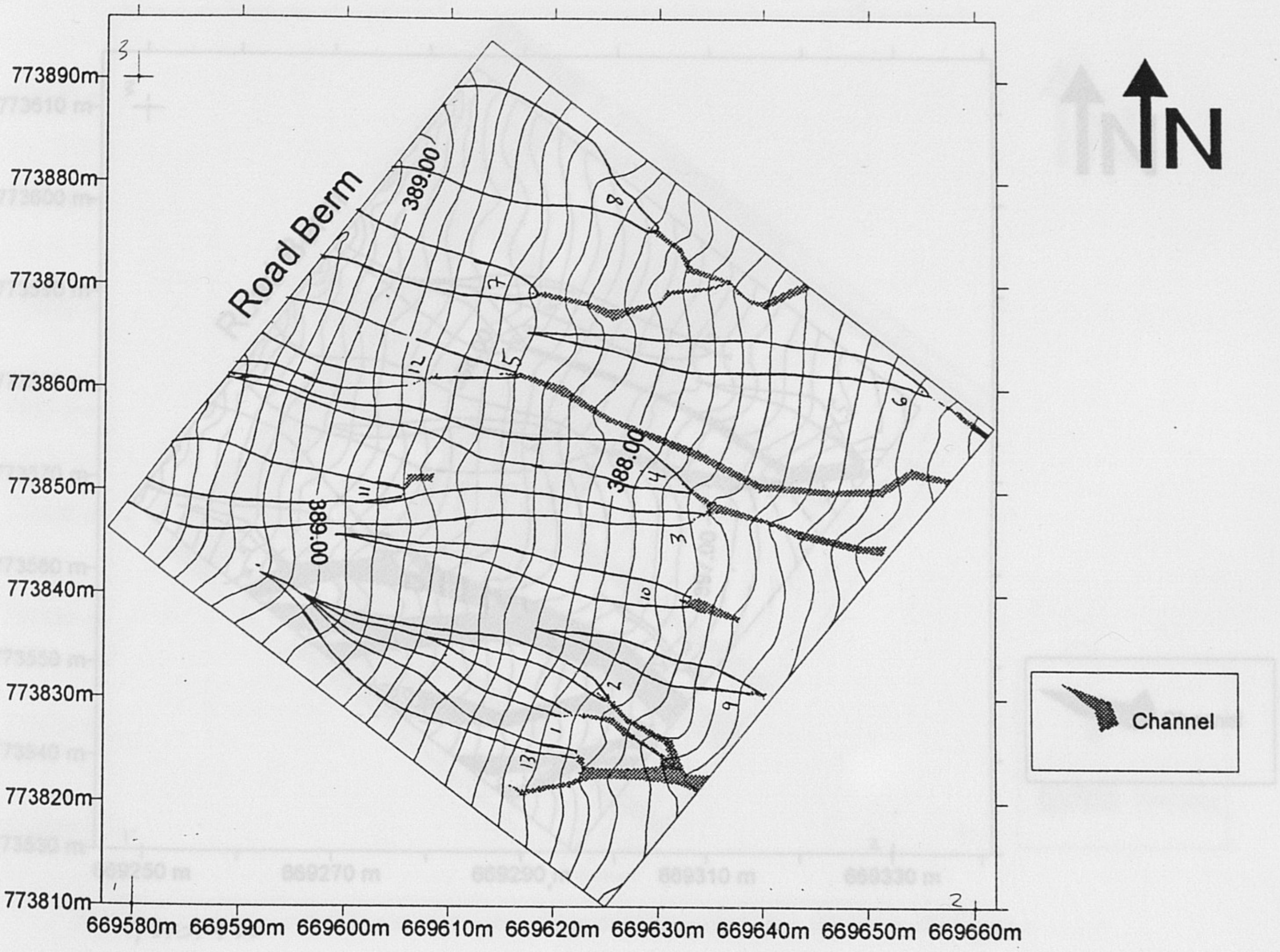
1) 610, 620
2) 690, 620
3) 610, 690

Road Plot 4

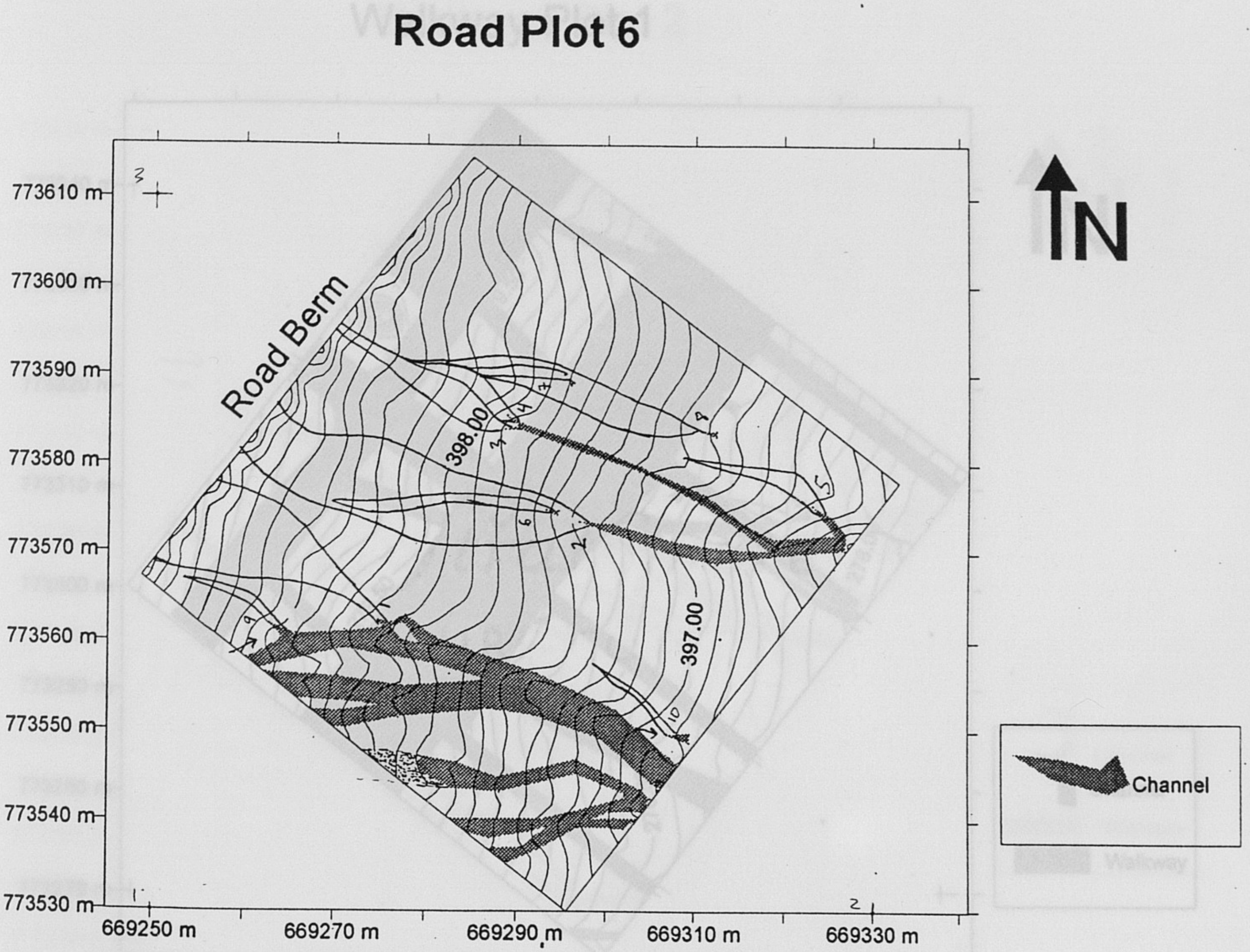


1) 110, 460
2) [illegible] 460
3) 110, 540

Road Plot 5

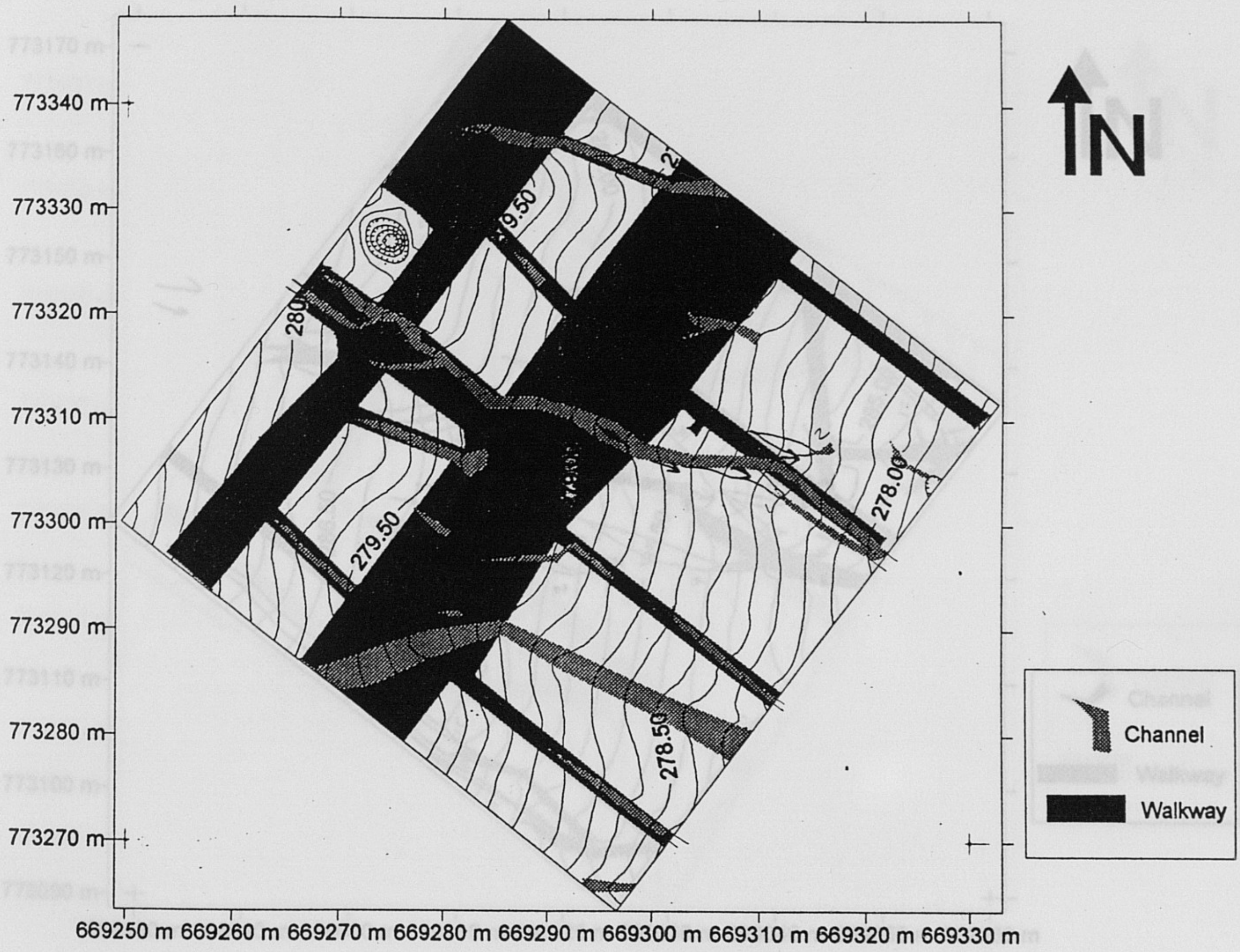


1) 580, 810
2) 660, 810
3) 560, 890



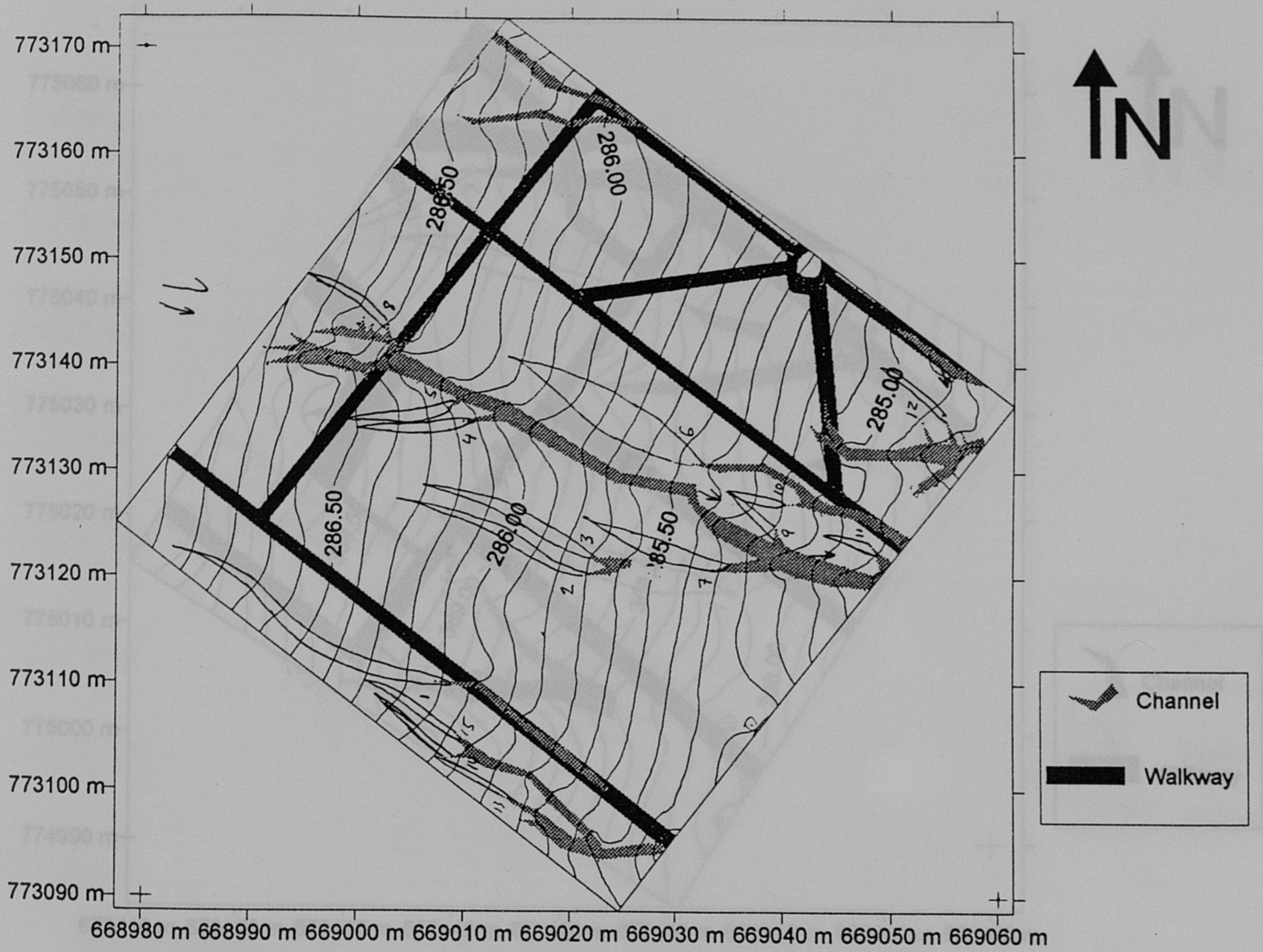
1) 250, 530
2) 330, 530
3) 250, 610

Walkway Plot 1



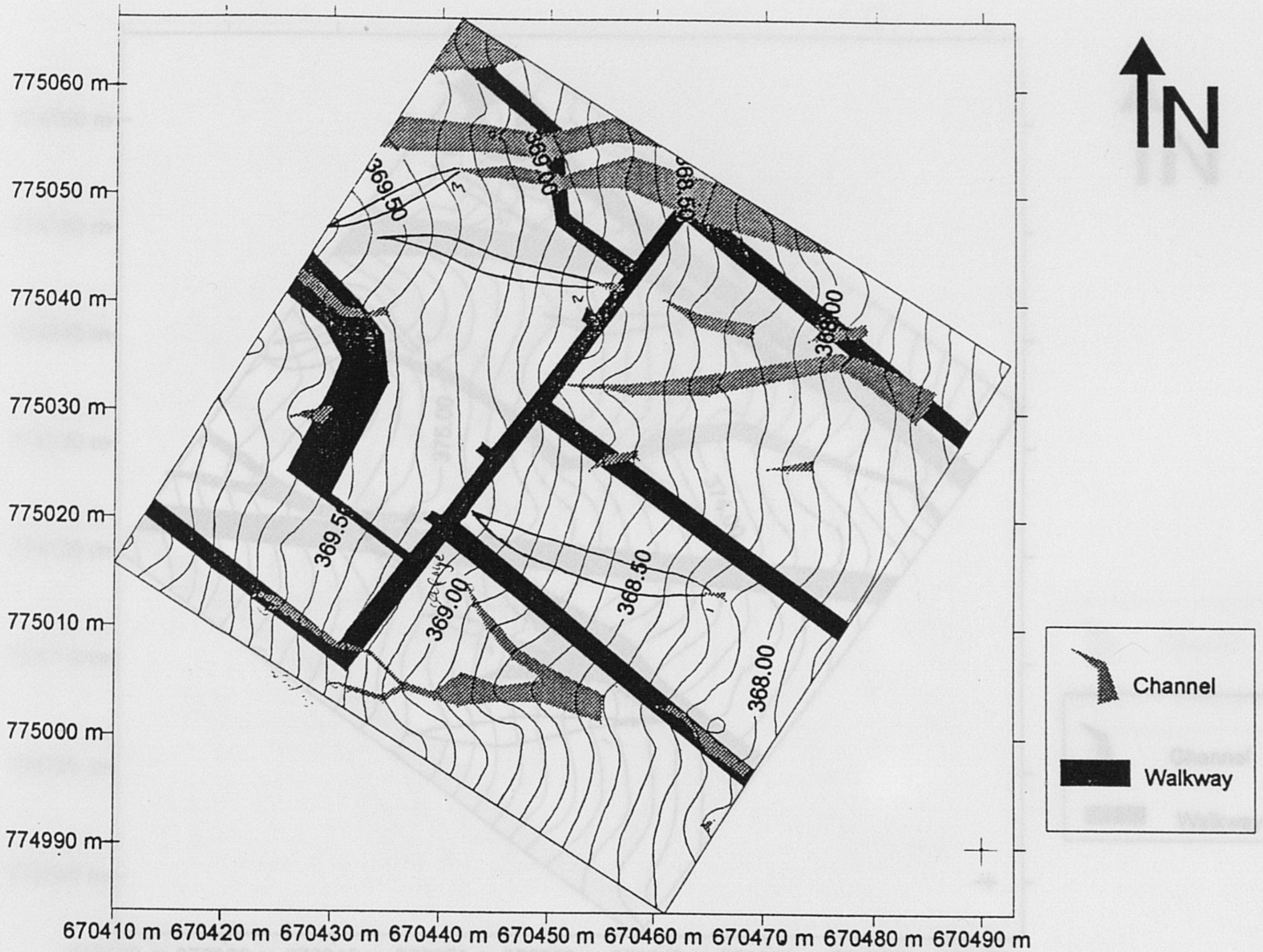
1. 250, 270
2. 330, 270
