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Mapping and Analysis of Catherine Creek Using Remote Sensing and Geographic Information Systems (GIS)

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Introduction

Geographic Information Systems (GIS) are organized procedures that process spatially referenced data to yield insight on structure and function at a locale or across a region. Data sets or layers that contain information, such as soils, vegetation, topography, precipitation, geology, etc. can be superimposed or combined in a logical fashion to yield new information. Aerial photographs, satellite images, and other remotely sensed information are particularly helpful and have been widely used in GIS analysis.

By combining existing information, other parameters can be determined. These include slope and aspect which are derived from elevation models, erosion hazards from soils and topography, and habitat suitability generated from vegetation, topography, and cover layers. A myriad of other parameters can be produced if base maps or appropriate data layers exist. These systems facilitate the interpretation of data. They have revolutionized the analysis of landforms and can improve monitoring, interpretation, analysis, and management of landscapes.

Fine scale monitoring of streams and their associated watersheds can be executed by aerial photography, videography, or radiometry coupled with ground measurements. Areas of special interest can be photographed in scales up to 1:1000 for detailed work from fixed-wing aircraft. Blimp-borne photographic platforms have also been used for even higher resolution images. Both color and infrared photographic films are used if vegetative parameters such as cover (by species or class), biomass, or areas devoid of vegetation are to be determined.

Individual trees, shrubs, rivulets, and channels can be monitored and quantified over time by repetitive overflights which provides unprecedented analytical power to researchers and managers, especially when detailed ground surveying and measurement of the sites is done in conjunction with photography.

Catherine Creek and associated pastures on the Hall Ranch have been well documented both from low-level aerial photographs and ground measurements since the late 1970s. Management actions are recorded and numerous graduate students and professors have carried out research projects on the stream and associated riparian systems. In 1994, the Oregon Agricultural Experiment Station provided a special grant to begin GIS analysis of the Catherine Creek watershed and its relation to the Hall Ranch. This paper represents preliminary results from the analysis.

Objectives

The objectives of this study were to quantify the surface hydrology of Catherine Creek on the Hall Ranch of northeastern Oregon as it relates to livestock grazing and salmon spawning. We employed aerial photographs to define the morphology, size, and change in stream channels which occurred between 1979 and 1994. This reach of stream is important because spring-run Snake River chinook salmon (*Onchorhynchus tschawytscha*), a fish recently added to the Federal Endangered Species List, spawn on the ranch, and management actions are well documented.

