Regeneration of Plains and Narrowleaf Cottonwood on South Boulder Creek, Boulder, Colorado

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ABSTRACT

The structure and function of many riparian forests in the arid and semi-arid western U.S. have been influenced by human activities. Channelization, water impoundment and diversion, groundwater pumping and livestock grazing are among the most serious impacts. This study examined changes in cottonwood forest abundance and stream channel position, quantified cottonwood seed germination on alluvial surfaces, and evaluated the contribution of asexual vs. sexual reproduction of plains cottonwood and narrowleaf cottonwood on South Boulder Creek.

Analysis of historic aerial photographs showed a decline in forest abundance between 1937 and 1955, part of which can be explained by extensive channelization and the resultant changes in hydrogeomorphic functions. Recovery to 1937 coverage had occurred by 1995.

Vegetation sampling revealed that the riparian forest is dominated by small narrowleaf cottonwoods. Plains cottonwoods occur at low densities and are mostly larger, older trees. Seedling recruitment was confined to a few alluvial bars that were at mid-elevations in the channel and were not continuously inundated by 1996 summer flows. The limited extent of channel meanders and associated point bars at these elevations limited sexual reproduction and seedling recruitment into the system. Asexual reproduction in the form of root suckering was common in narrowleaf cottonwoods but was not observed in plains cottonwoods. Thus, the dominant form of cottonwood recruitment observed on South Boulder Creek is clonal reproduction of narrowleaf cottonwoods.

Management efforts should be directed toward developing and maintaining conditions that will promote vegetative as well as sexual reproduction of riparian cottonwoods and several suggestions are provided.

INTRODUCTION

Riparian ecosystems in arid and semi-arid regions of western North America provide numerous ecological and societal values (Brinson et al. 1980, 1981, Knopf 1985, Lowrance et al. 1985, McArthur and Marzolf 1987, Ohmart et al. 1988, Brinson 1990, Brown and Daniel 1991, Snyder and Miller 1992, NRC 1995) largely because they are associated with scarce surface water and in many cases they support the only trees in otherwise treeless landscapes. These forests are comprised primarily of members of the *Salicaceae* family including cottonwoods and poplars (*Populus* spp.) and willows (*Salix* spp.).

Riparian forests have been subjected to a variety of land use practices which have had negative ecological consequences. Dam construction and the diversion of water for agricultural and municipal uses have resulted in dramatic alterations to the physical processes of many western rivers and streams. Where dams have been constructed upstream from meandering stream reaches, lateral migration of the channel and the deposition of moist, bare sediment has been reduced or eliminated (Bradley and Smith 1986, Johnson 1992, Friedman et al. 1995). Because cottonwood seeds require these conditions for germination, sexual reproduction has been greatly reduced or eliminated (Johnson et al. 1976, Scott et al. 1995). In addition, water diversions can lead to alluvial ground water declines and reduce water availability to riparian trees resulting in drought stress, reduced growth and increased mortality (Rood and Mahoney 1990, Stromberg and Patten 1991, Tyree et al. 1994). In extreme cases, forest decline can be abrupt and ultimately can lead to nearly complete loss of trees (Rood and Heinze-Milne 1989, Snyder and Miller 1992).

Channelization of streams and rivers has been used extensively to convey floods, drain riverine wetlands and allow greater use of floodplains in general. This practice affects nearly all hydrogeomorphic processes as well as many biotic communities (Hupp 1992). Channelization directly removes vegetation, increases stream gradient and can lower the alluvial ground water table to levels beyond which riparian trees are rooted. The likelihood of channel meandering and over-bank flooding are also decreased when streams are channelized.

Recent studies of riparian ecosystems have focused on the effects of flow alterations on seedling recruitment (Auble et al. in press, Baker 1990, Mahoney and Rood 1991, Scott et al. 1993, Segelquist et al. 1993 Stromberg et al. 1991, 1993). These studies assume a model of riparian tree ecology driven by sexual reproduction and seedling establishment on moist sediment recently deposited from high stream flows. This model has been suggested for Boulder Creek (Friedman et al. 1995) and other streams and rivers in the arid west (Bradley and Smith 1986, Snyder and Miller 1991, Johnson 1992). However, cottonwoods can also reproduce asexually through suckering (the emergence of new shoots from preexisting parental roots and shoots).