3. 250, 340

Walkway Plot 2



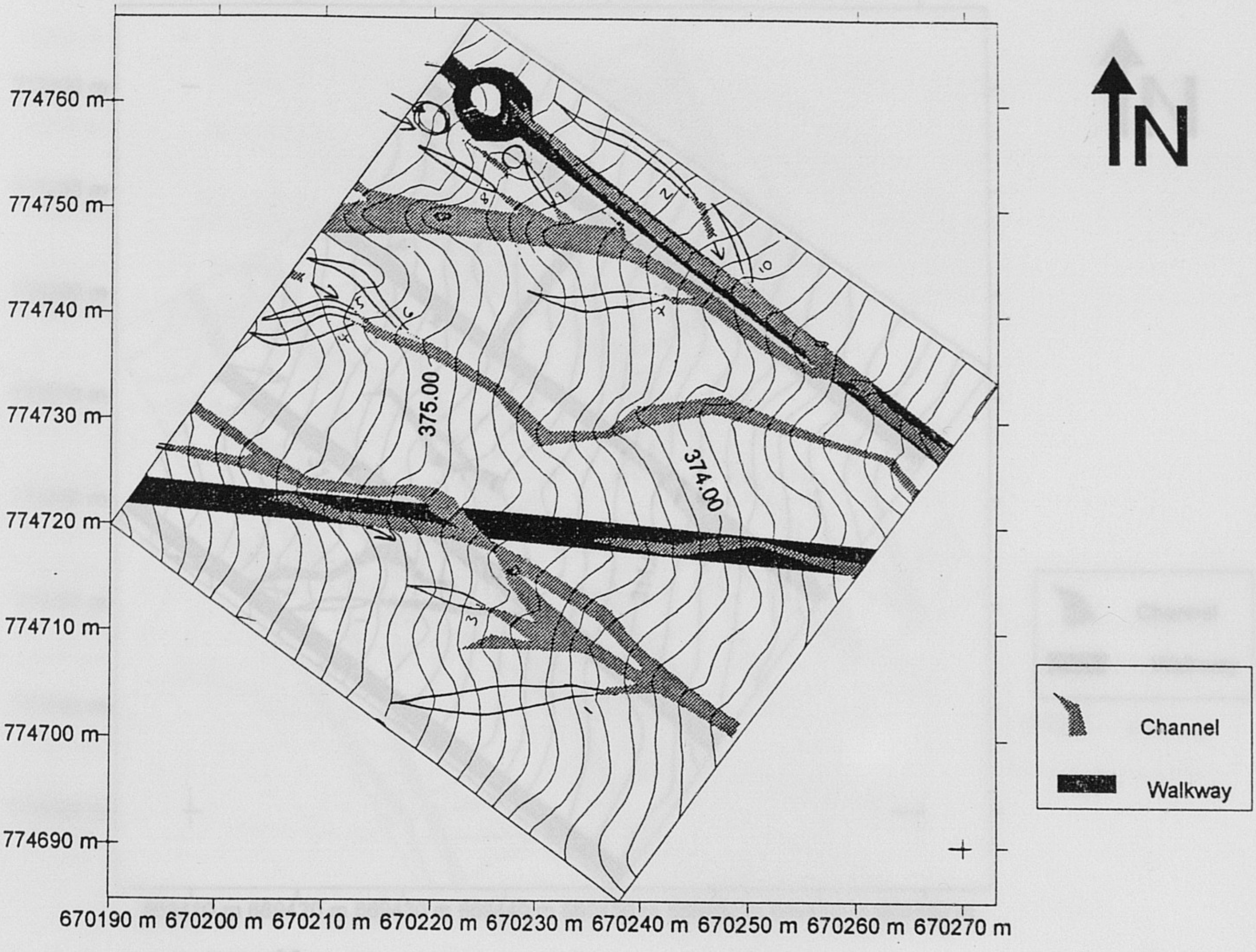
1. 980, 090
2. 1060, 090
3. 980, 170

Walkway Plot 3



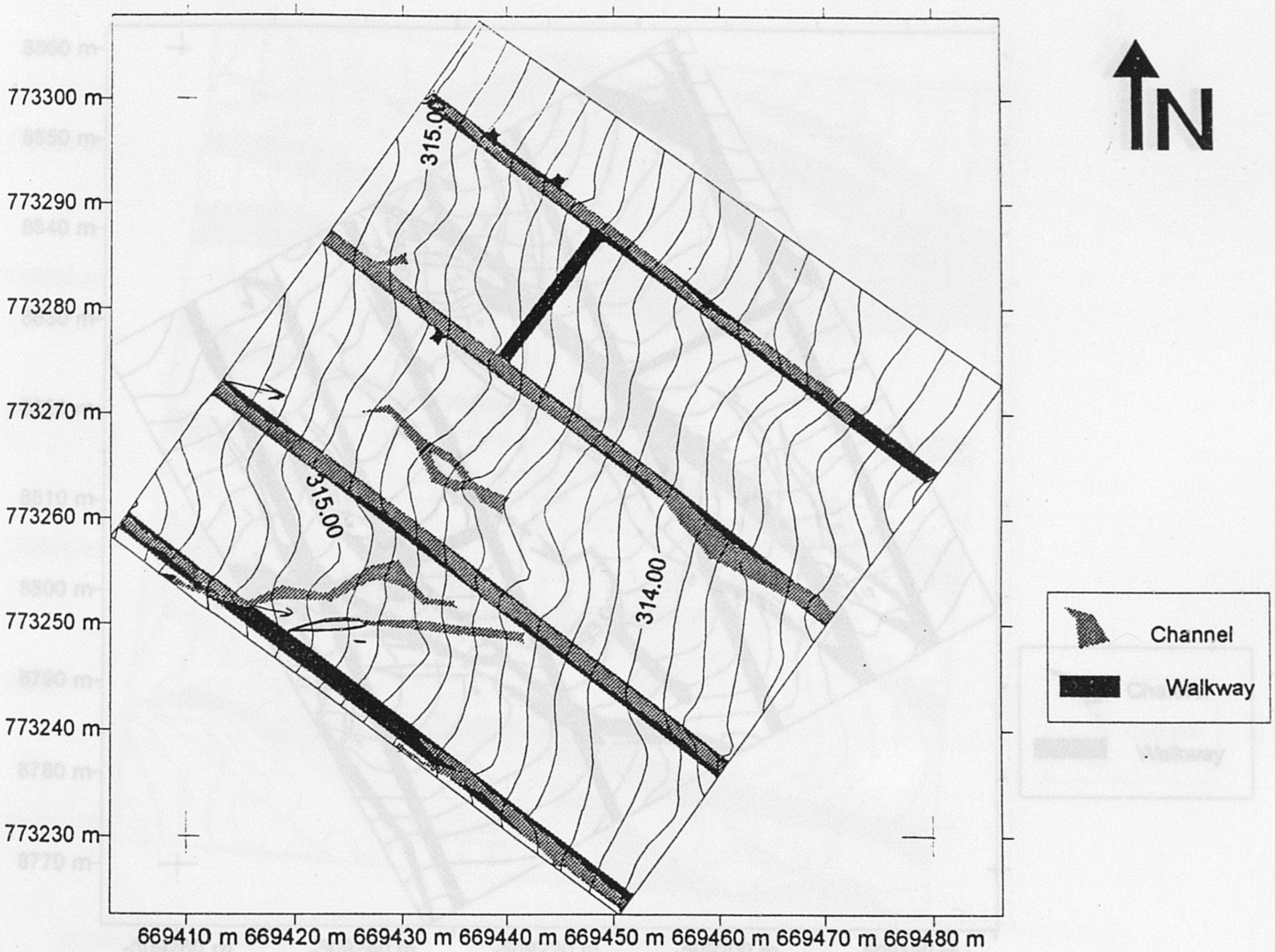
1. 410, 990
2. 490, 990
3. 410, 1060

Walkway Plot 4



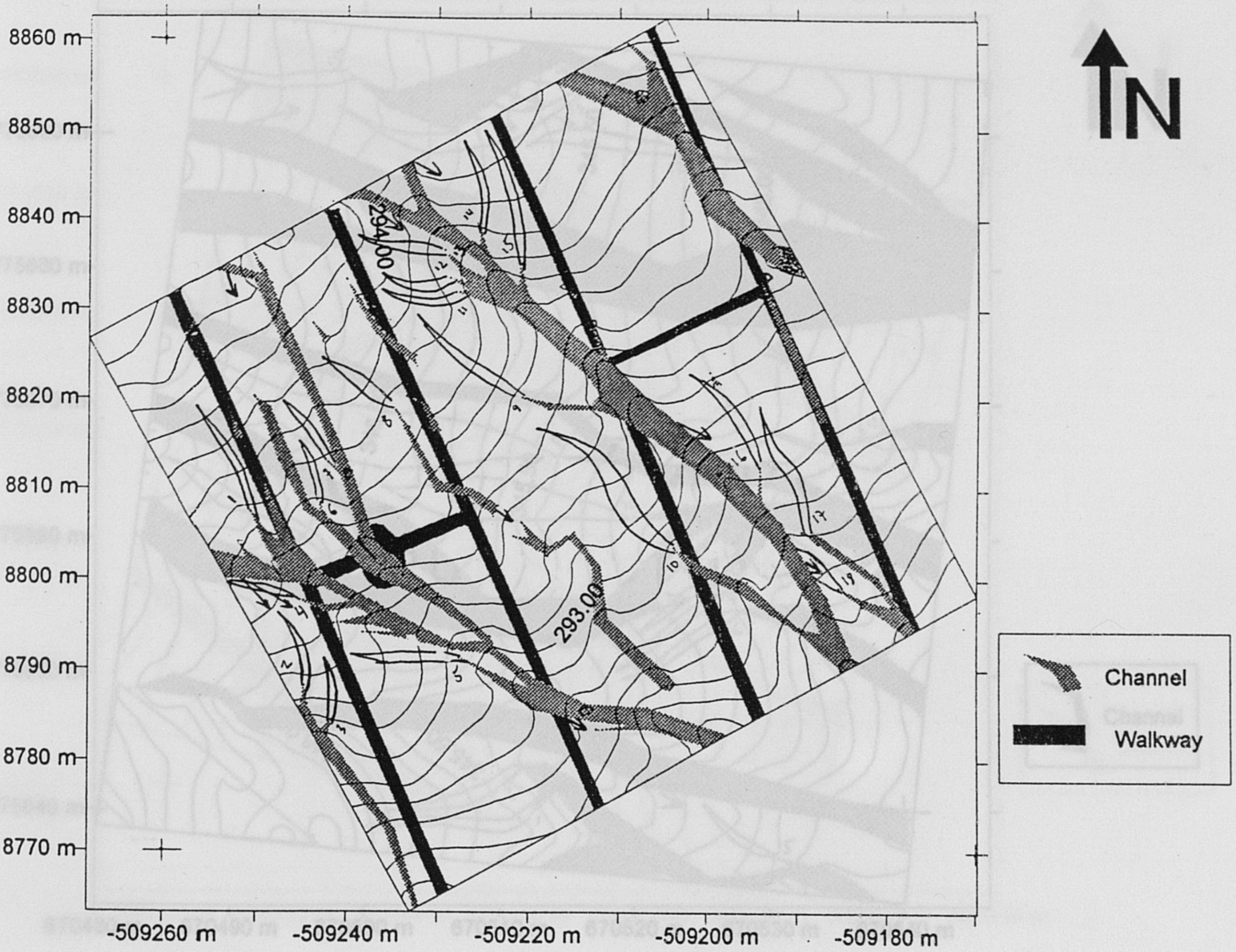
1. 190, 690
2. 270, 690
3. 190, 760

Walkway Plot 5



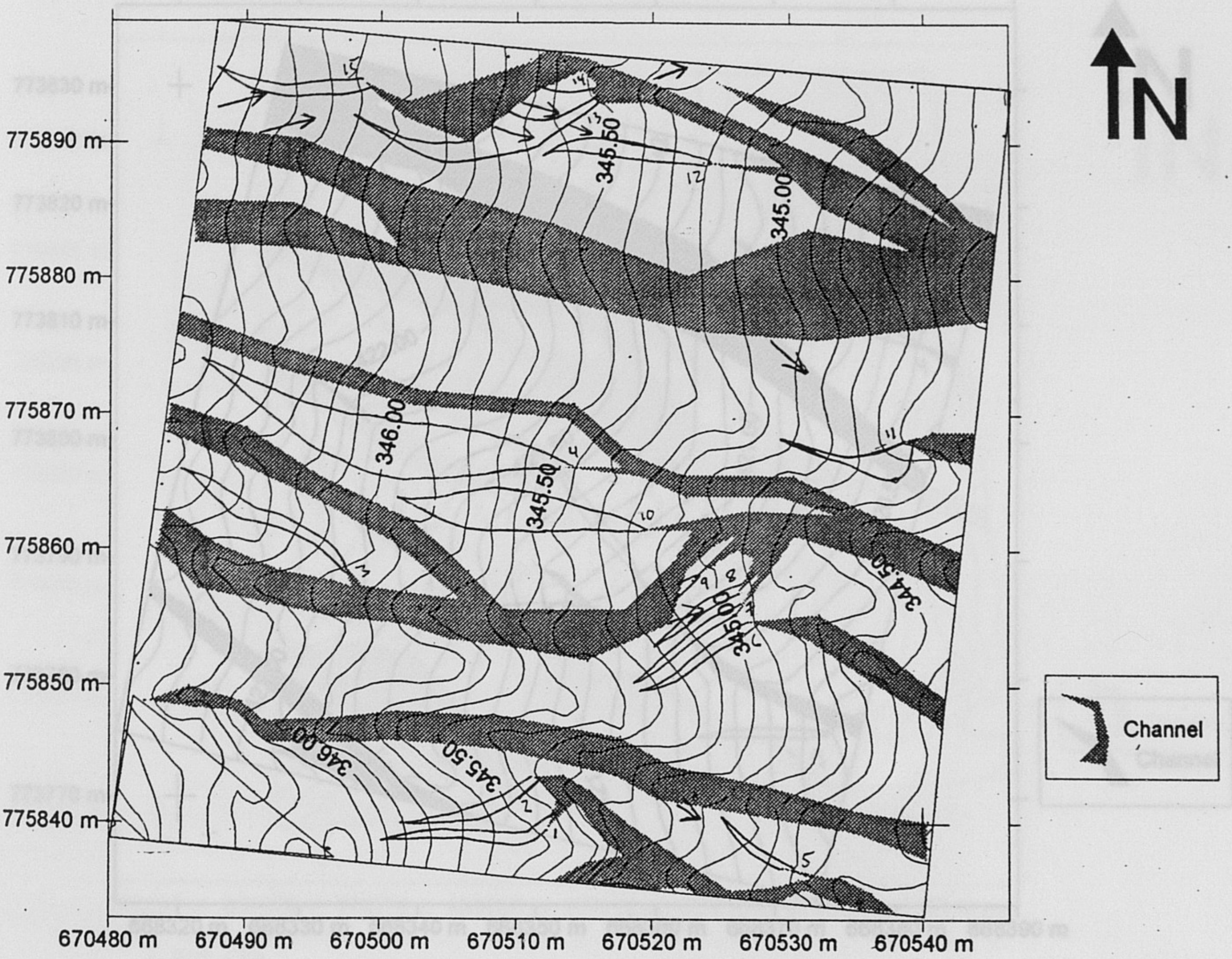
1. 410, 230
2. 480, 230
3. 410, 300

Walkway Plot 6