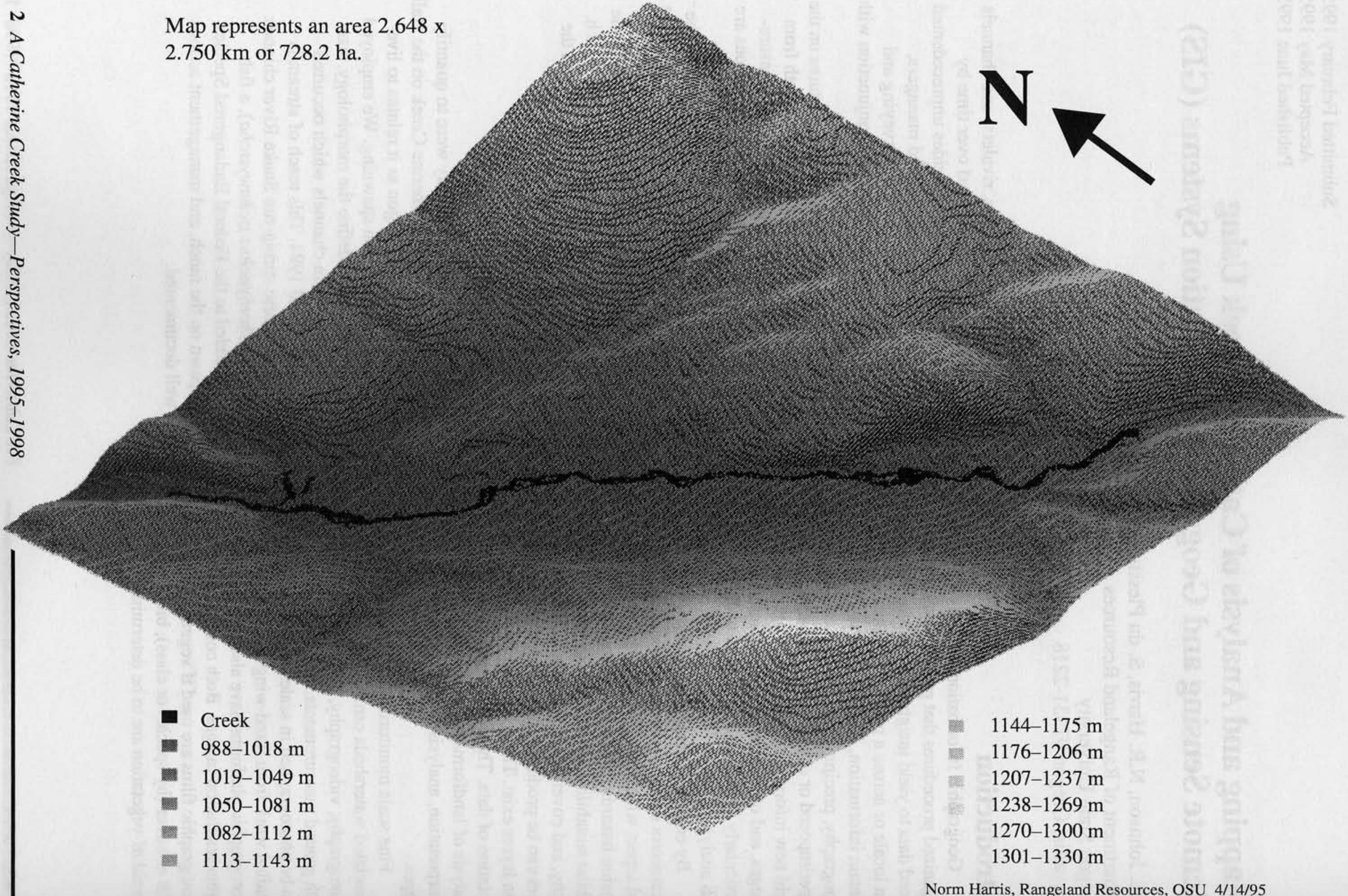


Figure 1. Orthographic view of the Hall Ranch, Union, Oregon. The outline of Catherine Creek as it was in 1994 is superimposed on the map.

Materials and Methods

Study Area

The study area on Catherine Creek is located 15 km southeast of Union, Oregon, on the Hall Ranch, operated by the Oregon State Agricultural Experiment Station. Elevation of the stream and its associated meadows is approximately 990 m as it courses through 3 km of State property (Figure 1). A stream gauging station (Number 13320000) operated by the U.S. Department of the Interior, Geological Survey (GS), is located approximately 1 km below the ranch. This station has relatively continuous flow records beginning in 1911.

Ground Data

Five plots, fenced to exclude livestock, were constructed in 1978 (Figure 2). These plots alternate with areas that are open to grazing by livestock and wildlife, so the linear-run of the main channel on the Hall Ranch was divided equally between grazed areas and exclosed areas. Using 1979 aerial photographs, we calculated the linear distance of the main creek channel by digitizing thalweg, or center-lines. There were 1,190 m of 1979 creek channel split between five exclosures. Grazed areas between these exclosures totaled 1,139 m of thalweg distance. Therefore, a total of nine experimental units or plots cover the creek as it passes through the ranch. Plots varied in size from 138 m to 359 m of thalweg distance. We should note that this design essentially doubles the livestock impact per linear unit of each grazed stream reach since animal access to the stream is restricted.

Outlines of each experimental unit were geo-positioned, as were "ground control" reference points, by collecting 180 locational fixes at each point using a Trimble Pathfinder[1] global positioning unit. Data points were differentially corrected using the BLM/Forest Service Base Station at Burns, Oregon, which provided positional accuracy of field locations within 3 meters. In addition, position of salmon redds were monitored and outlined daily on aerial photographs during the 1993 and 1994 spawning seasons by Teena M. Tibbs, Faculty Research Assistant. These outlines were digitized into a georeferenced data layer which was used in analysis.

Aerial Photography

On the dates listed in Table 1, aerial photographs were taken with a Hasselblad camera fitted with an 80 mm lens using color negative film. Flight altitude varied from 400 m to 700 m above the creek depending upon weather conditions.

Photographs were scanned on an Epson ES-300C flat-bed color scanner providing an electronic image with pixel resolution of 15 x 15 cm for the lowest photographs and 30 x 30 cm for the highest. Images were geo-corrected using 202 ground control points so that areas and distances could be accurately determined.

Figure 3 shows the layout of photographs taken in 1994, superimposed on the stream channel. This image also indicates that two passes were flown while obtaining the photographs.

Three bands of information were generated from photographic films: red, green, and blue. Each picture element or pixel has a Digital Number (DN) from 0 to 255 indicating intensity of that band. These Digital Numbers can be processed and mathematically manipulated to accentuate differences between plant species, stream surface, and soils.

Digital Elevation Model

A Digital Elevation Model (DEM) was constructed for the Hall Ranch region by digitizing elevational contours from 7.5 minute GS quad maps, transferring vectors to raster format and interpolating between contour lines. The interpolation algorithm employed uses north-south, east-west, and diagonal profiles across the image to estimate elevation of the profile for each cell. This procedure produced a digital map where a pixel or cell represents an area measuring 10 x 10 m or 100 m^2. The elevation model for the region including the Hall Ranch is shown in Figure 4.

[1]Use of trade names is for the benefit of the reader and does not constitute endorsement by Oregon State University or the Oregon Agricultural Experiment Station.

