

Stream change analysis using remote sensing and Geographic Information Systems (GIS)

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Abstract

Remote sensing and Geographic Information System (GIS) techniques are common tools for time change analysis, however, in most cases satellite imagery or small-scale aerial photography is used. The increased resolution of large-scale aerial photos helps in identifying small features on the ground and is highly useful in the assessment of riparian areas. The objectives of this study were 1) to examine changes in stream morphology over 20 years, 2) to assess if changes were associated with management, topography or other factors, 3) to determine the feasibility of using large-scale aerial photography, GIS and Global Positioning Systems (GPS) techniques as a tool for assessing change over time. The 2.5 km long study area, consisting of the stream and riparian area was separated into exclosures and grazed areas in 1978. Aerial photos from 1979 and 1998 (scale of 1:4000) were geo-referenced with ground control points, and various stream features were digitized using a GIS. Stream length, stream width and areas of change were identified for both years. Although stream length remained the same, stream width decreased in both grazed and exclosed areas. The area of change (3.65 ha) was slightly larger than the area of no change (3.2 ha). Number of islands and island perimeter decreased, while the island area increased. Exclosures and grazed areas responded similarly, and it was concluded that the topography and stream dynamics had a greater impact than the grazing regime in this study. The use of large-scale aerial photography, GIS and GPS proved to be a powerful tool for detecting change and it is expected that these techniques will become more common in rangeland analysis in the future.

Keywords: Time change analysis, remote sensing, Geographic Information Systems, GIS, stream morphology, large-scale aerial photography

Introduction

Recent progress in the fields of remote sensing, global positioning systems (GPS) and geographic information systems (GIS) has increased the use of this technology in rangeland studies (Anderson 1996). Aerial photography and satellite imagery have been used mainly for mapping vegetation and detecting vegetation changes over time (Everitt and Deloach 1990, Ferguson et al. 1993, Everitt et al. 1993, Strong et al. 1985).

However, there are few examples in the literature of the use of remote sensing/GIS in studying stream morphology change, especially over a long time period and using large-scale aerial photography. Miller et al. (1995) investigated changes in the landscape structure on the North Platte River, and Roth et al. (1996) used multiple spatial scales for the assessment of stream biotic integrity.

Large-scale aerial photography can be defined as scales from 1:1000 up to 1:10000 (Tueller 1996), although larger scale images have been used successfully (Warren and Dunford 1986, Tueller et al. 1988). The advantage of low altitude aerial photography lies in its high resolution, which facilitates interpretation of parameters in the photos (Golden et al. 1996, Warner et al. 1996). Features and landscape patterns are recognized easier from the air than from the ground (Hinckley and Walker 1993). For that reason, large-scale aerial photography is ideally suited for examining changes in stream morphology.

Johnson et al. (1995) used remote sensing and GIS technologies to map and analyze the Catherine Creek area several years ago. The authors measured some stream changes that had occurred from 1979 to 1994. The current study is based on and expands the work of Johnson et al. (1995).

The objectives of this study were 1) to assess changes in stream morphology in space (between grazed and ungrazed areas) and time (1979 to 1998), 2) to determine, if possible, to what extent these changes are associated with management, topography or other factors, and 3) to assess the viability of using large-scale (1:4000) aerial photography combined with GIS/GPS and ground truthing in time change analysis.

Methods and Materials

Study Site

The study area is located in northeastern Oregon, about 15 km southeast of Union on the Hall Ranch, which is operated by the Eastern Oregon Agricultural Research Center (EOARC) (45°06'N, 117°41'W). Catherine Creek runs for a length of 2.5 km through the study area, which is 41 hectares in size. The elevation of the stream and meadows is approximately 990 m height above the ellipsoid (HAE). The height was computed using the National Geodetic Survey GEOID 96 model. Catherine Creek is a third order tributary to the Grande Ronde River. About 5 km (3 miles) downstream from the study area, the US Geological Service, Water Resources Division operates a stream gauging station (Number 13320000), which has provided relatively continuous flow records since 1911; however, the gauging station was discontinued in 1996. The average discharge from 1979 to 1995 was $3.3 \text{ m}^3 \text{ sec}^{-1}$. Peak flows generally occur in April and May, associated with snowmelt runoff, while low flow conditions last from August to early February (United States Geological Survey 1999). Mean annual precipitation measured at the EOARC was 35 cm (1912-1998 data) and 38 cm (1979-1998 data), while mean annual temperature was recorded at 8.7 degree Celsius (1979-1998 data).

Prior to 1978, this area was grazed under a season long grazing regime. In 1978, five exclosures were constructed in the study area; they straddle the stream and alternate with grazed areas, so that the linear run of the stream is divided equally into exclosed and grazed sites (Fig 1). Since 1977, the study area has been grazed for 3-4 weeks in the fall to a utilization level of 70 %, and a stubble height of 5 cm on Kentucky bluegrass.

Fig. 1. Layout of the study area with 5 exclosures and outline of Catherine Creek in 1998

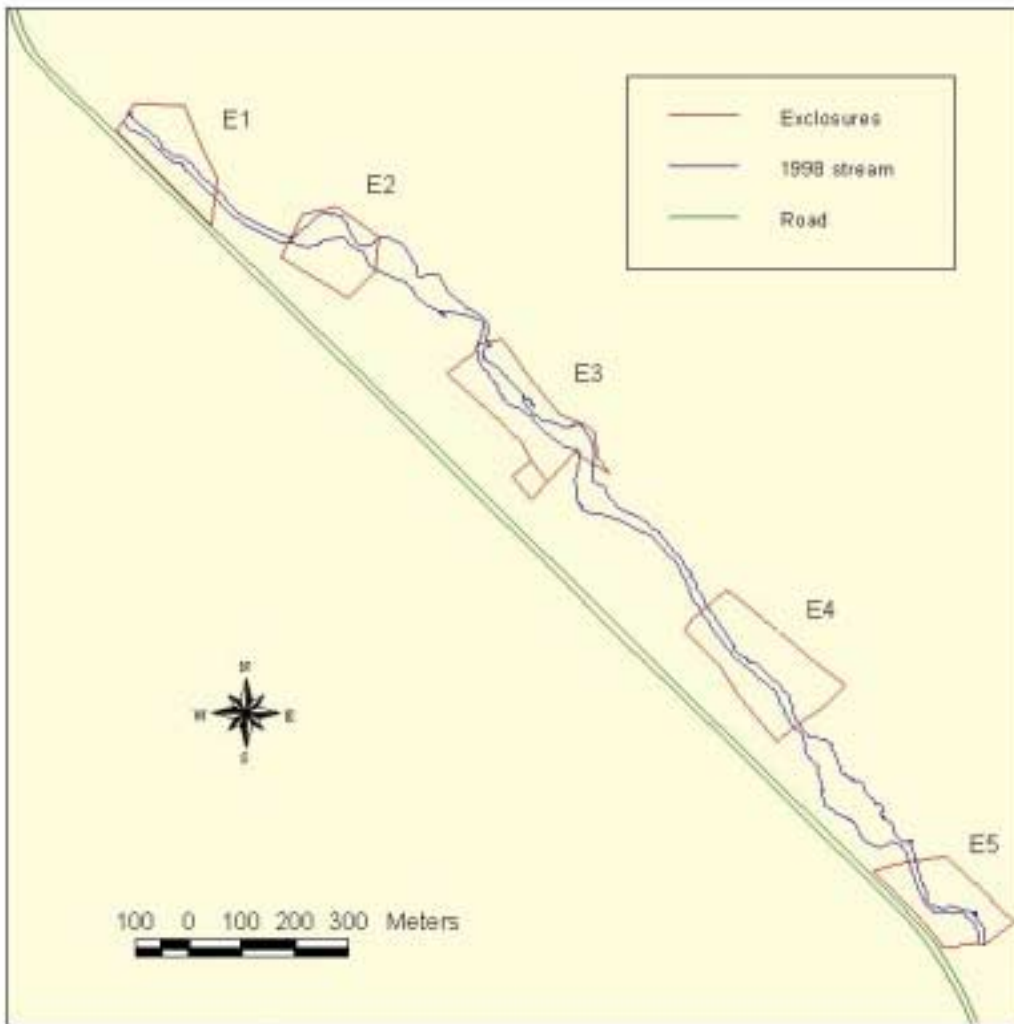


Table 1 shows the Animal Unit Months (AUM) for the Catherine Creek study site since 1977.

In 1958, and again in 1974/75, hawthorns (*Crataegus douglasii* L.) were removed from the Hall Ranch at a distance of 50 m from the stream for pasture improvement. The shrub was piled and burned, and the pasture was not seeded afterwards. In the mid-70s, a large landslide occurred on the middle fork of Catherine Creek within the wilderness boundary. Sediment discharge occurred in the following years after every rainfall (M.Vavra, pers.comm.).

Table 1. Grazing period and Animal Unit Months (AUMs) for the Catherine Creek study area.