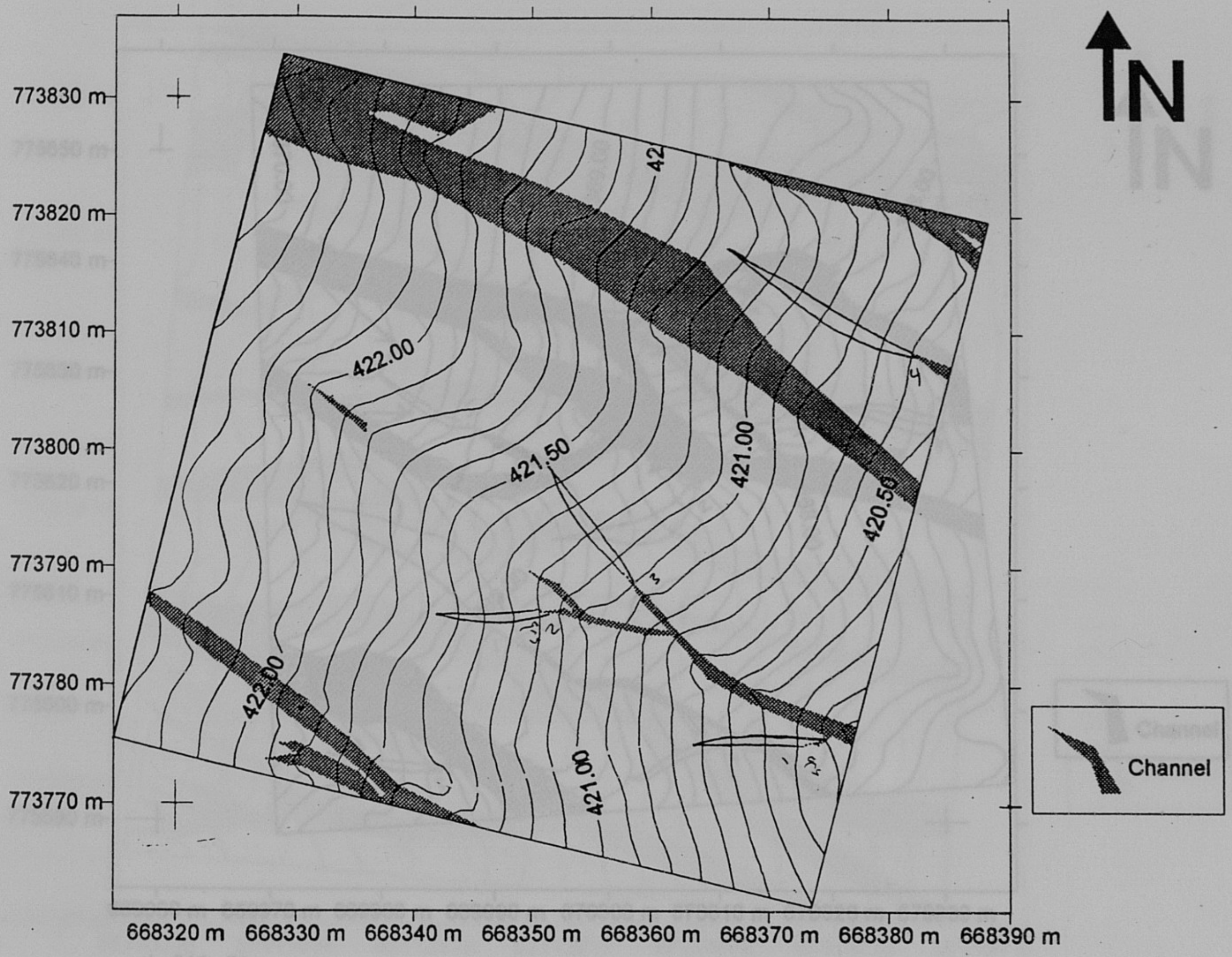
1.-260, 770
2. -180, 770
3. -260, 860

Control Plot 1



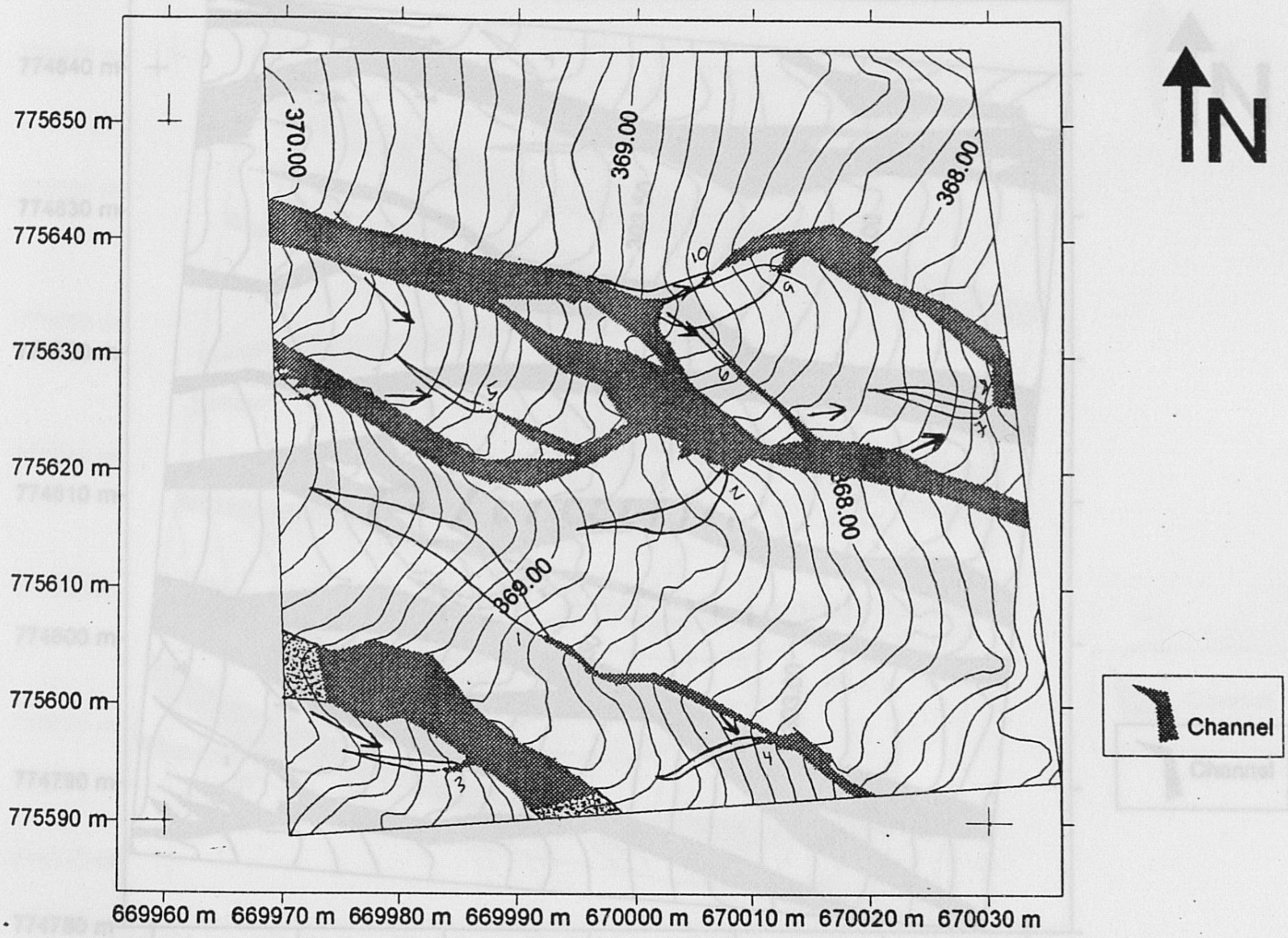
1. 480,840
2. 540,840
3. 480,890

Control Plot 2



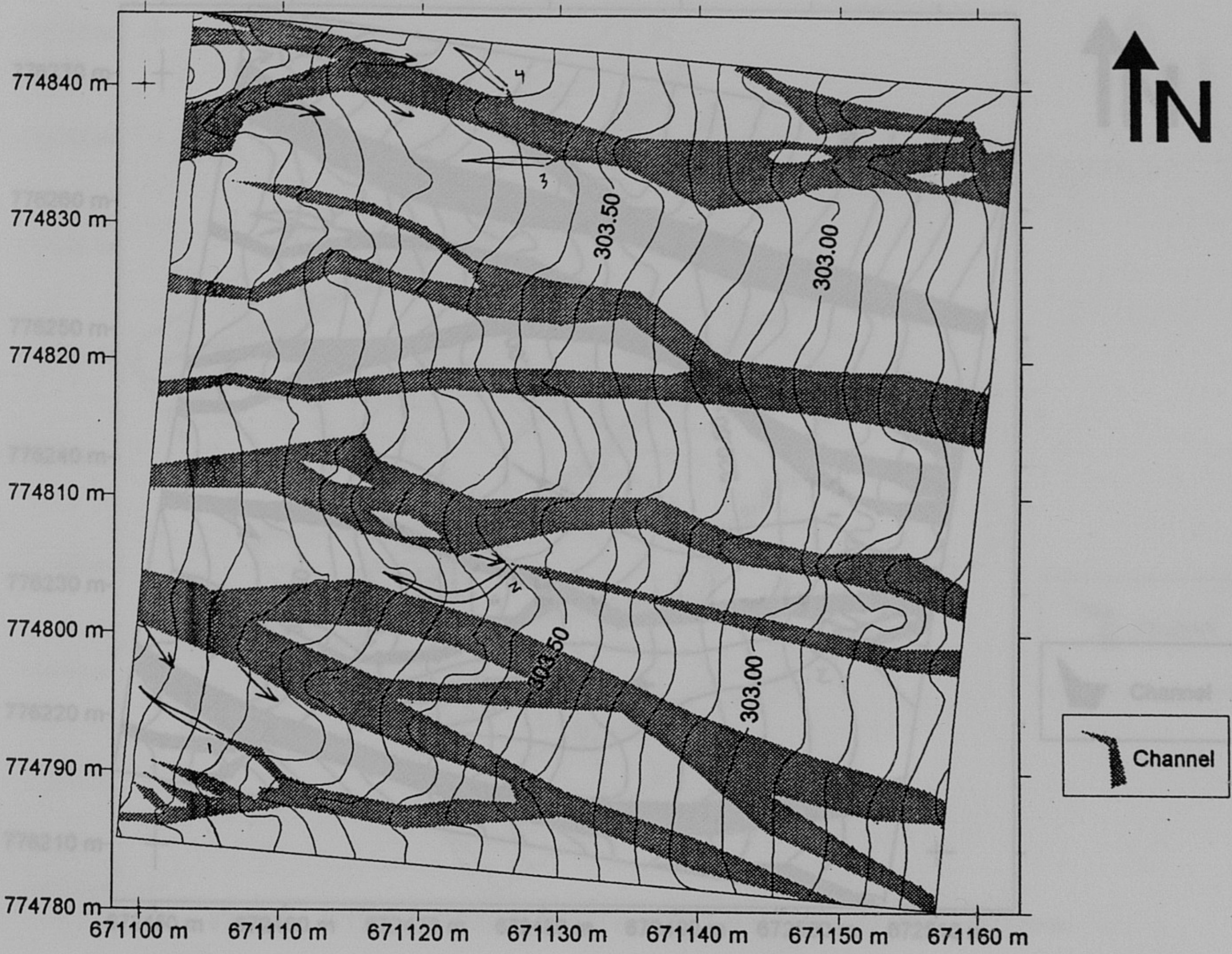
1. 320, 770
2. 390, 770
3. 320, 830

Control Plot 3



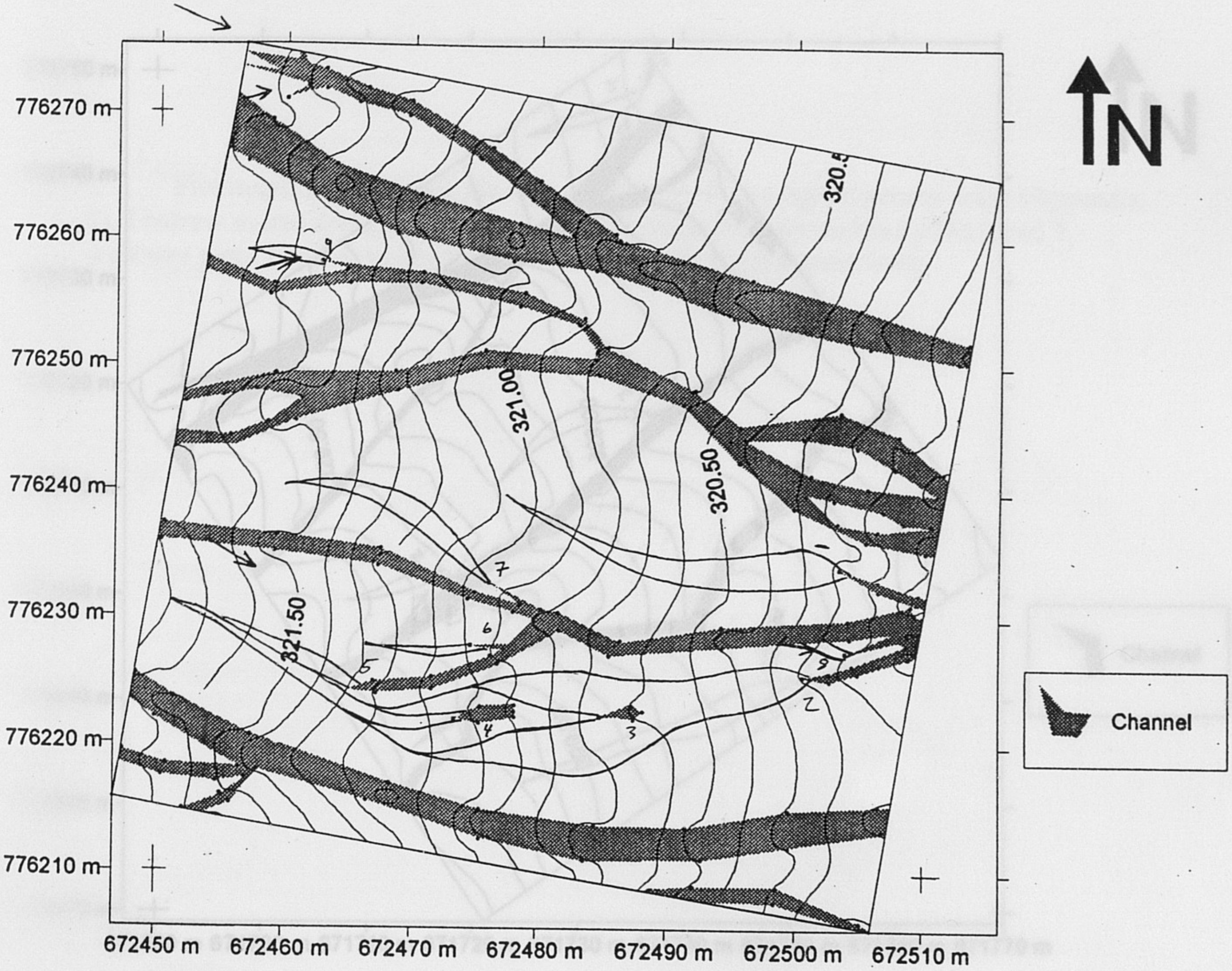
1. 960,590
2. 1030,590
3. 960,650

Control Plot 4



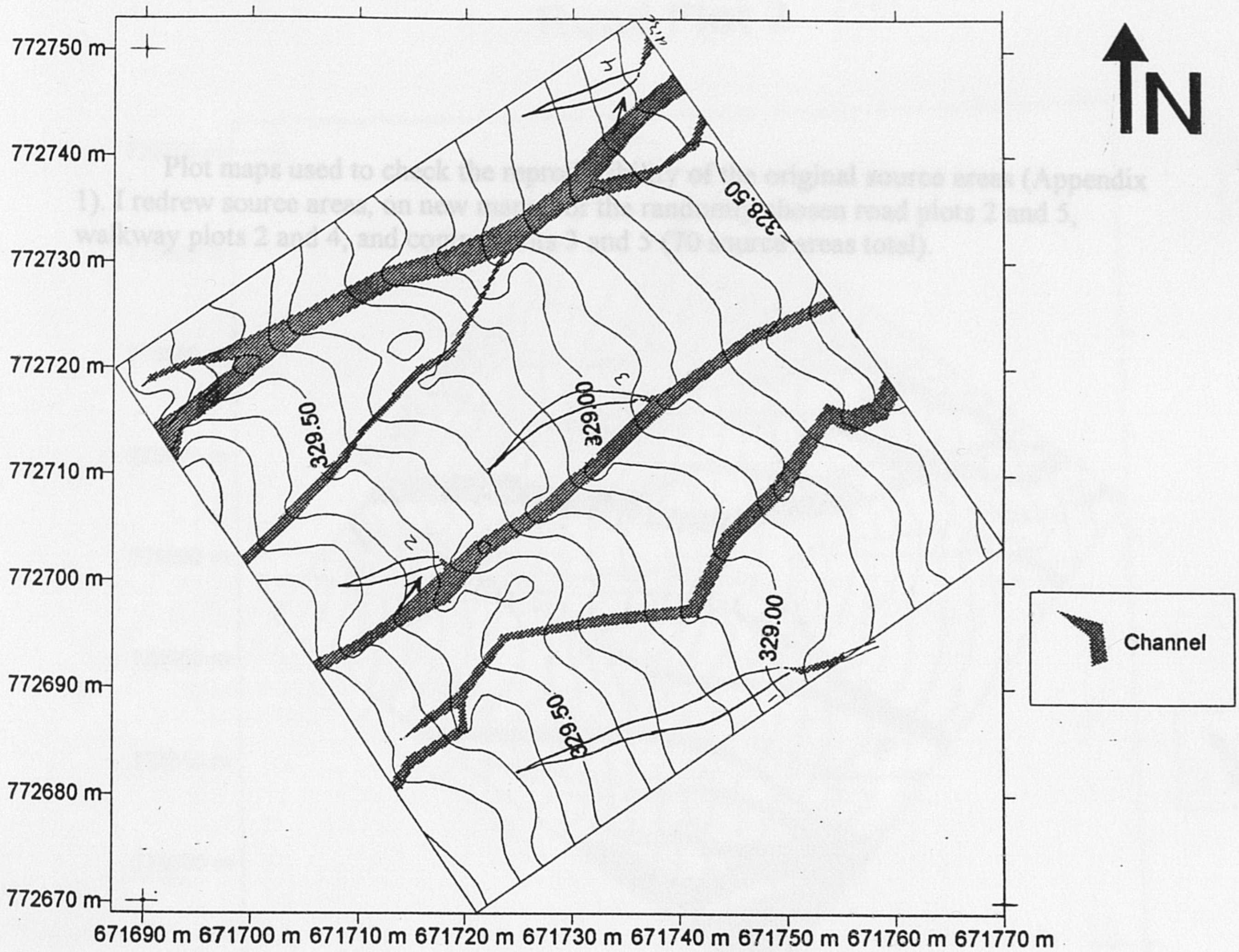
1. 100, 780