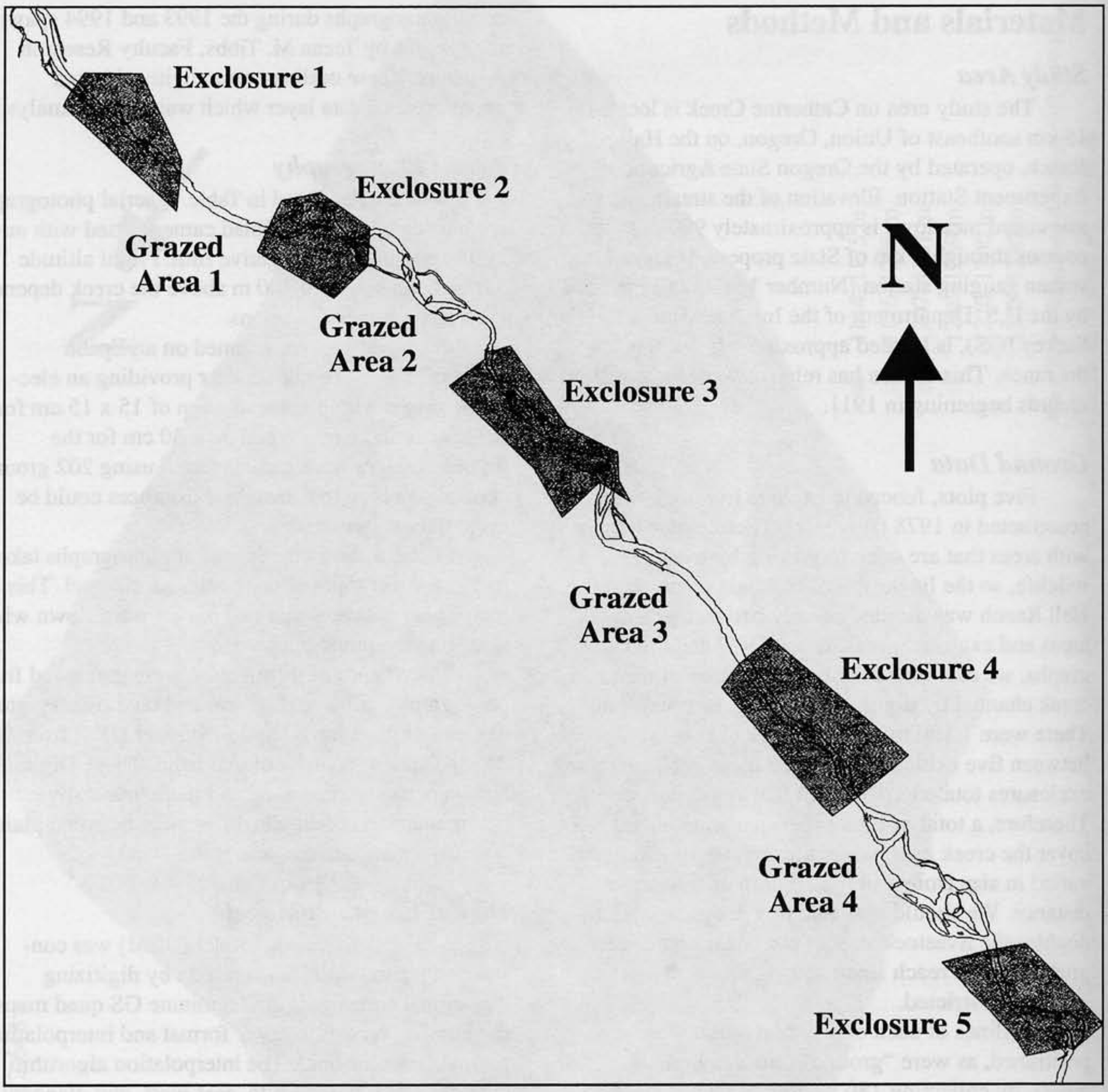
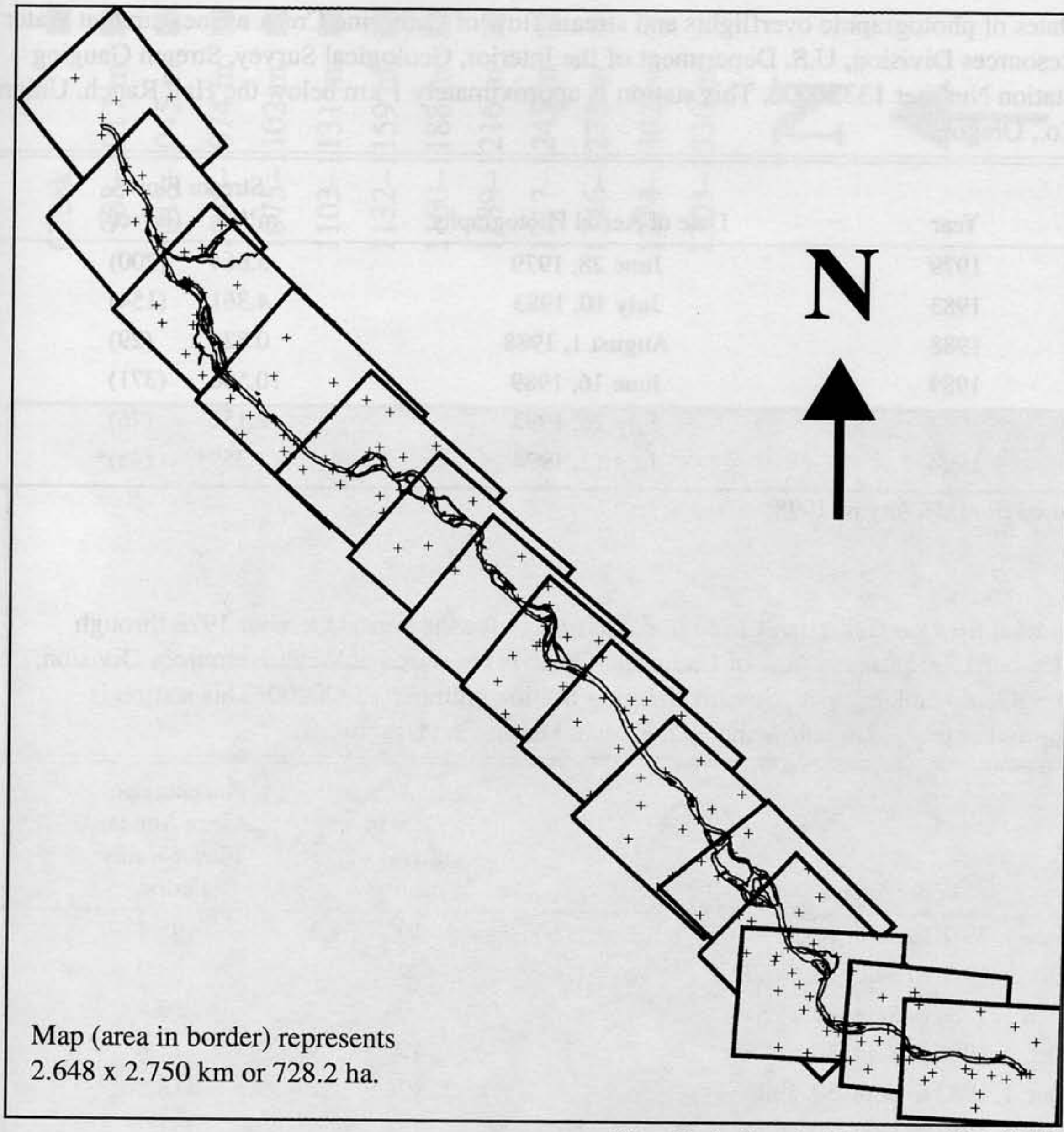