The ability of cottonwoods to reproduce clonally varies between species. Plains cottonwood has been reported reproducing asexually on an island in the Chippewa River in Wisconsin (Barnes 1985) along the Missouri River in North Dakota (Wilson 1970) and when grown in greenhouses (Schier and Campbell 1976). However, root suckering of plains cottonwood rarely occurred along the Little Missouri River in North Dakota (Everitt 1968) and Rood et al. (1994) noted that while clonal reproduction was common in balsam poplar (*Populus balsamifera*), narrowleaf cottonwood and interspecific hybrids, plains cottonwood did not propagate through root suckering. Suckering of narrowleaf cottonwood was also common along the Belly and St. Mary Rivers in southwestern Alberta (Shaw 1976, 1991).

The relative contribution of sexual versus asexual reproduction in riparian cottonwood forests in the arid western U.S. is poorly studied, especially among different species. However, Rood and Mahoney (1993) suggested that asexual recruitment in the form of suckering and coppicing is extensive and may even be the dominant form of reproduction in some systems (see Krasney et al. 1988, Irvine and West 1979). In addition, Shaw (1976) proposed that forest replenishment could be achieved through suckering even without seedling recruitment. It may be particularly important along high gradient mountain front rivers with low sediment waters and coarse substrates such as South Boulder Creek. If clonal reproduction is an important component of riparian forest maintenance, management efforts should be directed towards encouraging asexual as well as sexual recruitment.

OBJECTIVES

The objectives of this study were to (1) document long-term changes in cottonwood forest abundance and channel position through analysis of historic aerial photographs of South Boulder Creek, (2) examine cottonwood germination and seedling survival on alluvial bars and (3) examine the contribution of asexual reproduction of plains and narrow leaf cottonwoods to forest succession and maintenance.

STUDY AREA

South Boulder Creek originates along the Continental Divide in the Indian Peaks of the Southern Rocky Mountains. For approximately 40 km it flows through the Colorado Front Range before entering the Boulder Valley through Eldorado Canyon. From Eldorado Springs, it flows northeast for 15km to its confluence with Boulder Creek east of the City of Boulder (Figure 1). South Boulder Creek drains a 324 km^2 watershed and contributes approximately 40 percent of the flow of the Boulder Creek Basin.

Like most other snowmelt dominated systems in the arid and semi-arid west, peak discharges occur in late May or June (Scott et al. 1993, Figure 2). Peak discharges and flooding can also occur as a result of intense summer thunderstorms. The Colorado State Engineer has operated a gauging station 7 km upstream of the study area at Eldorado Springs nearly continuously since 1896. A flood with a ten year recurrence interval occurred on 18 June 1995 with a peak average daily discharge of 21.5 m^3/s. A peak average daily discharge of 12.5 occurred on 21 May 1996 and represented a flood with a 2.3 year recurrence interval.

South Boulder Creek is typical of many western North American streams that have been affected by water development and other land use practices. Its hydrologic regime has been altered by numerous diversion ditches and storage facilities that exist along much of its length. Constructed in the mid 1950's, Gross Reservoir is located on the mainstem of the stream 18 km above the study area and is operated by the Denver Water Board. Average daily peak flows have been reduced by 20 percent since the dam began operation in 1954 (Figure 2).

The Farmer's Reservoir and Irrigation Company (FRICO), currently the largest single water user, diverts water via the Community Ditch for agricultural and municipal use and for filling Marshall Reservoir. The Cities of Louisville and Lafayette obtain all of their municipal water from the stream. The City of Boulder and Public Service Company of Colorado also own surface water rights to South Boulder Creek. These withdrawals reduce June flows by as much as 75 percent between the Eldorado Springs gauge and South Boulder Road (Hydrosphere 1994, Figure 3).

The study area is on City of Boulder Open Space property along South Boulder Creek from north of the town of Marshall to Baseline Road (ca. 39°58'N, 105°14'W, Figure 4). The elevation ranges from 1650 m at the south end of the study area to 1610 m at the north end creating a relatively constant gradient of 0.009 m/m. The riparian area is managed for its natural values as well as for passive recreation and historic agricultural practices. A natural surface trail parallels the stream and is one of the heaviest used trails within the Open Space system receiving ca. 250,000 visitors per year. Cattle grazing occurs from late fall to early spring and hay is cut during the summer. Largely because the land surrounding South Boulder Creek is owned by the

City of Boulder and managed as open space, it is one of the last remaining streams in the Boulder area that is not channelized or developed.

The dominant trees in the study area are narrowleaf cottonwood *(Populus angustifolia*), plains cottonwood *(Populus deltoides* subsp. *monilifera)* and the interspecific hybrid of these two species, *Populus x acuminata,* which was identified by leaf form (Eckenwalder 1984, Weber 1990). Alder (*Alnus incana* subsp. *tenuifolia*), crack willow (*Salix fragilis*), Russian olive (*Elaeagnus angustifolia*), green ash (*Fraxinus pennsylvanica*), and box elder (*Negundo aceroides* subsp. *interius*) are also present. The dominant shrub along the stream is coyote willow (*Salix exigua*). Plant species nomenclature follows Weber (1990).