Year	Grazing Period	AUMs
1977	17 Aug – 2 Sept	72.4
1978	23 Aug – 13 Sept	63.8
1979	27 Aug – 17 Sept	56.8
1980	23 Aug – 16 Sept	90.0
1981	27 Aug – 16 Sept	59.3
1982	26 Aug – 15 Sept	40.7
1983	22 Aug – 11 Sept	57.7
1984	23 Aug – 13 Sept	63.8
1985	16 Aug – 4 Sept	66.5
1986	15 Aug – 3 Sept	67.9
1987	18 Aug – 4 Sept	60.5
1988	23 Aug – 20 Sept	43.5
1989	16 Aug – 28 Sept	46.6
1990	20 Aug – 10 Sept	16.8
1991	29 Aug – 11 Sept	53.5
1992	5 May – 1 June, 6 Aug – 19 Aug	9.0 56.0
1993	23 Aug – 13 Sept	47.6
1994	17 Aug – 12 Sept	22.3
1995	22 Aug – 8 Sept	32.4
1996	13 Aug – 11 Sept	47.7
1997	12 Aug – 10 Sept	39.3
1998	17 Aug – 15 Sept	59.9

Aerial photography and ground targets

Both large-scale and small-scale aerial photography was used in this study. For 1979 and 1998, the 2 main time periods of interest, large-scale photography of 1:3100 and 1:4000 was used, respectively. While the study was in progress, small-scale (1:18,000) old photography became available and was used as supplementary information. At that scale, 1 image covered the whole study area; however, the resolution was lower

compared to the large-scale images. The 1998 aerial photos were taken with a Zeiss large format mapping camera with a focal length of 305.252 mm, using 24 cm film. The study area was photographed with both color and color infrared film. Photos were obtained with 60 % overlap, with 8 images covering the study area. The resulting scale was 1: 4000.

The 1979 color aerial photos were taken with a Hasselblad camera fitted with an 80 mm lens using color negative film. Ten photos covered the study area. These images had a 10 % overlap and provided a scale of 1: 3100. The 1998 photos had higher resolution and better quality, with less distortion occurring near the edges. All of the smaller scale imagery was taken with mapping cameras.

In 1998, 102 targets were distributed in open areas all over the study site. These targets would become ground control points for geo-referencing of the aerial photos. Targets used were 1 square foot white painted paving stones, secured with metal rods and numbered consecutively from 1 to 102. Each target was geo-positioned using two Trimble® Pathfinder Pro XR® differential global positioning (DGPS) receivers with data loggers. One GPS unit was used as a base station, the other as a rover, and a phase processing mode was used with a residence time of 12 minutes. All points were differentially post-referenced by downloading the necessary data from the US Forest Service GPS page maintained on the Internet (USDA Forest Service GPS page 1999).

The targets were positioned with an average Northing error of 7 cm, an Easting error of 14 cm, and an elevational error of 14 cm. Target positions were expressed in Universal Transverse Mercator (UTM) coordinates. The target positions were displayed as a map with the GPS software (Trimble Navigation 1996) and converted to a GIS vector file format as well as a spreadsheet containing UTM coordinates of target positions.

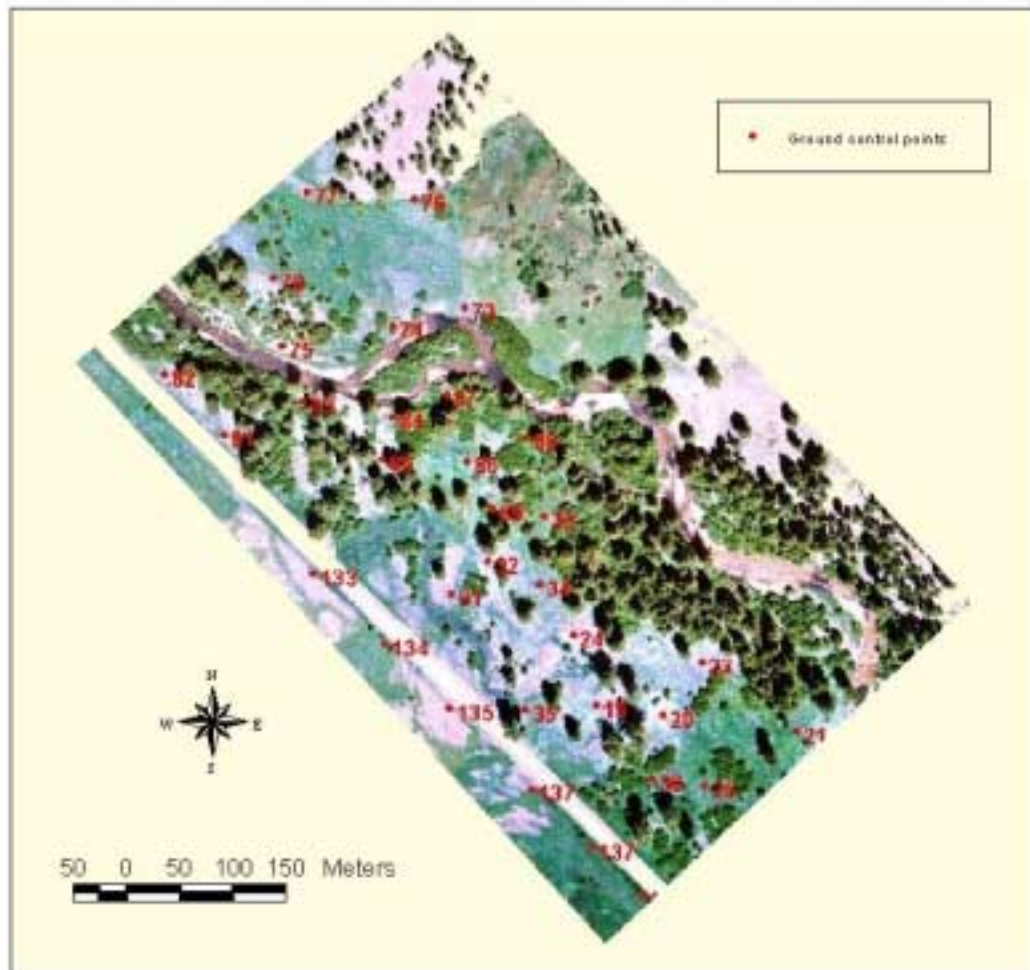
Image processing and geo-referencing

The next step was geo-referencing of the 1998 images, using the white targets that were easily identified on the photos. These images were used as the baseline for measurements and comparison of ground features with the 1979 images and also for the smaller scale photography from all other years. Aerial photos were scanned with a Hewlett-Packard® ScanJet® 6100C flatbed scanner at a resolution of 600 dpi (dots per inch). Although this created large image files of 85 megabytes, a high resolution was necessary for determination of ground features. Color images were saved in a 24-bit Tagged Image File Format (TIFF) after scanning, and then imported into the digital image processing program.

The 1998 images were geo-referenced using the software program ERDAS Imagine® (ERDAS® Inc. 1997), using a second order polynomial geo-referencing operation. The average Root Mean Square (RMS) error for 8 images was 1.56, with a pixel size of 10 cm, resulting in a ground accuracy of 16 cm. Details about this process can be found in Laliberte (2000). Figure 2 shows a corrected 1998 image with an overlay of the targets. Once all 1998 images had been rectified, the 1979 images were geo-referenced using the 1998 images as a baseline. This was more complicated than the 1998 image correction due to the time difference involved and the increased warping of the 1979 images. Twenty identical points such as tree stumps, rocks and other landmarks were chosen on both images.

The stream was not centered in all of the 1979 images, but was centered in all 1998 images. The downstream portion of the study area consisted of more open grassland,

Fig. 2. Geocorrected aerial photography with numbered ground control points



while the upper area was more vegetated with shrubs and trees. The denser vegetation presented more problems since it was difficult to identify certain shrubs or trees. In addition, the upper area had steeper topography, and the 1979 photos showed that the pilot had banked the plane to begin his flight, which resulted in considerable tilt in the first image. Due to the location of the stream away from the image center, the resulting distortion at the photo edge and lack of image overlap for the 1979 images, it was decided to perform an additional error assessment. For each corresponding image pair (1979/1998), eight points, visible on both images within 48 m of the stream edge were chosen. The points were chosen close to the stream since this was the area of interest for measurements. The UTM coordinates of the 1998 image were recorded first, followed by the same points for the 1979 image. The difference between the same location on the 1979 image and the 1998 image was on average 48 cm in the x and 47 cm in the y direction.

Digitizing of stream features

The outline of the stream was digitized on-screen from each aerial photo separately, using the software program ArcView (Environmental Systems Research Institute (ESRI) 1996). These vector files obtained from each photo were then appended into one vector file of the whole stream outline. The distortion of the lower quality 1979 photos resulted in a poor match of the vector lines from each image. The lines were joined in what was considered a best fit. As a control, it was decided to produce a mosaic of all 1979 images and overlay the finished stream outline to correct for any obvious errors.

Due to the distortion in the original images, some error in the overlap areas was unavoidable and had to be accepted since stream outlines from 2 years were to be compared later. The error in stream bank location due to photo distortion in the image overlap area was calculated by measuring the length of the overlap and its coordinates. In addition, the maximum and average distances of the vector lines (digitized from each photo) to the final stream outline were measured. The total length of overlap was 476.6 m, compared to a total stream length of 2318 m. The average error of the best fit line in this overlap area was 1.34 m.

The 1979 image mosaic and stream outline then became the standard for comparison with the 1998 images. None of the problems with joining of stream outlines were encountered in the 1998 photos, which were of higher quality. Due to 60% overlap of these photos, only the middle of each photo was clipped and used for analysis, thus reducing edge distortion dramatically. Vector files for the islands, thalweg and woody debris were created for the 1979 and 1998 images. In addition, outlines of all exclosures and perimeter fences were digitized from the 1998 photos. Summary statistics for the parameters of both years were then extracted from the ArcView database and used for comparison. Some of these parameters included length of streambank and thalweg, and island and stream area.