Figure 2. Layout of the experimental units on the Hall Ranch, Union, Oregon. Outlines of the 1994 channel of Catherine Creek are superimposed.



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Digitized Channel Outlines and 202 "Ground Control" Points (small x's) are also shown.

Ground control points are easily identifiable photo objects that are georeferenced using a Global Positioning System.

This instrument uses 5 navigational satellites to obtain a position accurate to within 2 meters.

Figure 3. The positions of the fifteen aerial photographs of the 1994 flight line superimposed on the outline of Catherine Creek on the Hall Ranch, Union, Oregon.

Table 1. Dates of photographic overflights and stream flow of Catherine Creek as measured at Water Resources Division, U.S. Department of the Interior, Geological Survey, Stream Gauging Station Number 13320000. This station is approximately 1 km below the Hall Ranch, Union Co., Oregon.

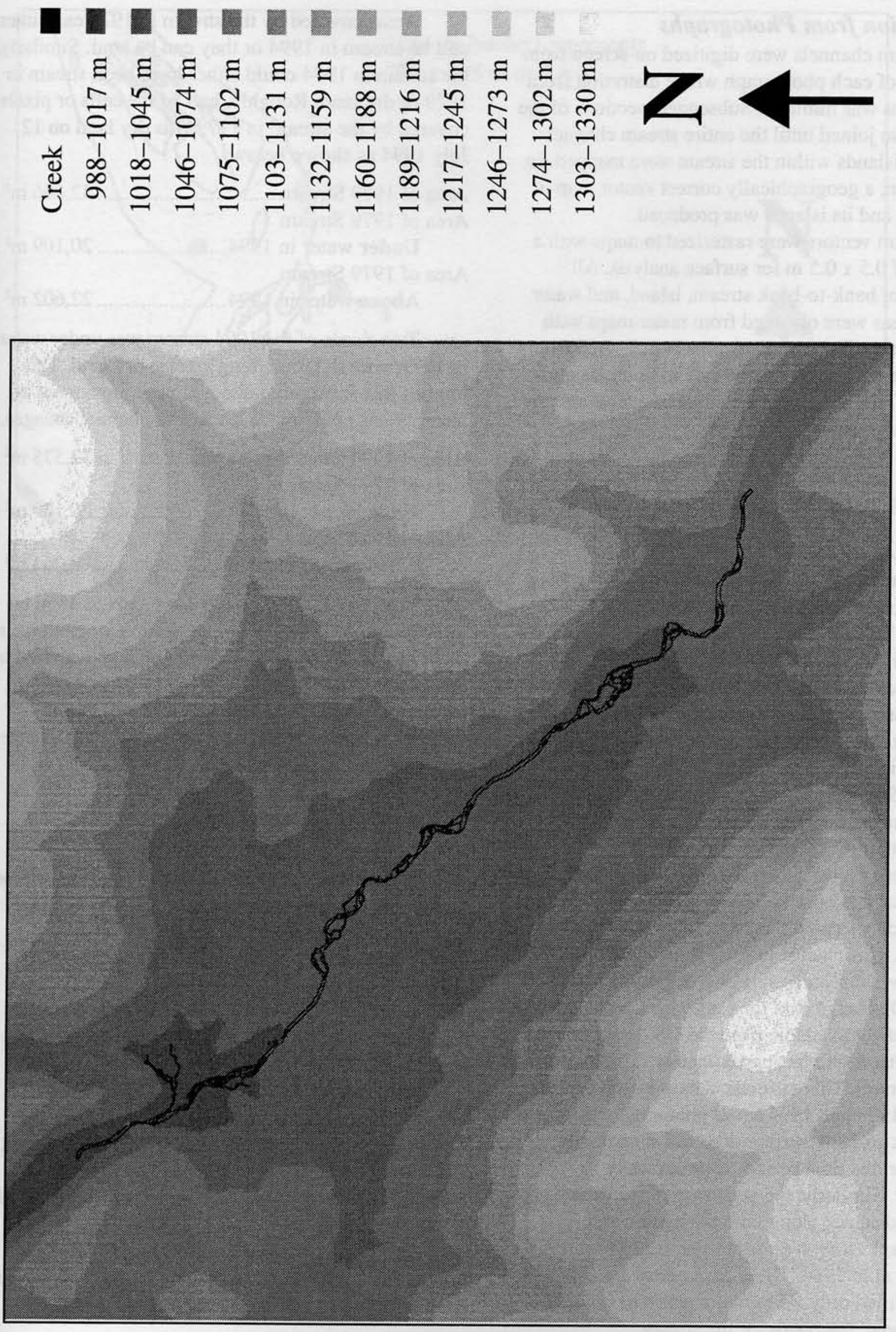
Year	Date of Aerial Photography	Stream Flow m^3/sec	(ft^3/sec)
1979	June 28, 1979	5.664	(200)
1983	July 10, 1983	4.361	(154)
1988	August 1, 1988	0.821	(29)
1989	June 16, 1989	10.506	(371)
1993	July 26, 1993	2.152	(76)
1994	July 12, 1994	1.359*	(48)*