2. 160, 780
3. 100, 840

Control Plot 5



1. 450, 210
2. 510, 210
3. 450, 270

Control Plot 6

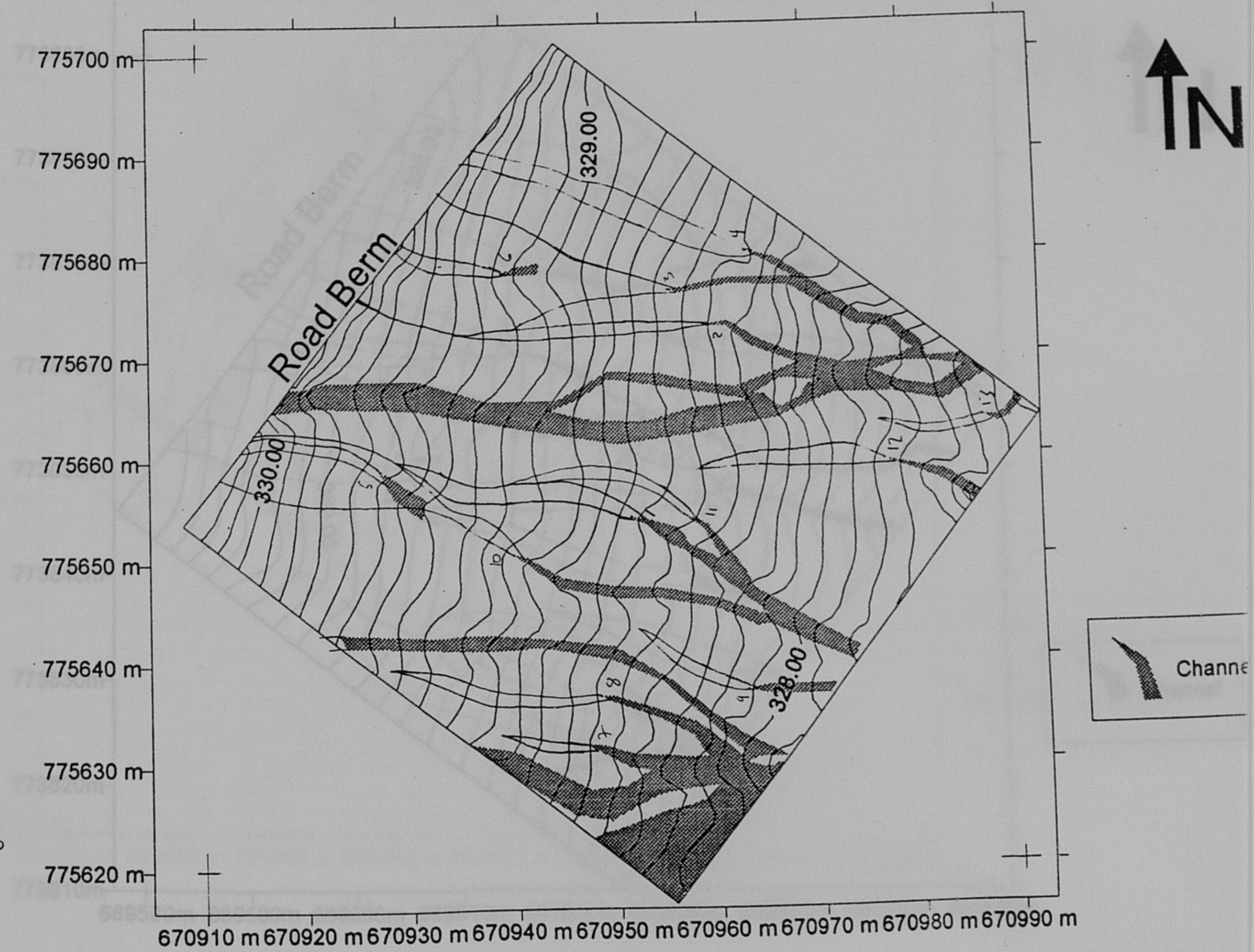


1. 690, 670
2. 770, 670
3. 690, 750

Appendix 2

Plot maps used to check the reproducibility of the original source areas (Appendix 1). I redrew source areas, on new maps, for the randomly chosen road plots 2 and 5, walkway plots 2 and 4, and control plots 3 and 5 (70 source areas total).