For the aerial photos from 1937, 1960, 1969 and 1982, that became available while the study was in progress, a similar procedure for geo-correction and digitizing was used, with a few exceptions. Due to the smaller scale of these images, it was not possible to recognize enough of the same features on the photos for comparison with the 79 and 98 images. Therefore, additional GPS points were collected in the field to serve as ground

control points for geo-correction. Table 2 shows the RMS error, pixel size and ground accuracy of all images used.

Table 2. RMS error, pixel size and ground accuracy of aerial photography of Catherine Creek. Ground accuracy equals pixel size times RMS error.

	Small scale				Large scale	
	1937	1960	1969	1982	1979	1998
Scale	1:21,000	1:14,300	1:19,400	1:18,300	1:3,100	1:4,000
RMS error	0.7317	0.8613	0.8687	0.9183	1.0509	1.5584
Pixel size (m)	0.78	0.40	0.78	0.72	0.10	0.10
Ground accuracy (m)	0.57	0.34	0.68	0.66	0.11	0.16

Due to the lower resolution, it was not possible to digitize the stream and island outlines accurately in the small-scale images. Hence, it was decided to digitize only the thalweg for these images, so that accuracy would not be compromised.

Relationship between streamflow and stream width

Since the objective was to compare stream channel outlines and width for different years, the decision of where the channel was digitized became very important. Aerial photos had been acquired on different dates in different years, and the relationship between discharge and changing water level had to be accounted for. Hence, wetted area of the stream was not used, since it would change the most as discharge changed. It was decided to attempt to digitize what was considered to be bankfull width. Bankfull is defined as the stage that “corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming of changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels” (Dunne and Leopold 1978). Bankfull refers to that location on the stream bank which characterizes the change between a state where a stream flows within its channel and the beginning of flooding stage, where the stream overflows its banks (Rosgen 1996). Bankfull measurement would be the most reliable tool for comparing changes.

Measurement of bankfull was also conducted in the field on 5 cross-sections of the stream, so that an accurate bankfull width and stream type could be determined. In addition, a longitudinal profile of several sections of the study area was done to determine stream slope (Rosgen 1996).

Change analysis for stream and island areas

The objective was to determine the amount of change that had occurred in the stream channel and islands from 1979 to 1998. In GIS analysis, it is common to use a cross-classification method for the comparison of the same features in two different years (Eastman and McKendry 1991). A cross-classification shows all possible combinations of the categories on the two maps. Images and cross-tabulation matrices were used to display the change analysis results for stream and islands.

Determination of stream width

To determine stream width for both years, the vector files of the left streambanks were converted to raster files, then a distance module was run in the GIS. This allowed measurement of the stream width every 0.5 m, resulting in 5070 width measurements along the 2,375 m long right streambank (numbers for 1998). If an island was present in the stream, the island width was eliminated from this measurement, so that only stream bank-to-bank width was calculated (Laliberte 2000).

Data Analysis

The results obtained for stream width, length of bank and thalweg represent a measurement of the whole population. No sampling was involved; therefore, there was no need to apply statistics to these results. Instead, the results of these parameters in exclosed and grazed areas were presented as such or as percent increase or decrease over 19 years.

Results and Discussion

Bankfull measurements

As a result of the field measurements, Catherine Creek was classified as a C3 type stream (Rosgen 1996). Measurements from 5 cross-sections are shown in Table 3.

Table 3. Morphological description of Catherine Creek from five cross-sectional measurements and values for a typical C type stream.

Headstake #	Bankfull Width (m)	Entrenchment Ratio	Width/depth Ratio	Sinuosity	Slope (%)
34	12.10	5.2	18.56		
35	15.10	4.1	33.33		
49a ¹	11.60	1.0	17.55	1.17	1.3
49b ¹	8.50	2.8	17.35		
59	15.35	3.0	33.66		
90	15.20	4.6	28.60		
Typical C		>2.2	>12	>1.2	0.1-2.0

¹cross-sections taken at a location where the channel flowed on either side of an island

All cross-sections, except 49a, indicated a C type stream. Cross-sections 49a and 49b were taken at a location where the stream flowed on either side of an island. The entrenchment ratio of 49a was lower than for the other cross-sections, and at this point, one side of the channel (49a) was classified as an F type. Sinuosity was calculated from the aerial photography for the whole study area, while the slope was determined in the field by measuring a longitudinal profile over a distance of 637 meters.

The field measurements were taken in October during low flow. It became apparent that in some short sections of the stream the channel was braided, with 3 to 4 different small channels. There was a large amount of mid-channel deposition of gravel and

cobbles with the channels flowing at different elevations. This caused the water to flow perpendicular to the main channel in some places, moving from the higher to the lower elevation. Although no measurements were taken in those areas, it was expected that these sections would have been classified as a D type channel, indicating braiding.

Rosgen (1996) described the progressive stages of a stream channel adjusting to changes in driving variables. These may include changes in sediment and flow regime, which in this case may be related to the large landslide that occurred in the watershed in the mid-70s. A C 4-type stream often progresses to a C 4 (bar 6), and then to a D 4 type. The difference between C 4 and C 3 is the channel material: cobbles for C 3, and gravel for C 4 type stream channels.

Field observations at the cross-sections 49, 35 and 34 (Table 3) and comparison with older aerial photos showed increased bar depositions and lowered sediment transport capability, resulting in larger islands and mid-channel bars in 1998 compared to 1979. It is possible that a progression from a C to a D type channel, as described in Rosgen (1996), is occurring in this portion of the stream. This section is located below the straight stream section, and it is assumed that the increased sediment load resulting from the mid-70s landslide was at least partly responsible for this aggradation.

In the future, we plan to develop a detailed 3-dimensional model of the stream channel, using a laser range finder and directional compass. These measurements will be repeated over the years to measure and possibly predict channel changes at a large scale.

Relationship between stream flow and stream width

Bankfull measurements conducted in the field showed that bankfull width had been underestimated somewhat from the aerial photos (Table 4). Due to time constraints, these field measurements were conducted after the GIS work had been completed, and no adjustments to the channel outline were done. Even in the field, it is not easy to determine bankfull, and it is common to underestimate bankfull width (Rosgen 1996). Two different observers may come up with slightly different locations for bankfull. It is even more difficult to estimate this location from an aerial photo. However, bankfull is a consistent morphological index for comparing the stream in 2 different years since it is the location of the flow with a recurrence interval of 1.5 years (Dunne and Leopold 1978). Ideally, the field measurements should have been done before digitizing the stream.

Table 4. Comparison of bankfull measurements taken in the field and from aerial photos on the computer screen.

Headstake #	Bankfull width	Bankfull width
	Field	On-screen
	(m)	(m)
34	12.10	11.60
35	15.10	12.50
49a	11.60	9.50
49b	8.50	7.50
59	15.35	13.00
90	15.20	13.50

Changes in water level could potentially change the placement of the stream channel while digitizing it. To get an idea of how accurate the digitization was done (in other words, unaffected by fluctuations in stream flow), the relationship between discharge and stream surface area was determined. If the channel had been outlined too close to the wetted width, a change in discharge would have resulted in a large change in surface area. If, however, the channel was digitized close to bankfull, then a change in discharge should not have changed the surface area very much. Table 5 shows the relationship between discharge and surface area.

Table 5. Discharge, surface area and surface area/thalweg of Catherine Creek for 3 different dates of aerial photography.

Date	Discharge ($\text{m}^3 \text{sec}^{-1}$)	Surface area (m^2)	Surface area/thalweg (m)
28 June 1979	5.66	50,962.53	21.99
16 June 1982	16.65	54,383.88	23.51
3 August 1998	1.27	49,520.93	20.38

Since the stream gauging station was discontinued in 1996, the discharge for 1998 was estimated by averaging all stream flow values for August 3 from 1978 to 1996. The resulting value ($1.27 \text{ m}^3 \text{ sec}^{-1}$) closely resembled discharge measurements for 14 days on either side from the date the aerial photo was taken in 1998. In 1982, Catherine Creek had an above average discharge. While the average mean flow was $3.32 \text{ m}^3 \text{ sec}^{-1}$ (1979-1995), the peak flow for that year was recorded at $18.29 \text{ m}^3 \text{ sec}^{-1}$ (on 25 May 1982). This means that the aerial photo of 1982 was taken close to peak flow, which would give a reference point for bankfull width. The numbers in Table 5 show that a 3-fold increase in flow from 1979 to 1982 resulted in only a 6.7 % increase in surface area, while a 4.4 fold decrease in discharge from 1979 to 1998 resulted in a 2.8 % decrease in surface area. This small change in surface area caused by a large change in discharge means that the stream was able to absorb that increase by becoming deeper, and not much wider. Only a small amount of the width change would have occurred due to changes in discharge and water level. Therefore, observed changes in stream width were attributed to actual change in the stream channel as opposed to changes due to higher or lower discharge.

Change analysis for stream and island areas

The results of the change analysis for the stream and islands are shown in Table 6. This cross-tabulation matrix shows the areas of change and no change occurring from 1979 to 1998. It can be seen that the 1979 stream area was 5.07 ha, compared to 4.93 ha in 1998, representing a 2.76 % decrease in stream area. Areas of change include 1.74 ha (1979 land to 1998 stream) and 1.88 ha (1979 stream to 1998 land), for a total of 3.62 ha of change. The area of 1979 stream that remained stream in 1998 is 3.19 ha (no change). This shows that the area of change is nearly the same as that of the area of no change. The size of the area of land in 1979 that remained land in 1998 (37.82 ha) is large, since

Table 6. Cross-tabulation matrix of land and stream areas (in ha) for 1979 and 1998 at Catherine Creek. Bold numbers along the diagonal represent areas of change, off-diagonal cells represent areas of no change.