* Data acquired from GS August 1998.

Table 2. Annual flow on Catherine Creek in cubic meters for the period October 1978 through October 1993. Stream flow of Catherine Creek is measured at Water Resources Division, U.S. Geological Service, Stream Gauging Station Number 13320000. This station is approximately 1 km below the Hall Ranch, Union Co., Oregon.

Water Year	Total Annual Flow in millions of $meters^3$	Percentage of Mean Annual Flow for this Period
Oct. 1, 1978 to Sept. 30, 1979	102	95.8
Oct. 1, 1979 to Sept. 30, 1980	93	88.0
Oct. 1, 1980 to Sept. 30, 1981	96	90.4
Oct. 1, 1981 to Sept. 30, 1982	120	112.8
Oct. 1, 1982 to Sept. 30, 1983	126	118.2
Oct. 1, 1983 to Sept. 30, 1984	161	151.7
Oct. 1, 1984 to Sept. 30, 1985	94	88.5
Oct. 1, 1985 to Sept. 30, 1986	116	109.4
Oct. 1, 1986 to Sept. 30, 1987	—	—
Oct. 1, 1987 to Sept. 30, 1988	71	67.0
Oct. 1, 1988 to Sept. 30, 1989	114	107.6
Oct. 1, 1989 to Sept. 30, 1990	100	94.1
Oct. 1, 1990 to Sept. 30, 1991	105	99.4
Oct. 1, 1991 to Sept. 30, 1992	65	61.1
Oct. 1, 1992 to Sept. 30, 1993	123	115.9
Mean annual flow for this period	106	

* Data for October 1, 1986, to September 30, 1987, is not available.



Map represents 2.648 x 2.750 km or 728.2 ha.

Figure 4. Digital elevation model (DEM) of the Hall Ranch superimposed with the 1994 outline of Catherine Creek.

Digitization from Photographs

Stream channels were digitized on-screen from the center of each photograph where distortion from camera lens was minimal. Subsequent sections of the stream were joined until the entire stream channel including islands within the stream were mapped. In this fashion, a geographically correct vector map of the stream and its islands was produced.

Stream vectors were rasterized to maps with a cell size of 0.5 x 0.5 m for surface analysis. All estimates of bank-to-bank stream, island, and water surface areas were obtained from raster maps with this resolution. Bank-to-bank area is measured from the edge of the stream on one side to farthest opposite bank. This represents water surface area and any included islands.

Results and Discussion

Stream Dynamics

Catherine Creek has changed its course substantially in the years between 1979 and 1994 (Figure 5, Table 3). The 1994 thalweg measurements showed an increase of 330 m of channel length in grazed areas with 282 m of this increase occurring in grazed plot #2 (Table 4). Increased thalweg distances in some exclosed plots were partially offset by decreases in others resulting in an overall increase of 13 m by 1994.

Water surface area in late June of 1979 was approximately 43,000 m^2 when flow was 5.664 m^3/sec (Table 3). On 12 July 1994 water surface area was approximately 32,500 m^2 on the ranch which was a 24.1 percent reduction from the 1979 area. This change in surface area could result from a lower discharge rate or a deepening of the channel. Discharge data for Catherine Creek during 1994 is not yet available from the GS. However, we estimate that it will be approximately 1.7 m^3/second (60 ft^3/second). This estimate is based upon examination of 1993 and 1994 aerial photographs.

Bank-to-bank surface area was remarkably stable over this time period, approximately 54,000 m^2. Similarly, the perimeter of the stream or the linear distance along both the eastern and western banks also is quite similar, 6,226 m in 1979 and 6,260 m in 1994. These parameters are apparently modified only when major storm or runoff events change the course of the stream.

Areas covered by the stream in 1979 can either still be stream in 1994 or they can be land. Similarly, the stream in 1994 could either have been stream in 1979 or dry land. Roughly, half of the cells or pixels covered by the stream in 1979 was dry land on 12 July 1994 as shown below:

Area of 1979 Stream .... 42,806 m^2
Area of 1979 Stream
  Under water in 1994 .... 20,109 m^2
Area of 1979 Stream
  Above water in 1994 .... 22,602 m^2

Two thirds of the 1994 stream was under water in 1979, with the remaining area as dry land. This implies that substantial deposition or movement of material has taken place leading to channel changes.