Road Plot 2



1) 910, 620
2) 990, 620
3) 910, 700

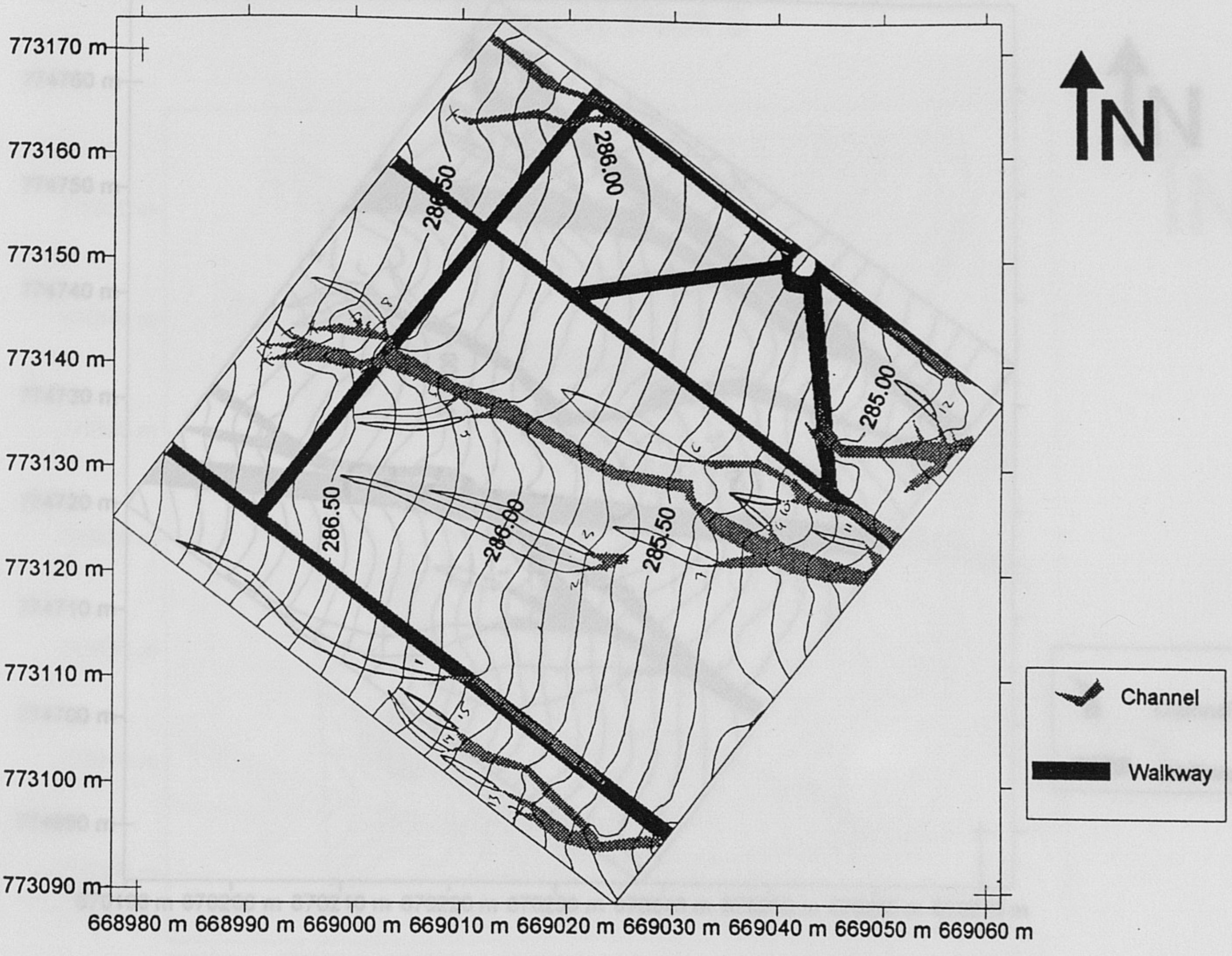
C

Road Plot 5

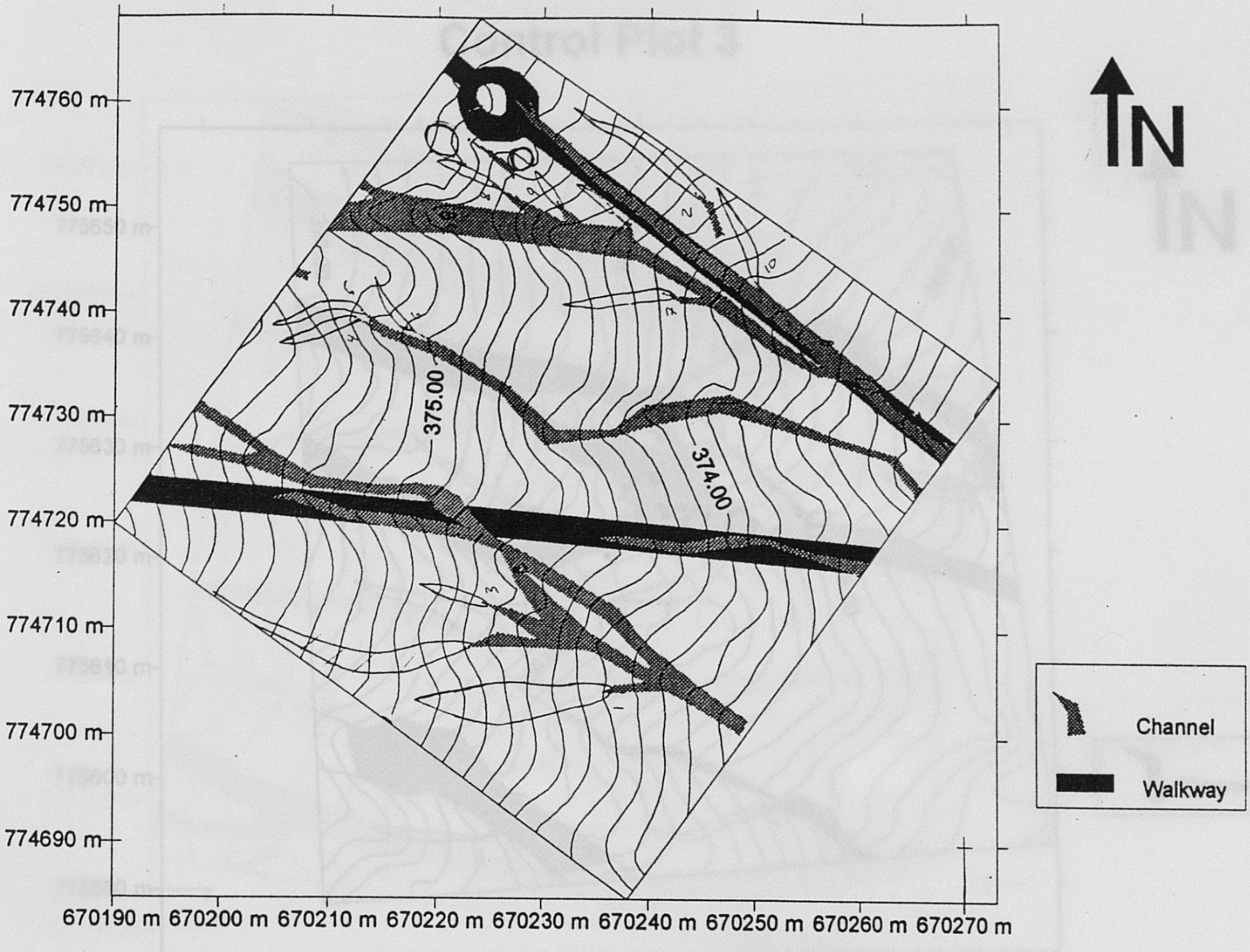
580, 810
660, 810
580, 890

C

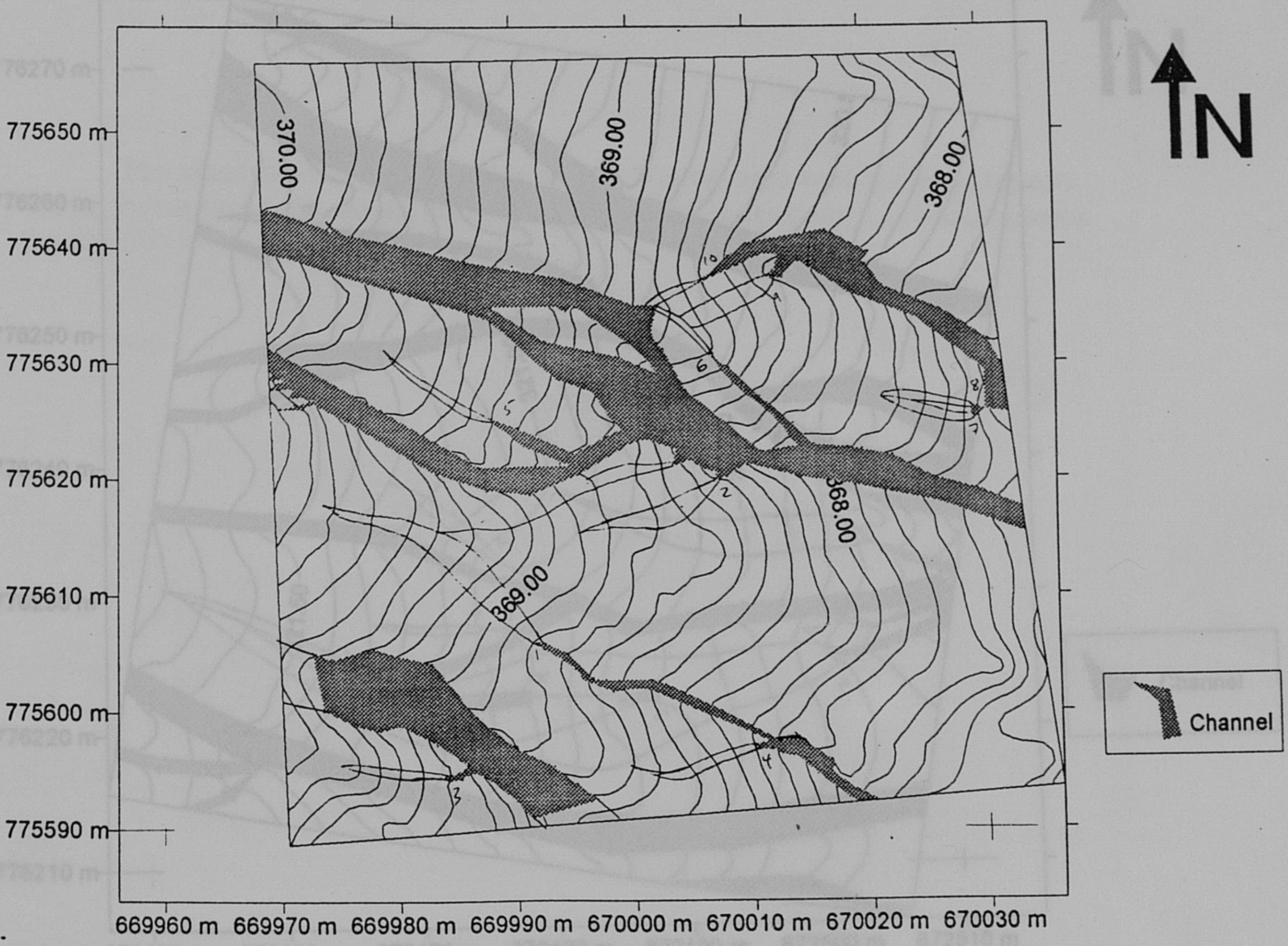
Walkway Plot 2



Walkway Plot 4

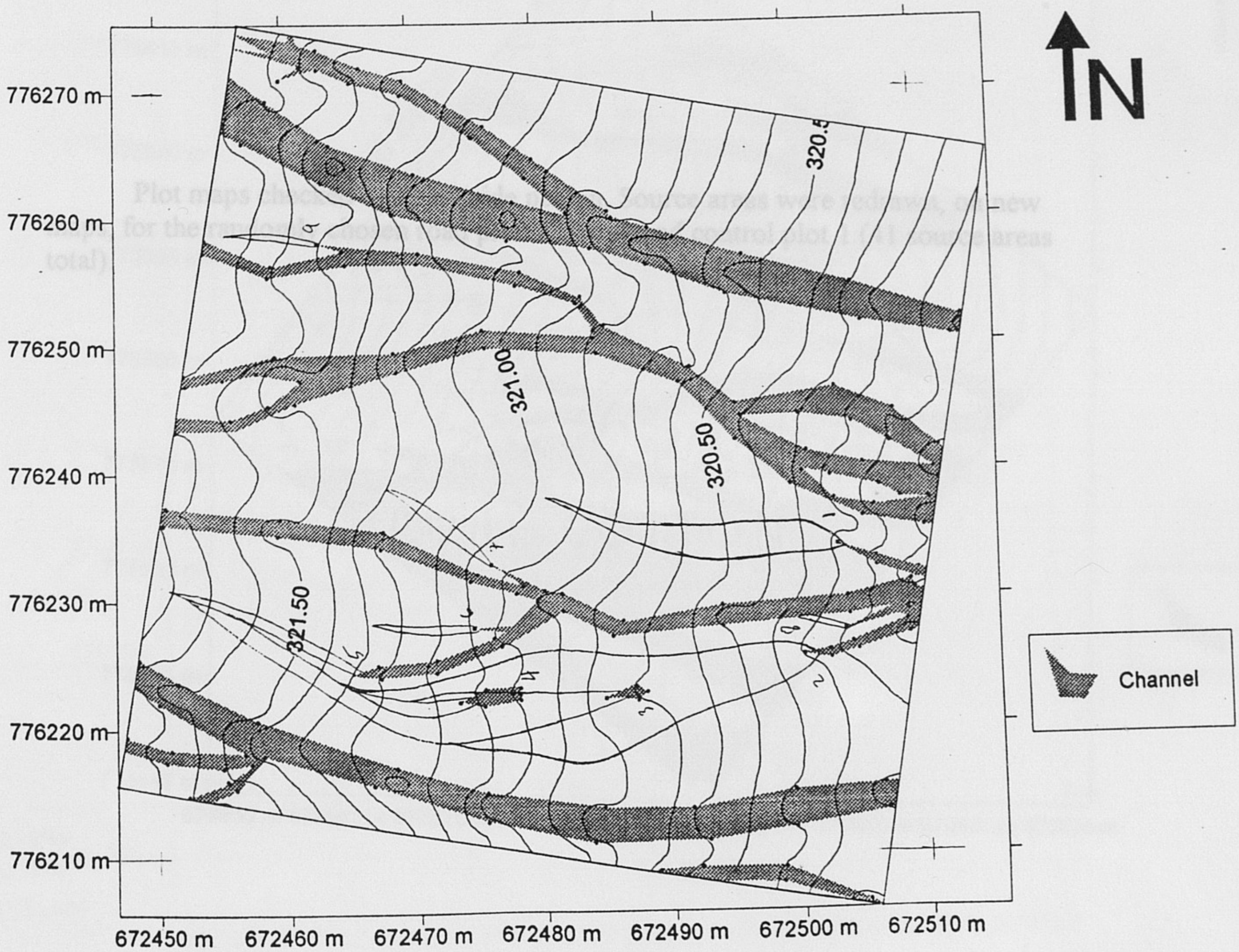


Control Plot 3



60,590
1030,590
960,650

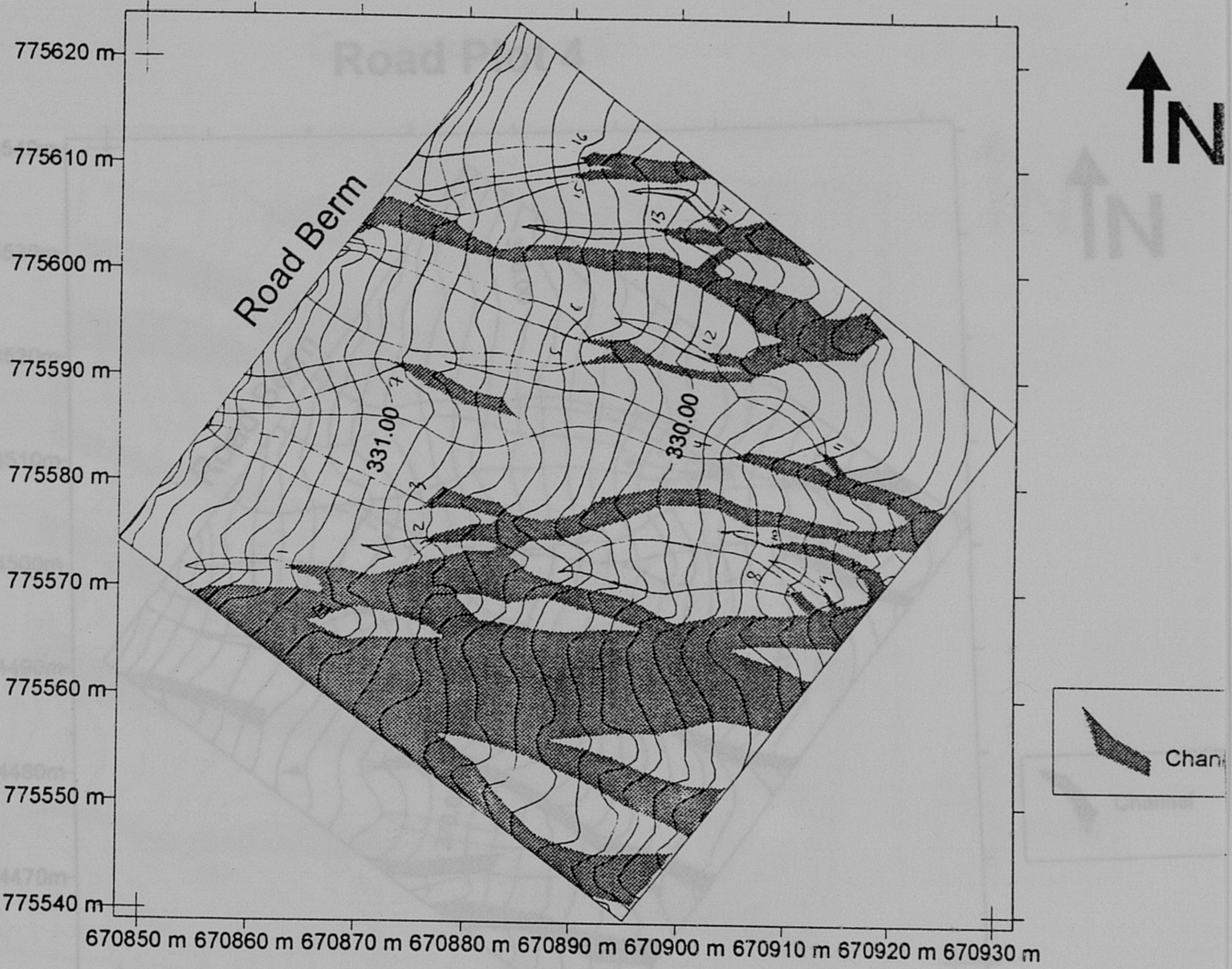
Control Plot 5



450,210
510,210
450,270

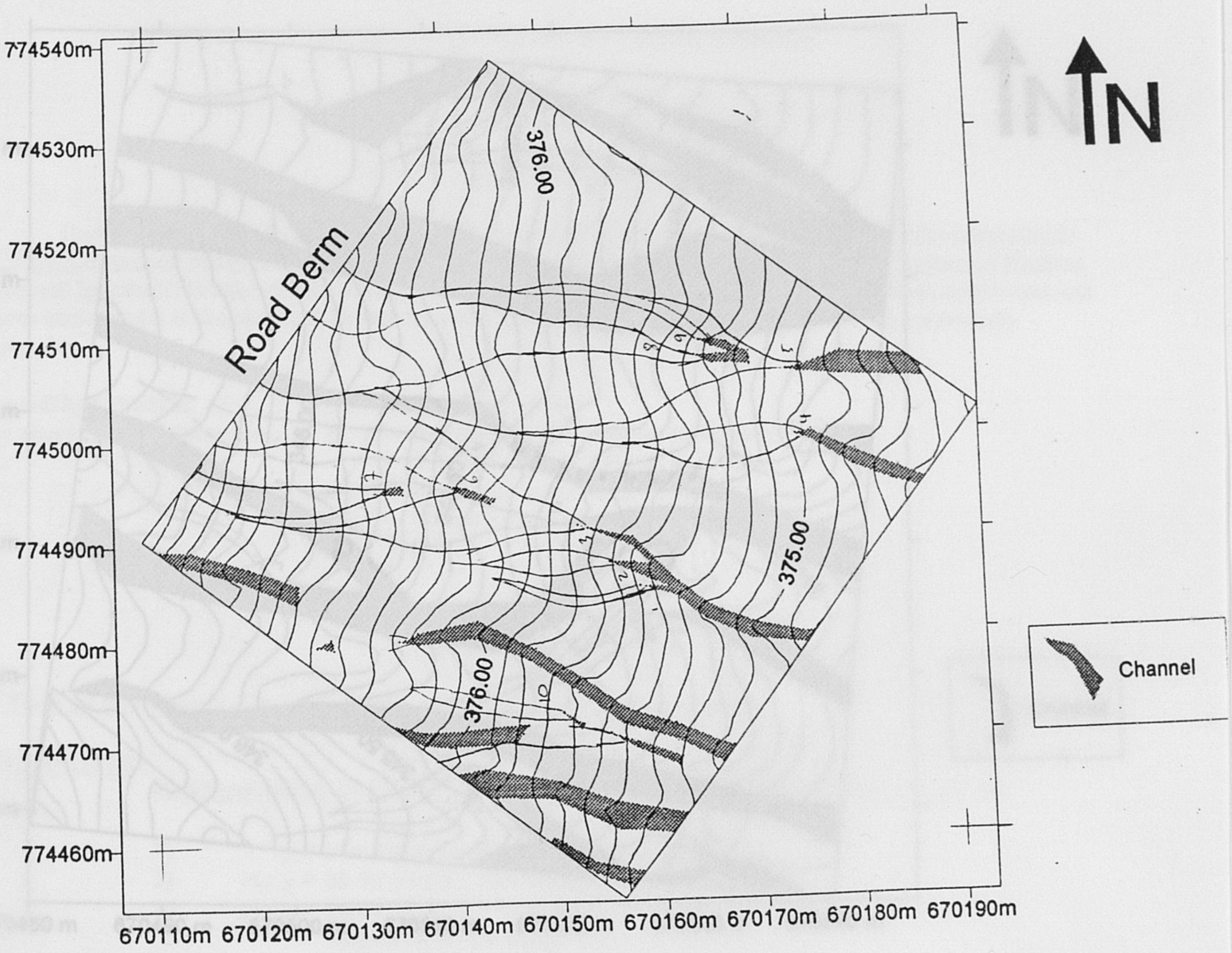
Plot maps checked by an outside person. Source areas were redrawn, on new maps, for the randomly chosen road plots 1 and 4, and control plot 1 (41 source areas total).