		1979		
		Land	Stream	Total
		(ha)		
1998	Land	37.82	1.88	39.70
	Stream	1.74	3.19	4.93
	Total	39.56	5.07	44.63

the whole study area is included. Although this represents an area of no change, our interest lies in the change detection within the stream channel boundaries.

The cross-tabulation image (Figure 3) shows areas of change colored blue (stream to land) and green (land to stream), while the stream channel area experiencing no change (stream to stream) is colored red. The processes of erosion and deposition can be seen clearly from this image; the stream erodes bank material in 1 area and deposits it downstream. The green area in the center of the study area shows how the outside of the stream meander is pushed outward, increasing the stream's sinuosity. In the lower right of the image in the upstream portion of the stream, large changes are visible. This is an area of the stream with several larger islands that have undergone changes, or where the stream channel changed from one side of an island to another.

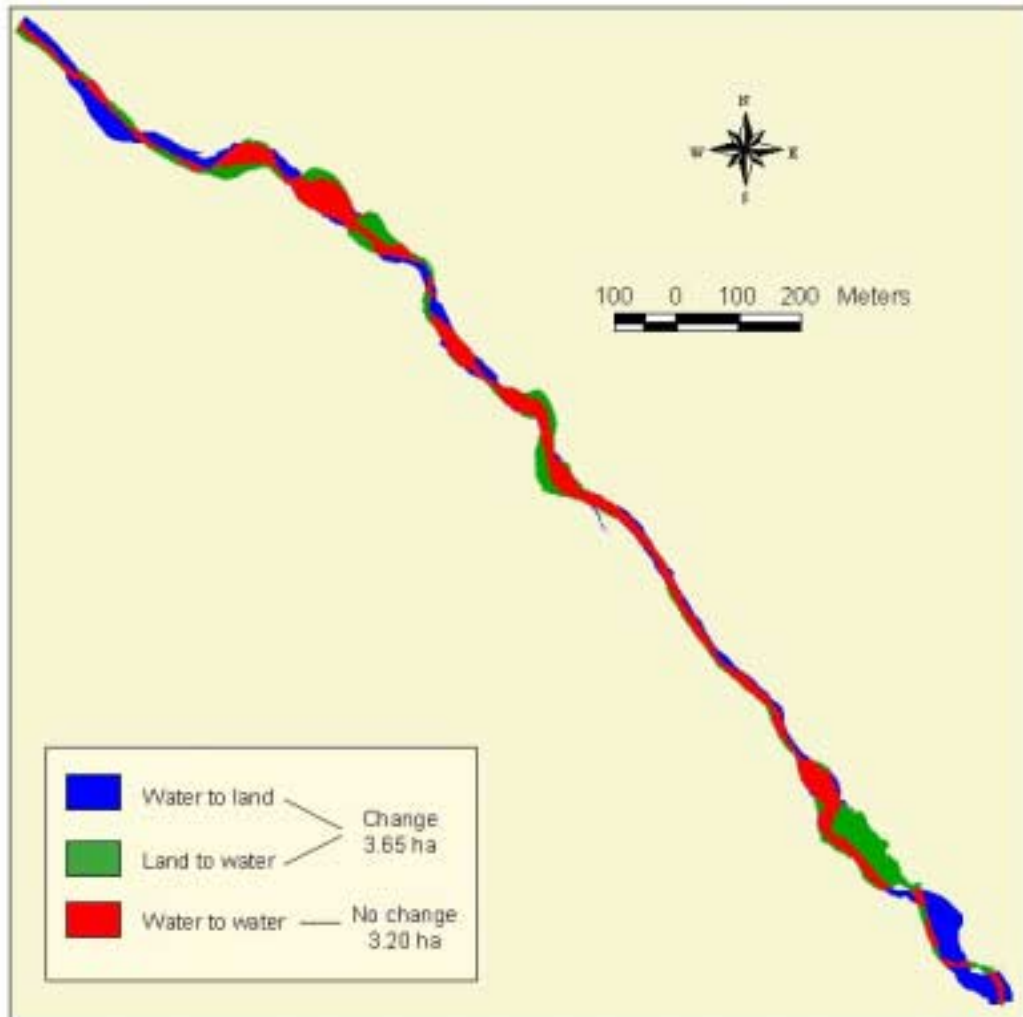
Changes in the islands were also analyzed with cross-classification (Table 7). The interest was in determining how much of the island area of 1979 had remained the same within the stream channel, and how much had changed. Areas of change included areas

Table 7. Cross-tabulation matrix of island and 'not island' areas for 1979 and 1998 at Catherine Creek. The bold numbers represent areas of change, off-diagonal cells represent areas of no change. 'Not island' includes those areas that were not classified as island in either 1979 or 1998 and were left blank.

		1979		
		Not island	Island	Total
		(ha)		
1998	Not island		0.71	
	Island	1.55	0.45	2.00
	Total		1.16	

of stream and land outside the stream channel moving to island and vice versa (islands moving to stream or land). Due to the nature of the cross-classification, areas being compared were island areas in 1979 and 1998, but the stream channel was not included. Hence, the area of 'not island' was left blank, since it consisted of the stream channel and the entire background of the image.

Fig. 3. Changes in the stream channel from 1979 to 1998



In this case, island area increased from 1.16 ha in 1979 to 2 ha in 1998, an increase of 72 %. The area of no change (0.45 ha) is very small compared to the areas of change (2.26 ha). The cross-tabulation image (Fig. 4) shows areas of change in red and areas of no change in blue. It becomes obvious how much change occurred in island area. The nature of this change is further explained by the summary statistics derived from GIS layers and shown in Table 8.

Table 8. Comparison of various measurements of Catherine Creek features from 1979 and 1998. Numbers were extracted from a GIS database.

Parameter	1979	1998	Change (%)
Length of left bank ¹ (m)	2,500.89	2,544.64	1.75
Length of right bank (m)	2,400.79	2,374.96	-1.08
Stream perimeter (m)	4,956.23	4,948.18	-0.16
Stream area (m ²)	50,962.53	49,520.93	-2.83
Wetted area ²	39,352.97	29,563.01	-24.88
Island area (m ²)	11,609.56	19,957.92	71.91
Mean	232.19	867.74	273.72
Max	2,148.86	5,962.06	177.45
Min	6.94	6.36	-8.36
Island perimeter (m)	3,113.38	2,853.87	-8.34
Mean	62.27	124.09	99.28
Max	250.52	470.06	87.63
Min	10.07	10.44	-2.43

¹ Left bank looking upstream

² Wetted area = stream area minus island area

While the total island area increased from 1979 to 1998 from 1.16 ha to 2 ha, the number of islands decreased from 50 to 23. Mean island perimeter increased from 62 m to 124 m, while minimum perimeter remained the same. Similar change was observed for mean island area, which increased dramatically (from 232 m² to 868 m²), while minimum island area remained relatively the same.

These numbers indicate that although fewer islands occurred in 1998, they were much larger than they had been in 1979. This is obvious from studying the images, which also show more vegetation occurring on the islands. Observations of the images showed that what was a small island in 1979 had grown to a much larger, densely vegetated island in 1998. Figure 5 shows one such area. It appears that the small island began to capture sediments carried by the stream, and the island gradually grew in size by increasing this sediment capture, coupled with vegetation that was able to take hold on the island. Aerial photos from the years between 1979 and 1998 confirmed the gradual growth of this island.

Fewer, larger and more vegetated islands suggest an increase in stability occurring over the 19 years. The original increase in deposition may be related to the mid-70s landslide that resulted in large amounts of sediment being deposited over the years.