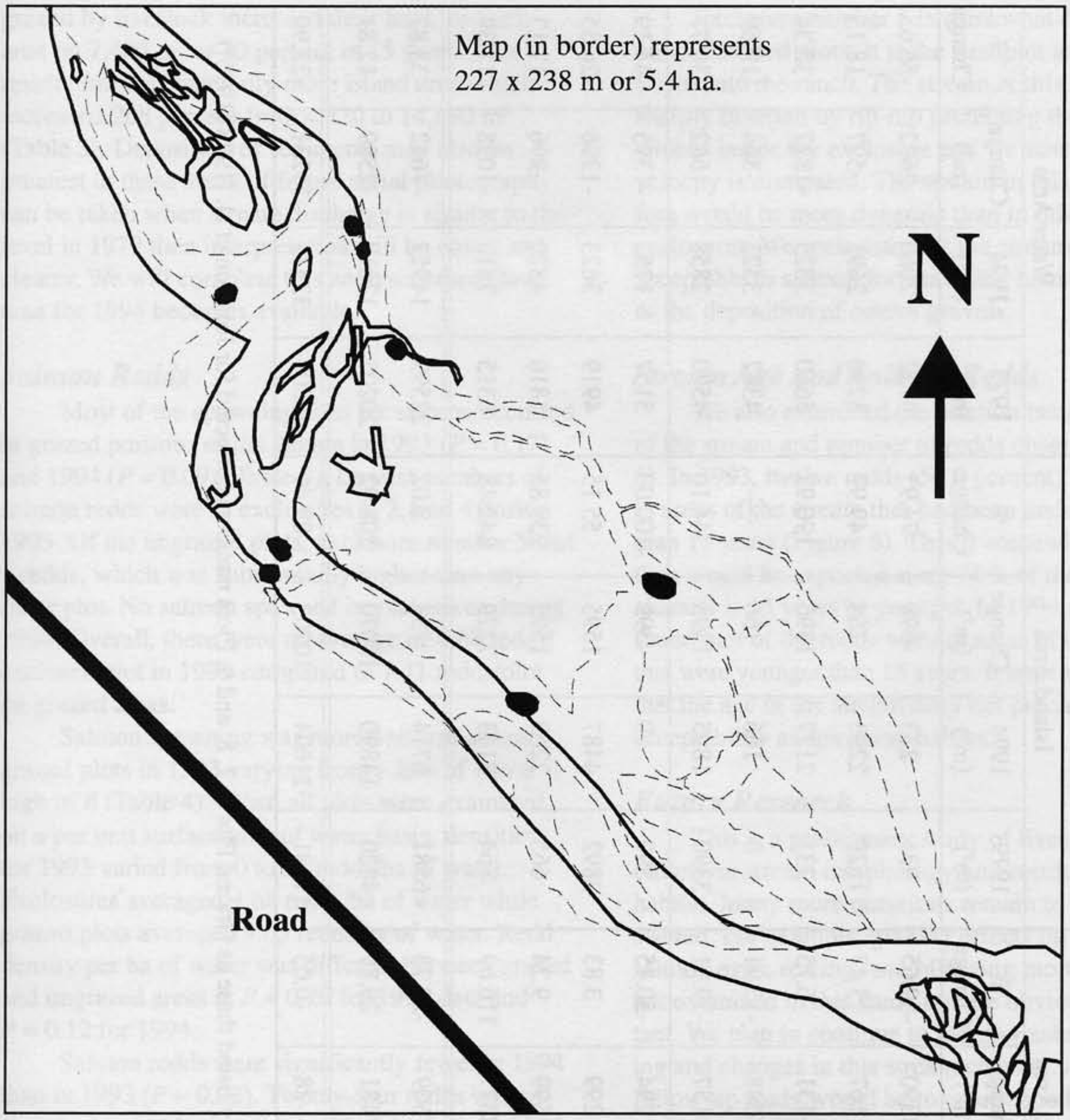
Area of 1994 Stream .... 32,575 m^2
Area of 1994 Stream
  Under water in 1979 .... 20,109 m^2
Area of 1994 Stream
  Above water in 1979 .... 12,364 m^2

In some places channels have moved 18 m or more laterally. This movement occurs when there is rapid runoff during spring. Major change occurred in the spring of 1984 (Dr. Marty Vavra, personal communication). As would be expected, during years with below average precipitation, little change was observed in the channel.

Effects of Livestock Grazing on Salmon Spawning

It is difficult to separate livestock effects on the stream because excluded areas are relatively small and closely associated with grazed parcels. However, both exclosed and grazed areas had smaller water surface areas in 1994. There was a 33.8 percent reduction in water surface area in the exclosed plots compared to 12.8 percent reduction in grazed plots from 1979 to 1994. Flow is lower in 1994 than in 1979 which accounts for some of this change. This also suggests that the channel is deepening more rapidly in areas left ungrazed. Total island area of exclosures increased by 2 percent (Table 3) while bank-to-bank surface area decreased by 25.7 percent.

Total water surface area of grazed plots decreased by 2,590 m^2. Grazed areas seem to be where most braiding of channels is taking place. Areas



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Approximate age of Redd formations can be estimated from placement of Redds on creek channel.

1979 Channel shown by solid black outline.

1994 Channel shown by dashed gray outline.

Eight 1993 Redds shown as black polygons.

Woody debris and downed trees are also outlined.

Figure 5. Overlays showing the position of Catherine Creek in early summer of 1979 and 1994. Also shown on this image is the location of some salmon redds in 1993. This indicates the dynamic nature of the stream channel in these meadows.