Road Plot 1



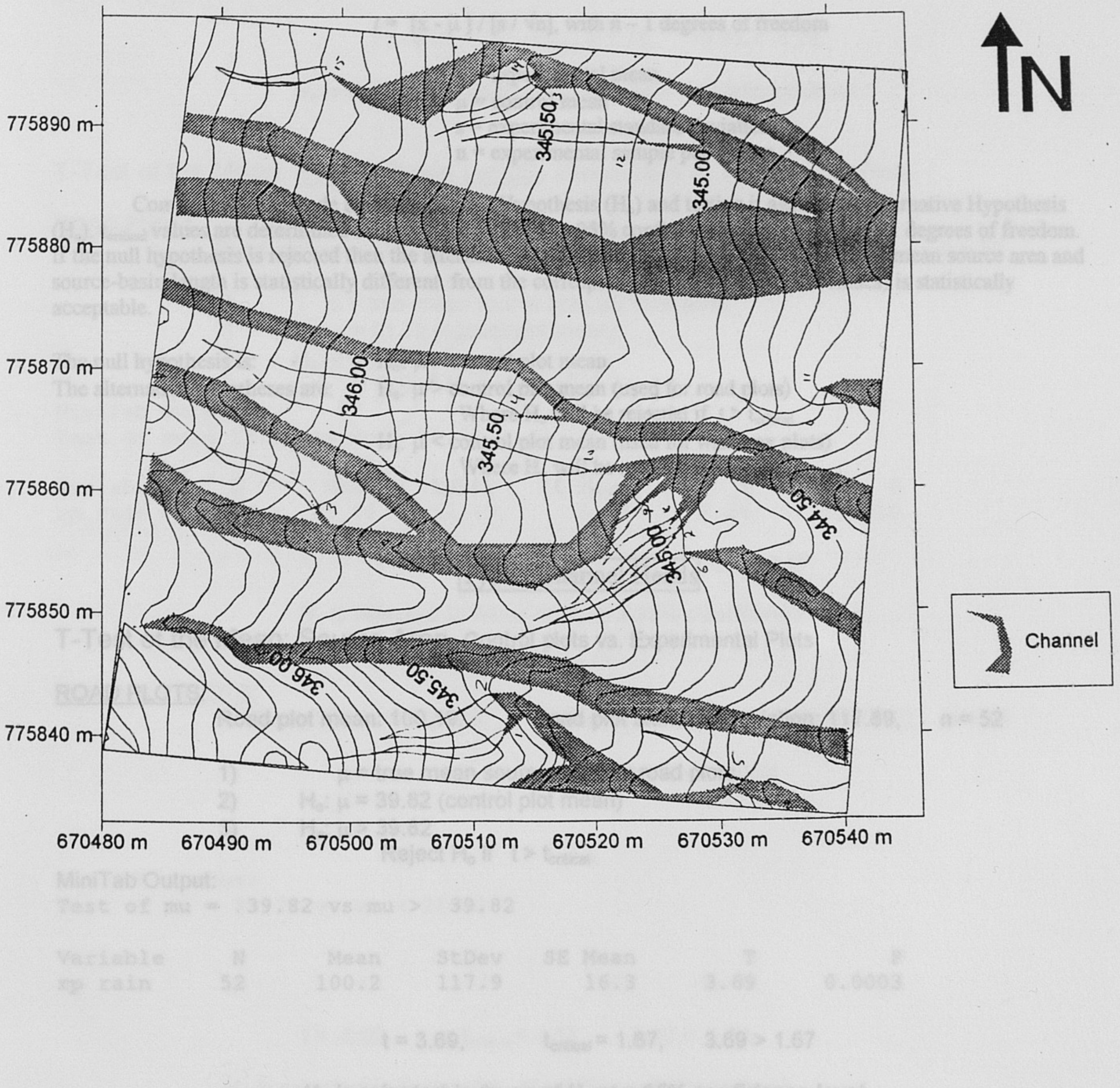
1) 850,540
2) 930,540
3) 850,620

Road Plot 4



10,460
190,460
110,540

Control Plot 1



Appendix 3

Statistical Analyses: t-tests of the sample populations. Experimental vs. control plot channel head mean source areas and source-basin lengths. The t-tests prove that the control plot mean source areas/basin lengths are statistically smaller than the road plot channel source areas/basin lengths (Type I and Type II). Conversely, they prove that the control plot mean source area/basin length is less than the mean walkway plot channel values (Type I and Type II).