Fig. 4. Changes in the islands from 1979 to 1998

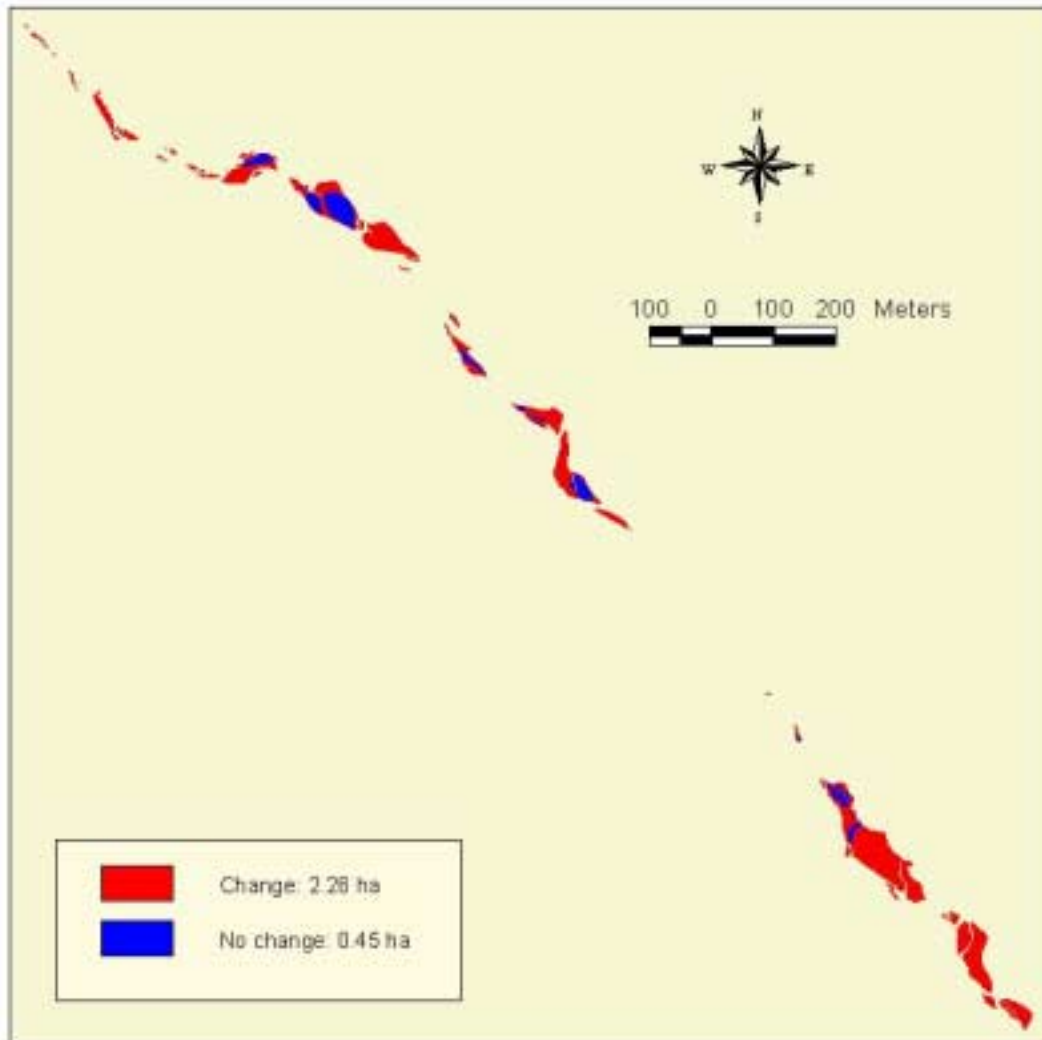
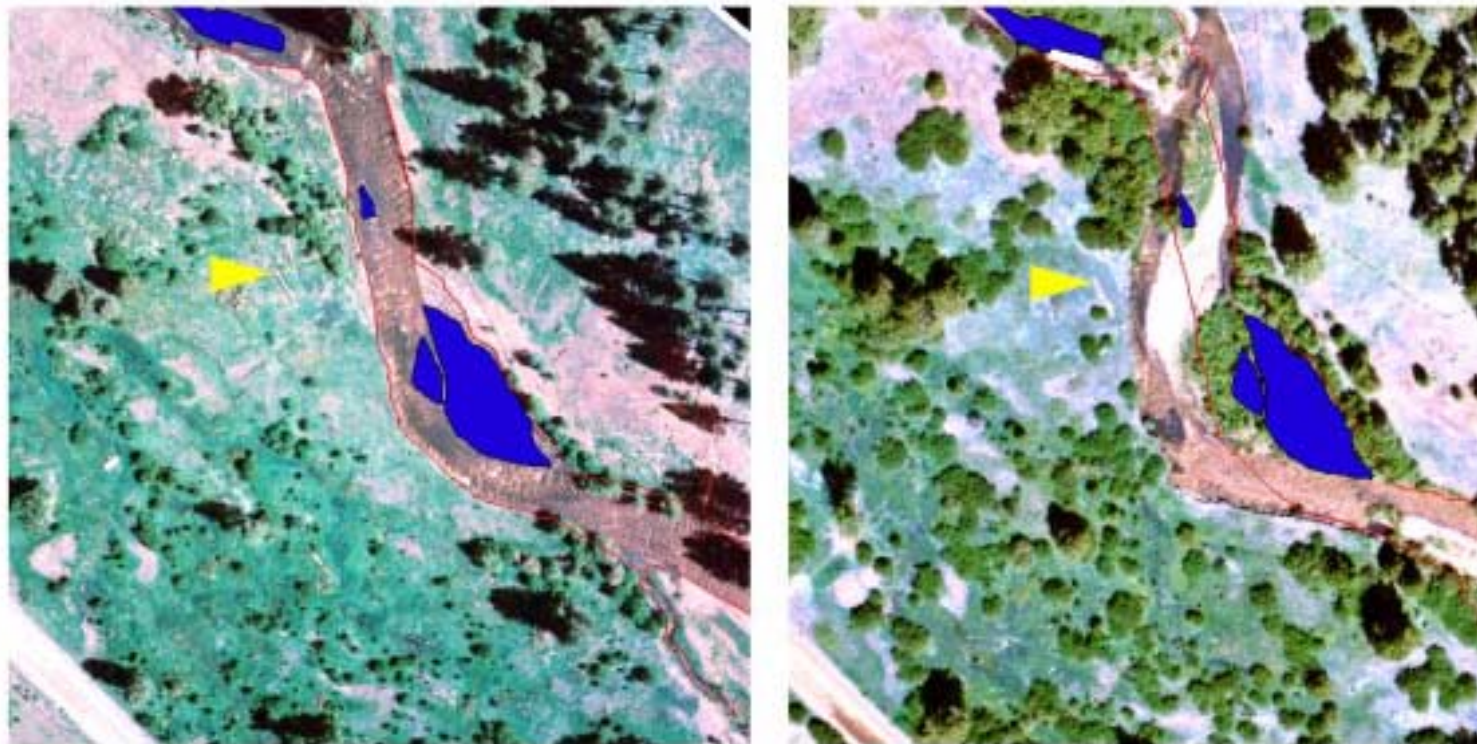
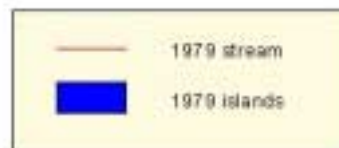


Fig. 5. Stream morphology changes from 1979 to 1998. Arrows indicate the same log in both images



1979 image with 1979 overlays

30 0 30 60 Meters



1998 image with 1979 overlays



Other stream statistics

The length of right and left stream bank changed very little from 1979 to 1998, increasing 1.75 % from 2500 m to 2544 m for the left bank, and decreasing 1.08 % from 2400 m to 2375 m for the right bank (Table 8). Likewise, the stream perimeter remained almost the same (decrease of 0.16 %). The larger change in the wetted area (-24.88 %) can be explained by the changes observed in the islands. Although the stream area did not change much, the increase in island area within the channel reduced the size of the area actually covered by water.

In some areas, lateral movement of the channel was as much as 20 m, independent of island area change (Fig 5). In this particular location the stream eroded the outside of the meander, cutting into the bank and depositing the material downstream. We observed deposition at downstream meanders and islands.

Another parameter of interest was length of thalweg and change in sinuosity, which is the ratio of stream length to valley length. Thalweg length was measured for both small and large-scale images; this allowed for a comparison of thalweg length and sinuosity over a period of 61 years. Figures 6 and 7 show how these parameters changed over time.

The graph illustrates variability in thalweg length, with the highest value occurring in 1998; however, the increase from the lowest to highest value is relatively small: an increase of 6.3 % from 2287 m (1960) to 2430 m (1998). Likewise, an increase in sinuosity from 1.099 to 1.168 is not large. Rosgen (1996) uses sinuosity as one of his level II inventory criteria for determining stream type. Sinuosity carries the least weight of these criteria. However, a general guideline for high sinuosity in a C type stream is >1.2 ; very high sinuosity in an E type stream is >1.5 . In those calculations, sinuosity ratios can vary by ± 0.2 units. Rosgen's (1996) work implies that the sinuosity change we observed is within normal range for C type streams.

The location of woody debris was digitized from the 1979 and 1998 images, but due to increased vegetation near the stream bank in the 1998 images, it was difficult to see the portion of the woody debris covered by bankside shrubs. It was concluded that although woody debris larger than 20 cm in diameter was clearly visible and could be digitized, the concealment by overhanging vegetation prevented an accurate measurement of its size. Therefore, woody debris size was not analyzed.

Determination of stream width

Stream width decreased in all exclosed and all grazed areas from 1979 to 1998 (Fig. 8). Values for stream widths are displayed in Table 9. Mean stream width in exclosed (E) sites decreased 36 % from 18.67 m to 11.85 m, compared to a 22 % width decrease in grazed areas (G) from 16.62 m to 12.96 m.