Table 3. Surface measurements for Catherine Creek on the Hall Ranch near Union, Oregon. Surface areas were calculated from geo-corrected low altitude aerial photographs taken in 1979 and 1994 that were digitized on-screen. Vectors were transferred to raster format and analysis completed with 0.5 x 0.5 m pixels.

	Bank-to-Bank Area				Island Area				Water Area			
	1979 (m^2)	1994 (m^2)	Change (m^2)	% Change	1979 (m^2)	1994 (m^2)	Change (m^2)	% Change	1979 (m^2)	1994 (m^2)	Change (m^2)	% Change
Exclosure 1	5683	2293	-3390	-59.65	931	233	-698	-74.97	4752	2060	-2692	-56.65
Exclosure 2	4819	4986	167	3.47	1529	2293	764	49.97	3290	2693	-597	-18.15
Exclosure 3	6381	5950	-431	-6.75	731	2127	1396	190.97	5650	3823	-1827	-32.34
Exclosure 4	4387	3689	-698	-15.91	0	166	166	—	4387	3523	-864	-19.69
Exclosure 5	7910	4753	-3157	-39.91	3390	1895	-1495	-44.10	4520	2858	-1662	-36.77
Grazed Plot 1*	3556	1762	-1794	-50.45	399	0	-399	-100.00	3157	1762	-1395	-44.19
Grazed Plot 2*	7811	8110	299	3.83	2892	4487	1595	55.15	4919	3623	-1296	-26.35
Grazed Plot 3*	6481	7080	599	9.24	665	2260	1595	239.85	5816	4820	-996	-17.13
Grazed Plot 4*	7179	15556	8377	116.69	864	8143	7279	842.48	6315	7413	1098	17.39
Exclosed Total	29180	21671	-7509	-25.73	6581	6714	133	2.02	22599	14957	-7642	-33.82
Grazed Total	25027	32508	7481	29.89	4820	14890	10070	208.92	20207	17618	-2589	-12.81
Grand Total	54207	54179	-28	-0.05	11401	21604	10203	89.49	42806	32575	-10231	-23.90

* In Johnson et al. (1995), Table 3 incorrectly listed these as Grazed Plot 6, 7, 8, and 9. Plots numbers corrected for Johnson et al. (1998 [1995]).

grazed by livestock increased their bank-to-bank area by 7,400 m^2 or 30 percent in 15 years. This results from substantially more island area which increased 208 percent from 4,820 to 14,890 m^2 (Table 3). Deposition of sediments may also be greatest in these areas. If future aerial photographs can be taken when stream discharge is similar to the level in 1979 then interpretation will be easier and clearer. We will complete this analysis when flow data for 1994 becomes available.

Salmon Redds

Most of the spawning sites for salmon occurred in grazed portions of the stream in 1993 ($P = 0.17$) and 1994 ($P = 0.09$) (Table 4). Lowest numbers of salmon redds were in exclosures 1, 2, and 4 during 1993. Of the ungrazed plots, exclosure number 5 had 6 redds, which was substantially higher than any other plot. No salmon spawned in exclosures during 1994. Overall, there were an average of 4.68 redds/exclosed plot in 1993 compared to 7.41 redds/plot on grazed areas.

Salmon spawning was more uniform across grazed plots in 1993 varying from a low of 1 to a high of 8 (Table 4). When all plots were examined on a per unit surface area of water basis, densities for 1993 varied from 0 to 21 redds/ha of water. Exclosures averaged 4.68 redds/ha of water while grazed plots averaged 9.65 redds/ha of water. Redd density per ha of water was different between grazed and ungrazed areas at $P = 0.29$ for 1993 data and $P = 0.12$ for 1994.

Salmon redds were significantly fewer in 1994 than in 1993 ($P = 0.02$). Twenty-four redds were observed in 1993 contrasted with only three in 1994. The density of redds was reduced from 7.41 redds/ha of water to only 0.62 in 1994 ($P = 0.02$).

Exclosure number 5 is somewhat different than other exclosed plots. It is the first plot as the creek flows onto the ranch. The stream at this point is sharply diverted by rip-rap protecting the road. It widens inside the exclosure and we suspect water velocity is dissipated. The stream in this area therefore would be more dynamic than in other exclosures. We speculate that the stream is more acceptable to salmon for spawning habitat because of the deposition of coarse gravels.

Stream Age and Salmon Redds

We also examined the relation between the age of the stream and number of redds observed (Table 5). In 1993, twelve redds (50.0 percent) were found in areas of the stream that had been under water less than 15 years (Figure 6). This is somewhat higher than would be expected since 38% of the stream channel is 15 years or younger. In 1994 again we found half of the redds were in areas of the stream that were younger than 15 years. It appears, however that the age of the stream does not preclude its acceptability as spawning habitat.

Future Research

This is a preliminary study of livestock grazing effects on stream morphology and resultant salmonid habitat. Many more questions remain to be answered. For example, grazing effects on survival of salmon eggs, rearing, and offspring mortality were not examined in this study but are obviously important. We plan to continue to monitor salmon spawning and changes in this stream channel. A logical follow-up study would be to examine other stream systems with different grazing intensities and/or seasons of use.

Table 4. Linear run of main channel (Thalweg distance) and number of islands in 1979 and 1994, and the number and density of salmon redds in 1993 and 1994 in each experimental unit on the Hall Ranch, Union Co., Oregon.