A *Student's t-test* was performed using MiniTab Statistical Software (Release 12.1) in order to compare the experimental plot (road and walkway) channel head mean source areas and source-basin lengths vs. the control plot mean source areas and source basin lengths. The following equation (Devore and Peck 1986) is utilized by MiniTab to determine the *t* value:

$$t = [x - \mu] / [s / \sqrt{n}], \text{ with } n - 1 \text{ degrees of freedom}$$

x = experimental mean
μ = control mean
s = experimental standard deviation
n = experimental sample population

Comparisons are made by stating a Null Hypothesis (H_o) and testing it against an Alternative Hypothesis (H_a). $t_{critical}$ values are determined using tabular values at a 95% confidence level and with n – 1 degrees of freedom. If the null hypothesis is rejected then the alternative hypothesis (the control plot channel head mean source area and source-basin length is statistically different from the corresponding experimental plot values) is statistically acceptable.

The null hypothesis is: H_o: μ = control plot mean
The alternative hypotheses are: H_a: μ > control plot mean (used for road plots)
Where H_o will be rejected if $t > t_{critical}$
H_a: μ < control plot mean (used for walkway plots)
Where H_o will be rejected if $t < - t_{critical}$

Type I Channel Heads

T-Test of the Mean: Source Area, Control plots vs. Experimental Plots

ROAD PLOTS:

Road plot mean: 100.19, road plot standard deviation: 117.89, n = 52

1) μ = true mean source area for road plots
2) H_o: μ = 39.82 (control plot mean)
3) H_a: μ > 39.82

Reject H_o if $t > t_{critical}$

MiniTab Output:

```
Test of mu =  39.82 vs mu >  39.82

Variable        N       Mean     StDev    SE Mean         T          P
rp rain        52      100.2     117.9       16.3      3.69     0.0003
```

$t = 3.69$, $t_{critical} = 1.67$, $3.69 > 1.67$

H_o is rejected in favor of H_a at a 95% confidence level.

WALKWAY PLOTS:

Walkway Plot mean: 18.27, walkway plot standard deviation: 9.83, n = 18

1) μ = true mean source area for walkway plots
2) H_o: $\mu = 39.82$ (control plot mean)
3) H_a: $\mu < 39.82$

Reject H_o if $t < -t_{critical}$

MiniTab Output:

```
Test of mu = 39.82 vs mu < 39.82

Variable      N       Mean    StDev   SE Mean        T          P
wp rain      18      18.27     9.83      2.32    -9.30     0.0000
```

$t = -9.33$, $t_{critical} = 1.73$, $-9.33 < -1.73$

H_o is rejected in favor of H_a at a 95% confidence level.

T-Test of the Mean: Source-Basin Length, Control plots vs. Experimental Plots

ROAD PLOTS:

Road plot mean: 26.89, road plot standard deviation: 11.49, n = 52

1) μ = true mean source area for road plots
2) H_o: $\mu = 21.72$ (control plot mean)
3) H_a: $\mu > 21.72$

Reject H_o if $t > t_{critical}$

```
MiniTab Output:
Test of mu = 21.72 vs mu > 21.72

Variable      N       Mean    StDev   SE Mean        T          P
rp rain      52      26.89    11.49      1.59     3.25     0.0010
```

$t = 3.25$, $t_{critical} = 1.67$, $3.25 > 1.67$

H_o is rejected in favor of H_a at a 95% confidence level.

WALKWAY PLOTS:

Walkway Plot mean: 15.49, walkway plot standard deviation: 5.27, n = 18

1) μ = true mean source area for walkway plots
2) H_o: $\mu = 21.72$ (control plot mean)
3) H_a: $\mu < 21.72$

Reject H_o if $t < -t_{critical}$

```
MiniTab Output:
Test of mu = 21.72 vs mu < 21.72

Variable      N       Mean    StDev   SE Mean        T          P
wp rain      18      15.49     5.27      1.24    -5.02     0.0001
```

$t = -5.02$, $t_{critical} = 1.73$, $-5.02 < -1.73$

H_o is rejected in favor of H_a at a 95% confidence level.

Type II Channel Heads

T-Test of the Mean: Source Area, Control plots vs. Experimental Plots

ROAD PLOTS:

Road plot mean: 21.94, road plot standard deviation: 23.85, n = 20

1) μ = true mean source area for road plots
2) H_o: $\mu = 8.41$ (control plot mean)
3) H_a: $\mu > 8.41$

Reject H_o if $t > t_{critical}$

```
MiniTab Output:
Test of mu =  8.41 vs mu >  8.41

Variable      N       Mean     StDev    SE Mean        T          P
rp Type      20      21.94     23.85       5.33     2.54      0.010
```

$t = 2.54$, $t_{critical} = 1.73$, $2.54 > 1.67$

H_o is rejected in favor of H_a at a 95% confidence level.

WALKWAY PLOTS:

Walkway Plot mean: 6.57, walkway plot standard deviation: 3.06, n = 20

1) μ = true mean source area for walkway plots
2) H_o: $\mu = 8.41$ (control plot mean)
3) H_a: $\mu < 8.41$

Reject H_o if $t < -t_{critical}$

```
MiniTab Output:
Test of mu = 8.410 vs mu < 8.410

Variable      N       Mean     StDev    SE Mean         T          P
wp Type      20      6.571     3.058      0.684     -2.69     0.0073
```

$t = -2.69$, $t_{critical} = 1.73$, $-2.69 < -1.73$

H_o is rejected in favor of H_a at a 95% confidence level.

T-Test of the Mean, <u>source-basin length</u>**,** control plots vs. experimental plots.

<u>ROAD PLOTS</u>:

Road plot mean: 13.99, road plot standard deviation: 5.93, n = 20

4) μ = true mean source area for road plots
5) H_o: $\mu = 8.40$ (control plot mean)
6) H_a: $\mu > 8.40$

Reject H_o if $t > t_{critical}$

```
MiniTab Output:
Test of mu =  8.40 vs mu >  8.40

Variable     N      Mean     StDev    SE Mean       T          P
rp Type     20     13.96      5.93       1.33     4.19    0.0002
```

$t = 4.19$, $t_{critical} = 1.73$, $4.19 > 1.73$

H_o is rejected in favor of H_a at a 95% confidence level.

<u>WALKWAY PLOTS:</u>

Walkway Plot mean: 7.61, walkway plot standard deviation: 2.61, n = 20

1) μ = true mean source area for walkway plots
2) H_o: $\mu = 8.40$ (control plot mean)
3) H_a: $\mu < 8.40$

Reject H_o if $t < -t_{critical}$

```
MiniTab Output:
Test of mu = 8.400 vs mu < 8.400

Variable      N       Mean     StDev    SE Mean        T           P
wp Type      20      7.607     2.610      0.584    -1.36       0.095
```

$t = -1.36$, $t_{critical} = 1.73$, $-1.36 < -1.73$, NO

H_o <u>can not</u> be rejected in favor of H_a at a 95% confidence level.

At a 90% confidence level H_o is rejected in favor of H_a

$t = -1.36$, $t_{critical}$ (@ 90% CL) = -1.33, $-1.36 < -1.33$

Appendix 4

<u>TYPE I:</u> Rainfall as only contribution to source area.

PLOT	Channel Head #	Source Area (m²)	Source-Basin Length (m)
WP 2	1	27.61	28.87
WP 2	2	14.44	18.14
WP 2	3	17.07	17.05
WP 2	7	16.67	13.47
WP 2	14	8.76	9.1
WP 2	15	10.1	10.12
WP 3	1	43.23	22.78
WP 3	2	27.54	19.91
WP 3	3	15.09	13.32
WP 4	1	30.27	19.09
WP 4	2	12.9	15.48
WP 6	1	9.13	12.35
WP 4	7	14.27	12.65
WP 6	5	11.49	10.49
WP 6	8	9.75	8.43
WP 6	9	13.99	13.07
WP 6	10	33.33	19.87
WP 6	17	13.25	14.55
CP 1	1	9.46	12.79
CP 1	2	7.76	10.44
CP 1	3	12.43	14.11
CP 1	4	70.65	28.58
CP 1	10	33.23	17.96
CP 2	4	18.24	17.64
CP 3	1	54.01	23.77
CP 3	2	19.85	14
CP 5	1	50.95	27.17
CP 5	7	21.62	17.5
CP 5	2	181.03	52.05
CP 5	3	59.81	35.4
CP 5	4	19.79	23.32
CP 5	5	14.16	10.84
CP 6	3	19.91	15.71
CP 6	1	44.23	26.19
RP 1	1	78.98	15.2
RP 1	2	20.09	17.04
RP 1	3	62.23	21.57
RP 1	4	286.6	45.02
RP 1	5	15.55	13.26
RP 1	6	27.06	24.32
RP 1	7	69.86	14.14
RP 2	1	58.62	27.12
RP 2	2	51.31	26.49
RP 2	3	216.39	27.46
RP 2	4	88.8	29.1
RP 2	5	17.03	11.09
RP 2	6	23.75	10.88
RP 3	1	70.33	36.57
RP 3	2	71.95	36.16
RP 3	3	533.56	53.58
RP 3	4	14.9	12.31
RP 3	5	202.95	45.82
RP 3	6	24.27	16.44
RP 3	7	166.45	39.57
RP 3	8	32.13	19.29
RP 3	9	23.21	18.15
RP 4	1	15.73	15.63
RP 4	2	48.4	24.54
RP 4	3	364.78	38.48
RP 4	4	82.04	33.09
RP 4	5	534.22	49.6
RP 4	6	59.51	25.14
RP 4	7	45.49	19.69
RP 4	8	251.26	41.65
RP 4	9	21.38	18.08
RP 5	1	35.28	27.56
RP 5	2	26.21	30.37
RP 5	3	120.28	53.97
RP 5	4	95.18	45.55
RP 5	5	117.8	23.38
RP 5	6	85.74	38.27
RP 5	7	71.69	19.72
RP 5	8	165.63	24.99
RP 5	9	33.51	20.77
RP 5	10	56.25	33.87
RP 5	11	83.7	23.28
RP 5	12	31.12	16.97
RP 5	13	67.25	35.48
RP 6	1	150.48	25.1
RP 6	2	277.89	37.36
RP 6	3	48.38	21.36
RP 6	4	18.54	14.39
RP 6	5	20.96	17.21
RP 6	6	27.35	23.65
RP 6	7	10.97	10.51
RP 6	8	87.27	28.19

TYPE II: Rainfall and stream spillover contribution to source area.

PLOT	Channel Head #	Source Area (m^2)	Source-Basin Length (m)	PLOT	Channel Head #	Source Area (m^2)	Source-Basin Length (m)
WP1	1	5.38	5.46	CP 1	5	4.05	6.31
				CP 1	6	6.28	9.72
WP 2	9	4.46	5.61	CP 1	7	4.9	9.93
WP 2	10	3.87	5.18	CP 1	8	4.37	7.63
WP 2	11	3.21	5.55	CP 1	9	0.91	1.51
WP 2	12	5.16	7.47				
				CP 1	11	9.41	6.62
WP 4	3	6.64	7.33	CP 1	12	11.36	12.14
WP 4	8	8.12	8.28	CP 1	13	26.14	18.24
WP 4	9	3.01	4.87	CP 1	14	9.56	5.46
WP 4	10	7.07	7.89	CP 1	15	9.6	11.04
WP 5	1	6.2	6.77	CP 3	3	6.18	8.87
				CP 3	4	5.83	8.9
WP 6	2	5.73	8.84	CP 3	5	6.43	8.47
WP 6	3	4.61	6.78	CP 3	6	2.61	2.66
WP 6	4	4.17	6.7	CP 3	7	5.7	9.11
WP 6	11	6.57	8.34	CP 3	8	5.98	8.2
WP 6	12	5.86	6.83	CP 3	9	29.62	10.47
WP 6	13	9.26	8.76				
WP 6	14	6.4	10.18	CP 4	2	6.39	9.84
WP 6	15	15.4	15.22				
WP 6	16	12.8	12.01	CP 5	6	5.11	8.48
WP 6	18	7.5	4.08	CP 5	8	8.26	2.54
				CP 5	9	4.44	6.26
				CP 6	2	8.28	9.56
				CP 6	4	11.95	11.32

TYPE III: Seepage Erosion Channel Heads

PLOT	Channel Head #	PLOT	Channel Head #
WP1	2	CP 2	1
		CP 2	2
WP 2	8	CP 2	3
WP 2	13		
		CP 4	1
WP 4	4	CP 4	3
WP 4	5	CP 4	4
WP 4	6		
WP 6	6		
WP 6	7		

Appendix 5

Local Slope of Type I, Control Plot Channel Heads

PLOT	Channel Head #	Distance between 2 Contours (m)	Local Slope (m / m)
CP 1	1	2.76	0.072
CP 1	2	3.93	0.051
CP 1	3	4.98	0.040
CP 1	4	4.71	0.042
CP 1	10	4.88	0.041
CP 2	4	5.12	0.039
CP 3	1	5.08	0.039
CP 3	2	3.59	0.056
CP 5	1	5.38	0.037
CP 5	7	6.14	0.033
CP 5	2	6.02	0.033
CP 5	3	8.42	0.024
CP 5	4	7.3	0.027
CP 5	5	5.79	0.035
CP 6	3	9.79	0.020
CP 6	1	9.31	0.021