This decrease in stream width had to be studied in conjunction with the change in island area. Since the stream width was calculated by excluding all islands, thereby measuring only wetted width, the decrease in stream width was related to the change in island area. In fact, when one looks at the overlay of island and stream outlines of both years, the large influence of the islands on stream width measurement becomes obvious. However, it is not easy to discern a pattern at a larger scale, such as for grazed or exclosed sites. In one area (E3, Fig. 9), a relatively large width decrease occurred

Fig. 6. Changes in the Catherine Creek thalweg from 1937 to 1998

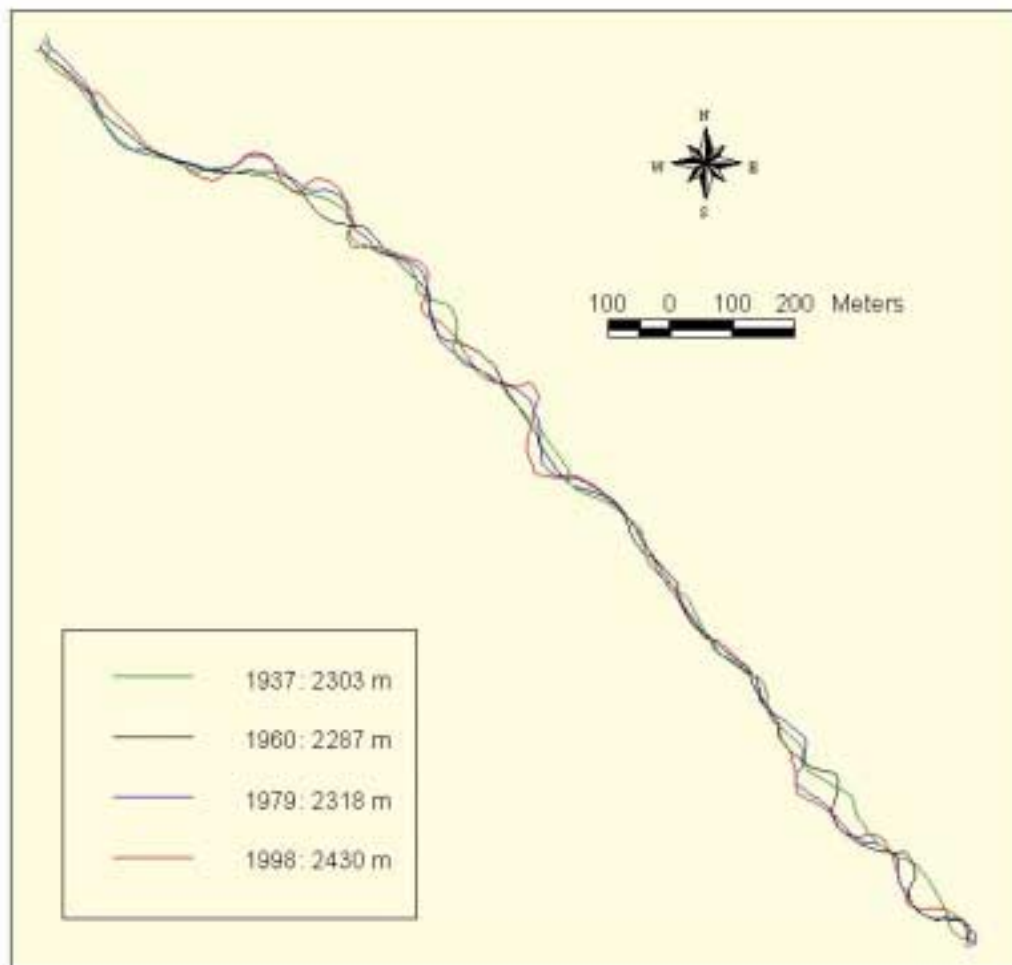


Fig. 7. Changes in stream length and sinuosity of Catherine Creek over 61 years

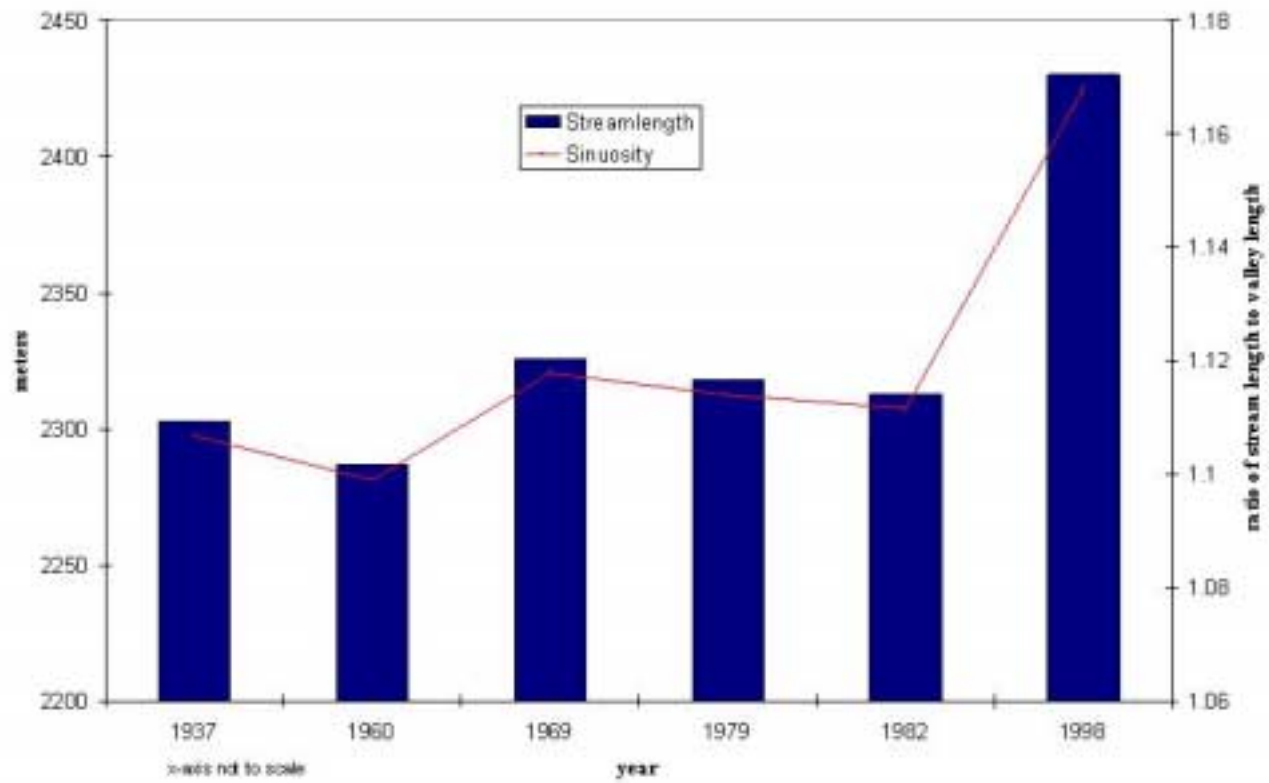


Fig. 8. Mean stream width and standard deviation (in m)
in exclosures (E) and grazed areas (G) in 1979 and 1998

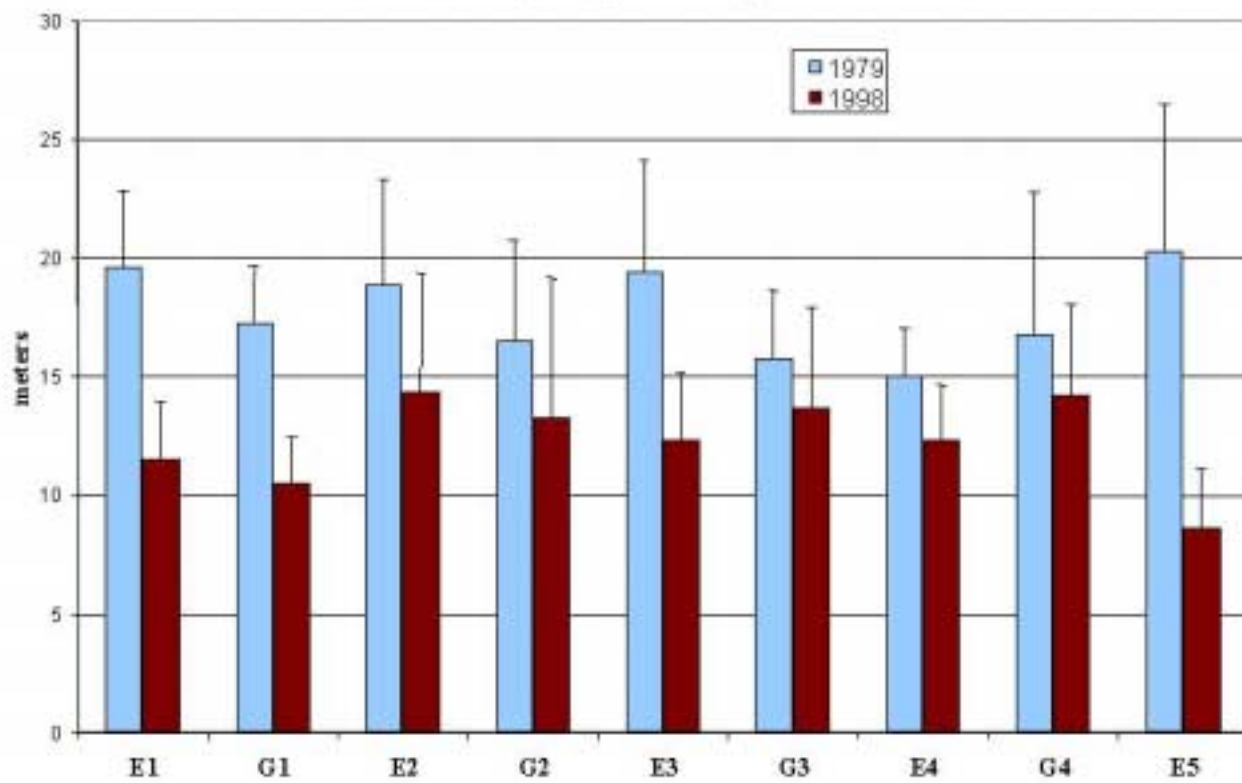


Fig. 9. Changes in stream and islands in enclosure E3 and grazed area G3 from 1979 to 1998