Experimental Unit	1979 Thalweg Distance	1994 Thalweg Distance	1979 Islands	1994 Islands	1993 Redds	1994 Redds
	meters	meters	Number	Number	No.	No.
Exclosure 1 (N)	233	203	10	2	0	0
Exclosure 2	159	195	7.5	4.5	0	0
Exclosure 3	274	320	8	10.5	1	0
Exclosure 4	301	274	2	2	0	0
Exclosure 5 (S)	223	211	9.5	3	6	0
Exclosure Total	1190	1203	37	22	7	0
Grazed 1 (N)	138	158	6.5	1	3	0
Grazed 2	285	567	5	9.5	5	1
Grazed 3	359	375	3	4.5	1	0
Grazed 4 (S)	357	369	15.5	14	8	1
Grazed Total	1139	1469	30	29	17	2
Grand Total	2329	2672	67	51	24	2

Table 5. Age of Catherine Creek channels that contained salmon redds in 1993 and 1994 on the Hall Ranch and on immediately surrounding area.

Age of Channel	Number of Redds in 1993	Number of Redds in 1994	Percentage of Redds in 1993	Percentage of Redds in 1994
2–5 Years	2		8.3	
6–9 Years	4		16.7	
10–14 Years	6	1	25.0	50.0
15+ Years	12	1	50.0	50.0
Total	24	2		

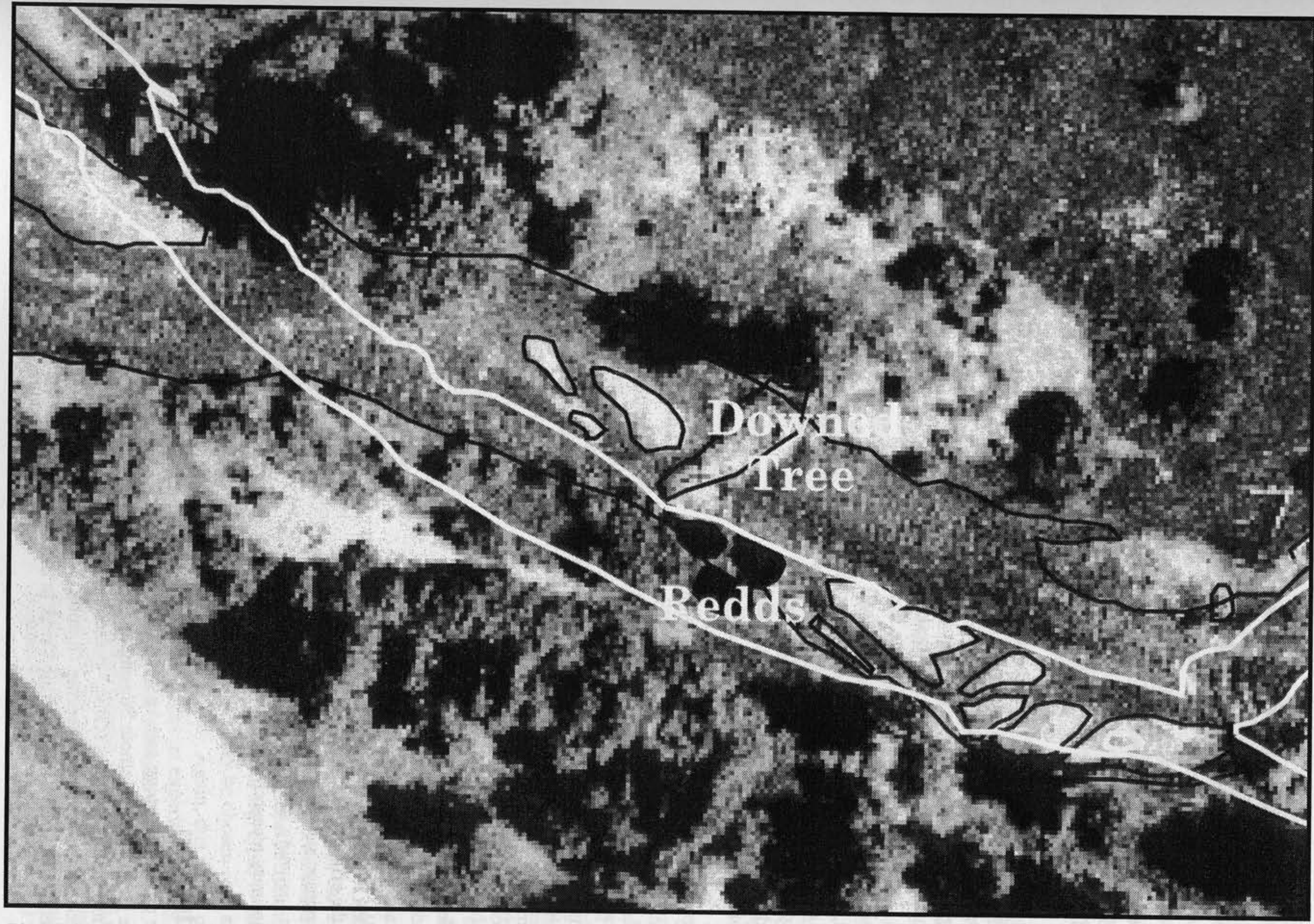

Photo shows area 151.8 x 106 m or 1.61 ha.

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Figure 6. A 1979 aerial photograph of a portion of Catherine Creek with the 1994 channel outline superimposed. The position of three of the 1993 salmon redds are also indicated.