Appendix 6

"Check" of Source Areas by Myself

PLOT	Channel Head #	Org. Source Area (m^2)	"Check" Source Area (m^2)	% Difference	PLOT	Channel Head #	Org. Source Area (m^2)	"Check" Source Area (m^2)	% Difference
WP 2	1	27.61	27.23	1.38	RP 2	1	58.62	40.31	31.2
WP 2	2	14.44	31.37	-117.24	RP 2	2	51.31	26.33	48.7
WP 2	3	17.07	18.67	-9.37	RP 2	3	216.39	208.98	3.4
WP 2	4	11.12	6.68	39.93	RP 2	4	88.8	57.02	35.8
WP 2	5	8.69	6.31	27.39	RP 2	5	17.03	14.49	14.9
WP 2	6	49.19	27.4	44.30	RP 2	6	23.75	15.21	36.0
WP 2	7	16.67	14.57	12.60	RP 2	7	17.8	7.92	55.5
WP 2	8	7.07	7.54	-6.65	RP 2	8	23.31	20.75	11.0
WP 2	9	4.46	19.4	-334.98	RP 2	9	13.52	13.57	-0.4
WP 2	10	3.87	3.2	17.31	RP 2	10	104.49	119.29	-14.2
WP 2	11	3.21	3.66	-14.02	RP 2	11	9.3	27.7	-197.8
WP 2	12	5.16	5.29	-2.52	RP 2	12	48.6	26.62	45.2
WP 2	13	4.18	4.39	-5.02	RP 2	13	12.2	10.01	18.0
WP 2	14	8.76	4.96	43.38					
WP 2	15	10.1	6.16	39.01	RP 5	1	35.28	21.4	39.3
					RP 5	2	26.21	17.48	33.3
WP 4	1	30.27	50.6	-67.16	RP 5	3	120.28	56.16	53.3
WP 4	2	12.9	17.09	-32.48	RP 5	4	95.18	91.26	4.1
WP 4	3	6.64	6.47	2.56	RP 5	5	117.8	69.75	40.8
WP 4	4	12.59	6.76	46.31	RP 5	6	85.74	37.43	56.3
WP 4	5	5.25	7.62	-45.14	RP 5	7	71.69	57.03	20.4
WP 4	6	10.48	4.51	56.97	RP 5	8	165.63	77.61	53.1
WP 4	7	14.27	12.93	9.39	RP 5	9	33.51	39.64	-18.3
WP 4	8	8.12	3.99	50.86	RP 5	10	56.25	46.02	18.2
WP 4	9	3.01	4.02	-33.55	RP 5	11	83.7	57.38	31.4
WP 4	10	7.07	9.68	-36.92	RP 5	12	31.12	27.25	12.4
					RP 5	13	67.25	85.86	-27.7
CP 3	1	54.01	40.45	25.11					
CP 3	2	19.85	18.5	6.80	CP 5	1	50.95	47.74	6.30
CP 3	3	6.18	6.97	-12.78	CP 5	2	181.03	217.89	-20.36
CP 3	4	5.83	10.65	-82.68	CP 5	3	59.81	79.87	-33.54
CP 3	5	6.43	10.6	-64.85	CP 5	4	19.79	8.75	55.79
CP 3	6	2.61	4.95	-89.66	CP 5	5	14.16	14.02	0.99
CP 3	7	5.7	6.63	-16.32	CP 5	6	5.11	5.42	-6.07
CP 3	8	5.98	6.24	-4.35	CP 5	7	21.62	9.17	57.59
CP 3	9	29.62	15.56	47.47	CP 5	8	8.26	2.24	72.88
CP 3	10	10.33	4.33	58.08	CP 5	9	4.44	2.98	32.88

70 channel heads checked/reproduced

Average difference in reproducing all 70 channel heads: 1.8% ± 61.38%

“Check” of Source Areas by an outside person

PLOT	Channel Head #	Org. Source Area	"Check" Source Area	% Difference	PLOT	Channel Head #	Org. Source Area	"Check" Source Area	% Difference
RP 1	1	78.98	8.8	88.86	CP 1	1	9.46	8.81	6.87
RP 1	2	20.09	6.27	68.79	CP 1	2	7.76	9.4	-21.13
RP 1	3	62.23	50.43	18.96	CP 1	3	12.43	8.1	34.84
RP 1	4	286.6	243.83	14.92	CP 1	4	70.65	51.75	26.75
RP 1	5	15.55	13.46	13.44	CP 1	5	4.05	5.49	-35.56
RP 1	6	27.06	37.84	-39.84	CP 1	6	6.28	13.43	-113.85
RP 1	7	69.86	34.58	50.50	CP 1	7	4.9	3.44	29.80
RP 1	8	55.08	69.68	-26.51	CP 1	8	4.37	9.53	-118.08
RP 1	9	6.58	5.42	17.63	CP 1	9	0.91	2.7	-196.70
RP 1	10	3.7	1.74	52.97	CP 1	10	33.23	51.19	-54.05
RP 1	11	8.54	11.87	-38.99	CP 1	11	9.41	7.54	19.87
RP 1	12	6.49	10.03	-54.55	CP 1	12	11.36	11.36	0.00
RP 1	13	11.41	10.86	4.82	CP 1	13	26.14	5.66	78.35
RP 1	14	13.4	5.95	55.60	CP 1	14	9.56	12.99	-35.88
RP 1	15	19.36	24.55	-26.81	CP 1	15	9.6	8.46	11.88
RP 1	16	37.69	45.56	-20.88					
RP 4	1	15.73	14.88	5.40					
RP 4	2	48.4	22.94	52.60					
RP 4	3	364.78	377.53	-3.50					
RP 4	4	82.04	41.71	49.16					
RP 4	5	534.22	530.92	0.62					
RP 4	6	59.51	155.1	-160.63					
RP 4	7	45.49	49.23	-8.22					
RP 4	8	251.26	201.68	19.73					
RP 4	9	21.38	20.68	3.27					
RP 4	10	11.56	22.43	-94.03					

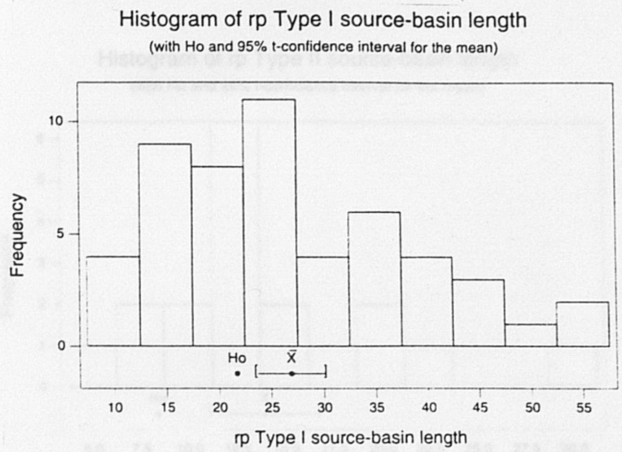
41 channel heads checked/reproduced

Average difference in reproducing all 41 channel heads: 7.89% ± 61.02%

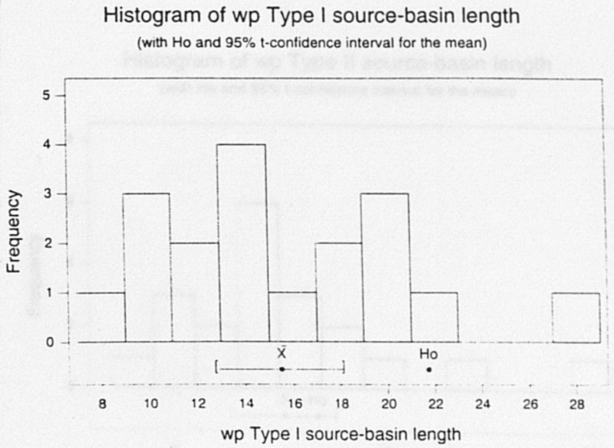
Appendix 7

Relative frequency histograms of Type I (strictly rainfall as overland flow source) source areas and source-basin lengths. X represents the mean value of the plot being compared to the corresponding control plot mean (H_o). If H_o falls with the brackets surrounding X than the mean in question is not significantly different at 95% confidence.

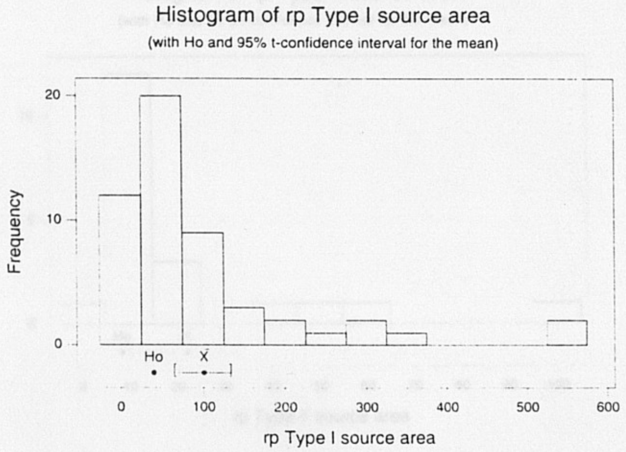
Note: rp = road plots, wp = walkway plots, H_o = corresponding control plot mean.



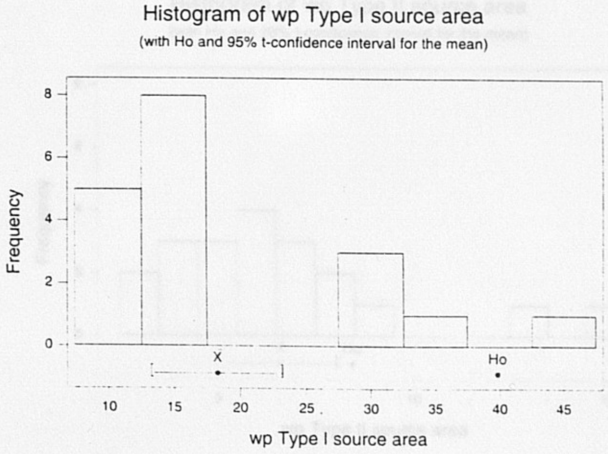
Road Plots: Source-Basin Length



Walkway Plots: Source-Basin Length



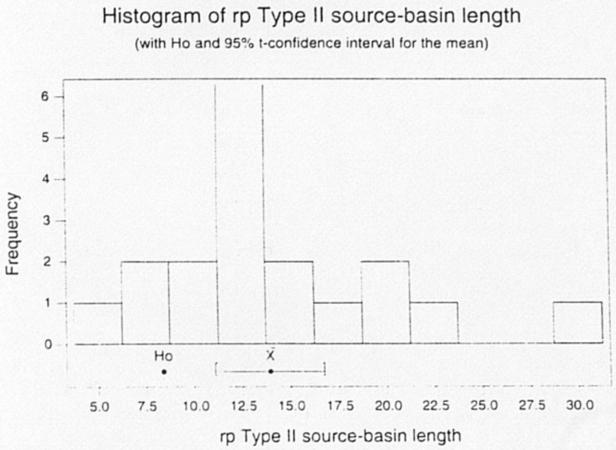
Road Plots: Source Area



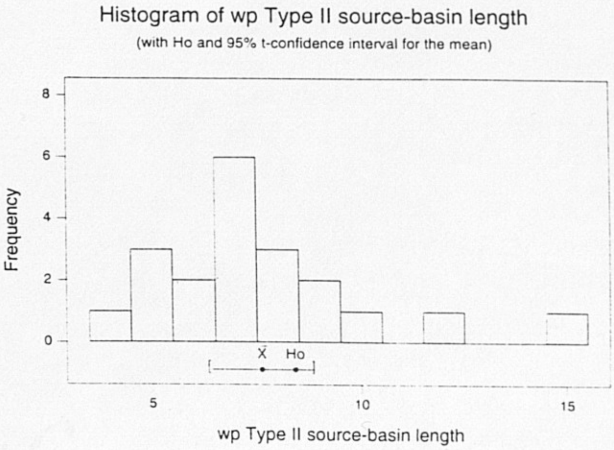
Walkway Plots: Source Area

Relative frequency histograms of Type II (rainfall and stream spillover as overland flow source) source areas and source-basin lengths. X represents the mean of the plot being compared to the corresponding control plot mean (H_o). If H_o falls with the brackets surrounding X than the mean in question is not significantly different at 95% confidence. Note: rp = road plots, wp = walkway plots, H_o = corresponding control plot mean.

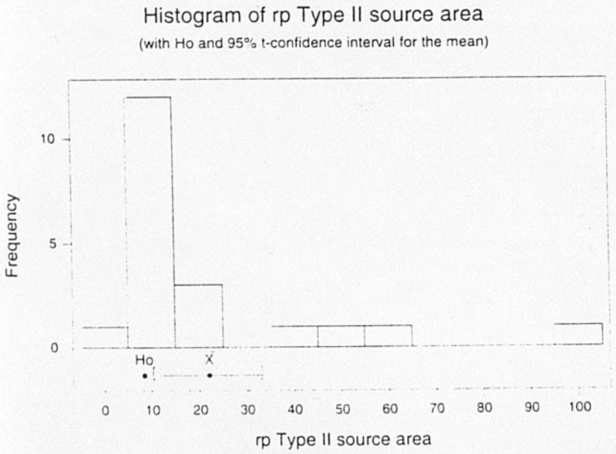
Type II Walkway Plot mean source-basin length is not significantly different (at 95% confidence) from the control plot mean, since H_o (control plot mean) falls within the bracket surrounding X. However, at 90% confidence the two means are significantly different.



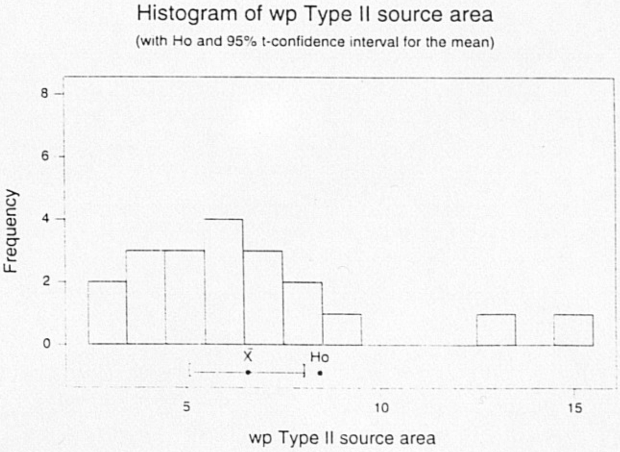
Road Plots: Source-Basin Length



Walkway Plots: Source-Basin Length



Road Plots: Source Area



Walkway Plots: Source Area