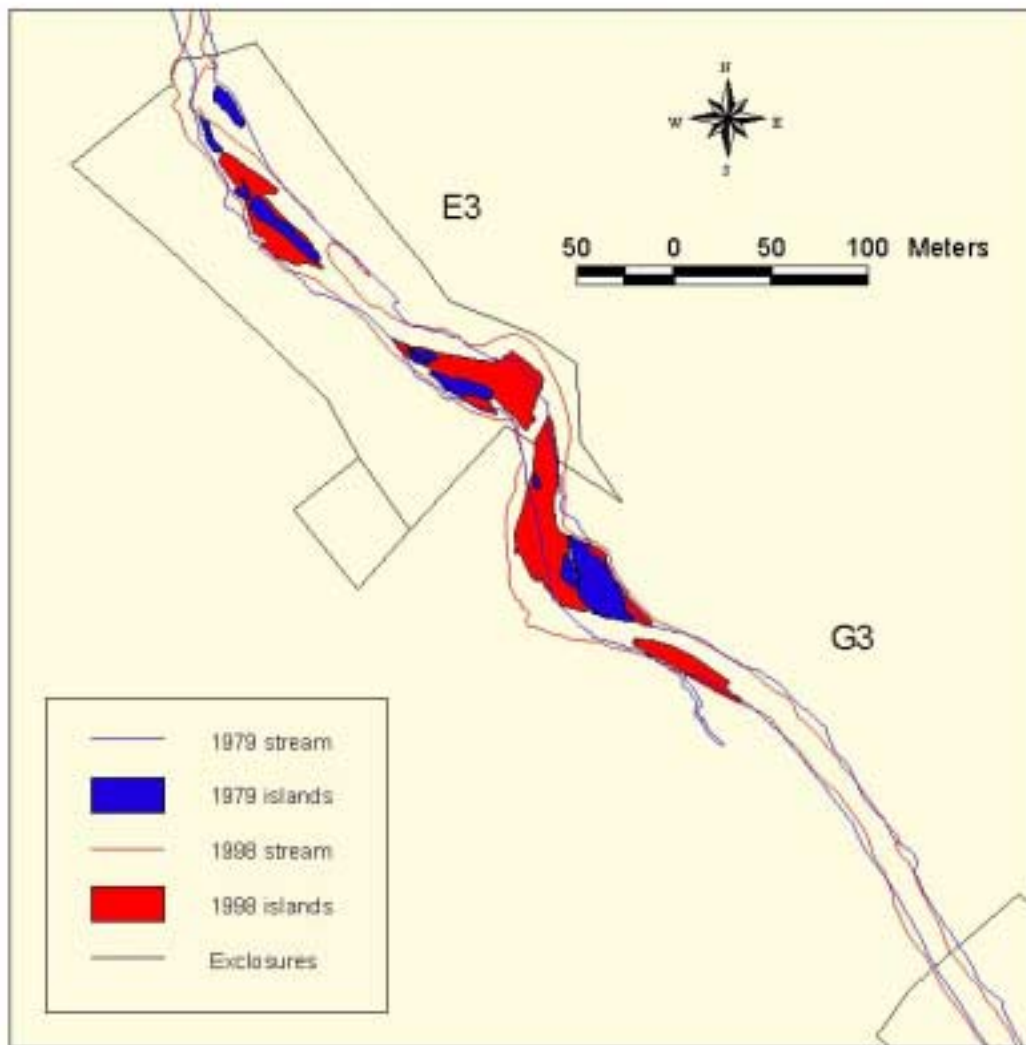


Table 9. Catherine Creek mean stream widths excluding islands for 1979 and 1998 in exclosures (E) and grazed areas (G). Stream width was measured every 0.5 m.

	1979	1998	Change
	(m)	(m)	(%)
E1	19.64	11.53	-41.29
E2	18.91	14.36	-24.06
E3	19.43	12.33	-36.54
E4	15.04	12.38	-17.69
E5	20.35	8.65	-57.49
G1	17.30	10.56	-38.96
G2	16.54	13.32	-19.47
G3	15.82	13.68	-13.35
G4	16.83	14.26	-15.27
Mean E	18.67	11.85	-36.54
Mean G	16.62	12.96	-22.06

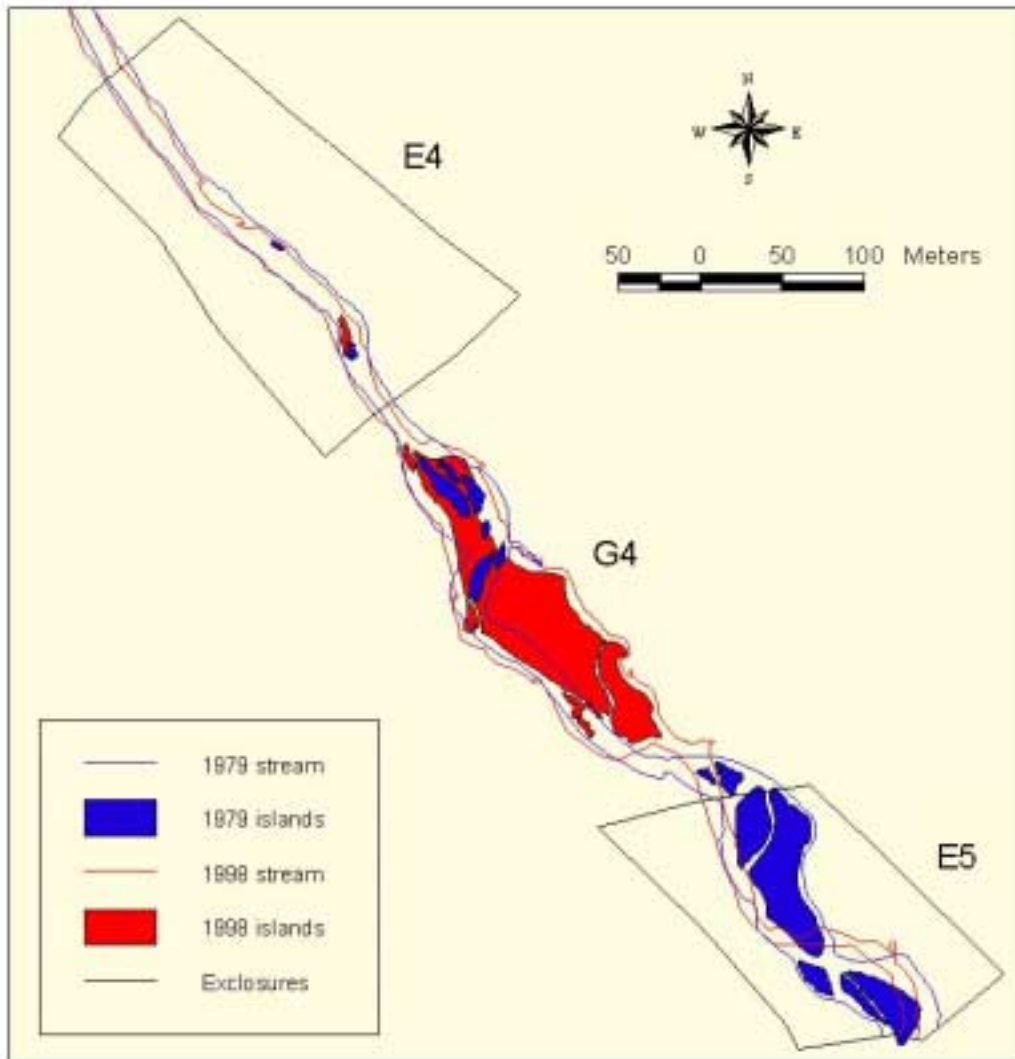
concurrent with a large change in island area, while in E4 (Fig. 10), a small change in width and a small change in island area occurred together.

On the other hand, the site of smallest change in stream width (G3) appears to have areas of little change, where the stream has remained straight, as well as areas of large increase in island area. The site G4 shows large changes in island area; however, these changes did not affect stream width to a high degree since the channel split on either side of the island. In the area of largest stream width decrease (E5), there was also a large decrease in island area, causing the stream to become narrower. In E1, the stream tried to erode its banks near the road and was straightened by the Highway Department in 1990. This would account for the stream width decrease in that area.

These results show that over the whole length of the stream, one could observe an increase in island area and a narrowing of the channel, but locally (such as in E5), a decrease in island area was observed concurrently with narrowing of the channel in that section. This demonstrates the importance of scale when studying time change in a stream system. What occurs in one small area does not reflect the response for 2.5 km of study area. The response of one exclosure did not reflect the response of all others. Since islands straddle fence lines in exclosed and grazed areas, the interaction of island change and stream width is difficult to interpret within these boundaries, and the assessment of the whole study area seems more appropriate for island change and its effect on stream width.

The stream width was highly affected by island morphology: if a stream section had a large island in the channel, with water flowing on either side, the stream width was narrower than it would have been without an island in that location. There was a large difference between a section of stream with one channel and another section where it flowed on either side of an island. Stream width as well as width to depth ratio are affected by these changes in stream morphology. When a stream becomes narrower, it

Fig. 10. Changes in stream and islands in enclosure E4 and E5 and grazed area G4 from 1979 to 1998



also deepens. The narrowing of Catherine Creek, coupled with increased vegetation on islands and stream bank, demonstrates a trend towards increased stability for this stream.

We did not find large differences between grazed and exclosed areas. Results of others comparing grazed and exclosed sites vary widely, from no differences to significant differences. Magilligan and McDowell (1997) studied 4 eastern Oregon streams for their responses to the removal of cattle grazing. In all 4 areas, cattle grazing had not occurred for at least 10 years. The authors found significant changes between grazed and ungrazed reaches, such as increased pool areas and channel narrowing in the exclosures. These changes were mostly attributed to increased vegetation and, therefore, increased channel roughness following removal of cattle grazing. However, the authors also determined that local effects, such as considerable flow reduction in the summer and particle size, influenced the magnitude of channel adjustments.

Other authors reported no differences between exclosures and grazed sites. Medina and Martin (1988) observed channel width and depth increases in both exclosed and grazed areas in their study in southwestern New Mexico. The changes were attributed to a previous wildfire and hydrological processes of stream equilibrium. Kondolf (1993) measured cross-sections in exclosed and grazed areas in California and observed no significant differences between the 2 treatments. He concluded that this could possibly be attributed to a lag in adjustment of the stream channel after livestock had been exclosed for 24 years from the site.

At Catherine Creek, it appears that the topography, stream dynamics and the road have a larger impact on stream morphology than the grazing regime. The influence of local topography on channel morphology was also observed by Clifton (1989) in a central Oregon study relating vegetation and land use to channel morphology over a 50-year period. The author determined that temporal variability was related to exclusion of grazing, while spatial variability (between different stream reaches) was due to the prevailing riparian vegetation, input of large organic debris and local physiography. Specifically, channel width, wetted perimeter and channel shape were mostly correlated with local vegetation variability (Clifton 1989).

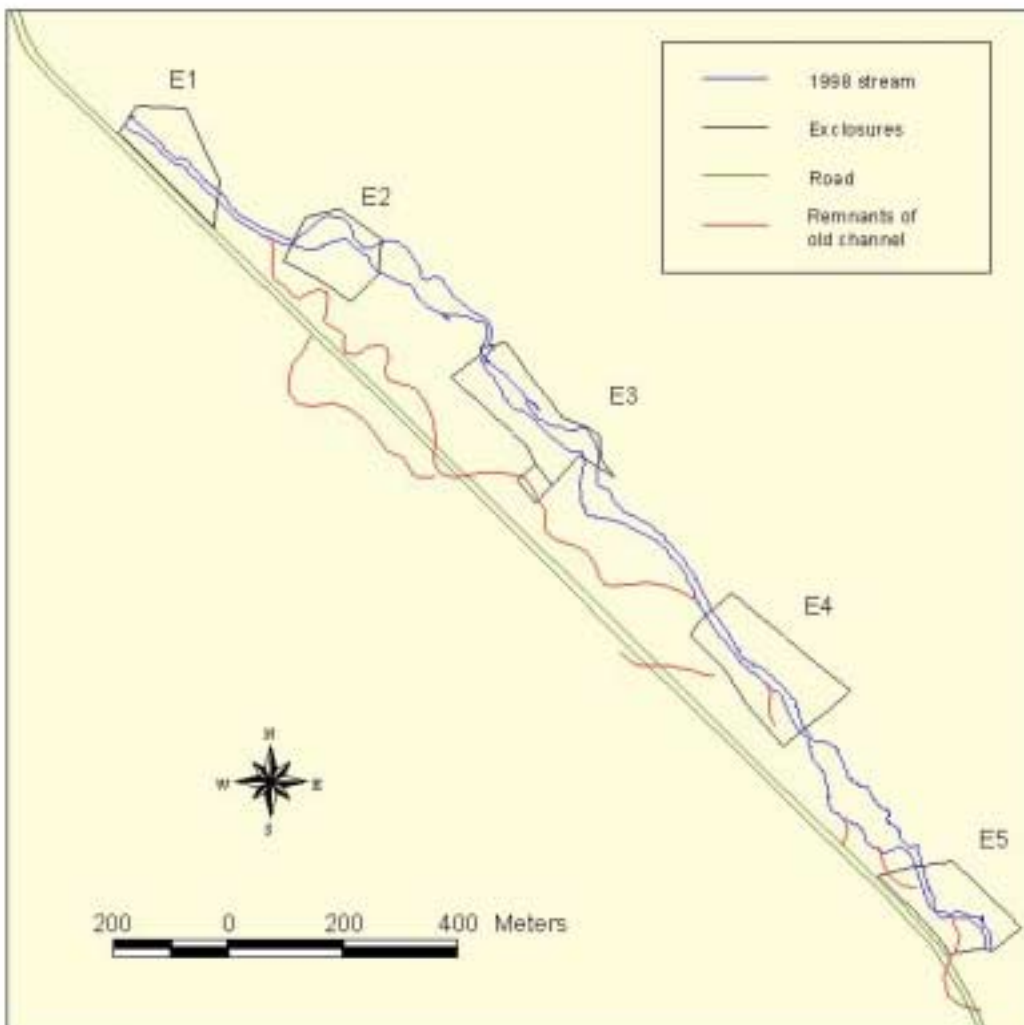
In streams bordered by trees, the input of large woody debris plays a considerable role in channel change. Large logs in the stream divert the flow of water and become sources of deposition and pools; bank erosion may be reduced or enhanced locally, and stream energy is dissipated (Keller and Swanson 1979). We observed similar channel changes in aerial photography from 1990, although those images had not been scanned and digitally analyzed at the same fine resolution of this study. A large Ponderosa pine tree fell in the stream in 1990, and in the photos of the following years, the diversion of water flow could be observed, leading to a knickpoint that moved downstream over the following years.

The impact of the road also has to be taken into consideration. In the 1937 aerial photo, the road is visible in the same location as it is today. Visits to the local museum in the town of Union confirmed that the hot springs upstream from the study area were a popular destination at the turn of the century. It is, therefore, assumed that the road has been in the same location for a long time. There is also evidence that the stream was moved to one side of the valley, possibly to accommodate the road. Old meanders visible on the aerial photography cross the road in several places. Large, old cottonwoods still remain near these meanders and are additional indicators of old stream channels. The

remnants of these old channels were digitized from the images and overlaid on the map of the study area (Fig. 11). Before Catherine creek enters enclosure E 5, at the southeast corner of the study area, the stream encounters the road and makes a sharp turn from flowing west to north-northwest. Rip-rap has been placed there by the highway department to reduce erosion. If the road were not present, the stream would continue on its westerly course, flowing in the old channel visible from the aerial photo.

For these reasons, it has to be assumed that the stream was moved over to accommodate the road and actions were taken over the years to reduce erosion at the point where road and stream met at a sharp angle. Further downstream, the road prevented the stream from flowing through its old channel, and the stream had to adjust to the lower sinuosity. This increased bank erosion, bar deposition and channel aggradation. The channel changes observed in portions of the stream may be the result of the stream's attempt to deal with these changes.

Fig. 11. Study area in 1998 with overlay of old stream channel



Conclusions

Over the 19-year time period from 1979 to 1998, a variety of changes in stream morphology have taken place at the Catherine Creek study area. Some measured parameters changed to a large degree, others did not, and the observations can be categorized into those of small or large change. Parameters of small change included: length of thalweg, left and right streambank, sinuosity, stream perimeter and stream area (including islands). Parameters of larger change were: island area, island number, stream width and wetted area (excluding islands).

Although the stream area itself changed little, the results from the cross-classification showed that the area of change was almost equal to the area of no change, in terms of water changing to land, vice versa or remaining the same. It appears that at a small scale (i.e. the whole study area) the stream remains largely where it has been since 1979. On a larger scale, however, localized changes become visible. These include lateral movement of the stream bank or the increase in amplitude of some meanders, although this did not result in increased sinuosity. The topography of the area and the road prevent a large increase in sinuosity. Any large change observed seemed to be connected with the islands: their area increase or decrease affected the wetted area and, therefore, the stream width.

Several signs of increased stability have become apparent in this area over the time period studied. The decrease in island number and increase in island area, coupled with increased vegetation on the islands, demonstrates this trend. Narrowing of a stream is usually associated with greater stream depth and better fish habitat, although the lack of stream depth data for 1979 prevents us from making any detailed conclusions about changing stream depth.

Stream width decreased in grazed and exclosed area, but was smaller in grazed sites. However, the reason for width decrease was tied to the island changes, and it was observed that both an island area increase and decrease could result in a narrower stream.

The lack of distinct responses for grazed or exclosed areas suggests that the topography, stream dynamics (erosion, deposition and especially island formation) and the road have a larger impact on stream morphology than the grazing regime in this particular system.

Catherine Creek is confined by steep hills on one side and a road on the other. This is especially true in the upper 1/3 of the study area. In the lower portion (E1), the stream tried to erode its banks near the road and was straightened by the Highway Department. Rip-rap was added at the upper end near E 5. If allowed to run its course without the road, the stream would have had more meanders and increased sinuosity. Today, areas for sinuosity increase or change in meanders appear to be limited due to topography and the road.

The use of remote sensing, GIS/GPS and ground truthing provided a definite advantage over only ground data collection. Many of the statistics are quickly extracted from the GIS database for analysis. Other parameters would be difficult or nearly impossible to attain without these techniques. For example, a cross-classification is valuable in time change analysis since it yields areas that have changed from land to water and vice versa. Without the GIS, it would have been time consuming to produce. The ability to overlay many features and measure distances on-screen is helpful in

analyzing change. The visual aspect of GIS allows the user to perceive changes where they may not be obvious otherwise. Not many time change analysis studies have been done at such a large scale (1:4000), but this project demonstrates that it can be done successfully.

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