The study area lies within the Colorado Piedmont section of the Great Plains Physiographic Province (Madole 1991). The climate is continental with cold winters and warm summers. Mean annual precipitation is approximately 47 cm (Colorado Climate Center 1992). Niwot Series soils predominate on the low terraces and bottoms along the stream where they formed in loamy alluvium (Moreland and Moreland 1975). These soils are shallow and overlie unconsolidated cobble, gravel and sand. Bedrock is shallow and consists of 2438 m thick Pierre Shale.

METHODS

Aerial Photograph Analysis

A time series of aerial photographs of the study site were used to document the extent of cottonwood forests along South Boulder Creek and examine changes in forest abundance and channel location through time. Photographs from 1937, 1955, 1974 and 1995 were analyzed with a stereo facet plotter (OMI, Rome, Italy) by tracing the outline of cottonwood stands and the centerline of the stream channel onto equally scaled based maps (Rood et al. 1994). Total area of cottonwood forest was digitized and calculated for each year using AutoCad (Autodesk, 1993) and change in forest area was calculated relative to 1937 coverage. The position of the stream channel was also determined from each years' photos and a chronology of channel movement was prepared.

Seedling Establishment

During field visits in the summer and fall of 1995, twenty-four alluvial bars were noted on the inside of meander bends (point bars) or parallel to the channel (lateral bars). Most bars were small (25-50 m^2), devoid of vegetation and composed of gravel and cobble intermixed with coarse sand. All bars were inundated by discharges of 21.5 m^3/s, the peak average daily discharge of 1995.

Bars were periodically surveyed for cottonwood seedlings from mid-June through September, 1996. When encountered, seedlings were counted in randomly placed 1m² plots. One meander bar had extensive coverage of seedlings and two plots, one on the inside of the meander bar and one on the outside, were used here. Shallow monitoring wells were installed in the center of each of these two plots. On bars where only a few scattered seedlings occurred but random placement of a plot frame did not sample the seedlings, their presence was recorded along with notes on where they occurred. General notes on location of seedlings on the bar and any associated vegetation were also recorded. Shading was visually estimated on a scalar from 1 (full sun) to 5 (full shade). Particle size of bar substrate was estimated using a modified Wentworth scale (Gordon et al. 1992). Shallow PVC or steel monitoring wells were installed on seven bars that were exposed in mid-May and depth to the water table was measured approximately once every two weeks.

To help determine if the quantity or timing of seed dispersal limits seedling establishment, seed traps were placed along the creek through the study area. Each trap consisted of a 10cm square piece of plywood nailed to a wooden stake 30 cm above the ground. The plywood surface of each trap was coated with Tanglefoot® adhesive paste to capture seeds as they dispersed. Seed traps were placed in the field before cottonwood capsules began to open in early June and seeds were counted periodically until late July when seed dispersal had ended.

<u>VEGETATION</u>

To characterize the woody vegetation of South Boulder Creek, 22 - 20 m by 20 m plots were established haphazardly in cottonwood stands along the creek. All trees and shrubs in each plot were recorded by species and the diameter of cottonwoods was measured one meter above ground. Trees were grouped into five size classes: saplings, <2.54 cm (1 in.) in diameter; small trees, 2.55-7.62 cm (1-3 in.); medium trees, 7.63-15.24 cm (3-6 in.); large trees, 15.25-30.48 cm (6-12 in.); and very large trees, >30.49 cm (>12 in.).

In three stands with high densities of small cottonwoods, tree roots were traced to determine whether trees were reproducing asexually. Root suckers were identified by their connection to other stems via shallow, lateral roots and by the absence of a vertical tap root. Roots were traced by gently unearthing the shallow lateral roots which were typically within 10 cm of the ground surface and following the root from stem to stem. Roots were reburied immediately after being exposed to prevent damage to the roots or tree mortality. Diagrams were produced to show root and stem distribution, and connectivity between trees.

RESULTS AND DISCUSSION

AERIAL PHOTOGRAPH ANALYSIS

In 1937, the riparian cottonwood forest through the study area covered 132 ha (Figure 5). By 1955, it had been reduced by 57 percent to 57.5 ha. An increase in forested area occurred from 1955 to 1974 and by 1995, recovery to 1937 levels had occurred.

South Boulder Creek occupied a sinuous channel in 1937 (Figure 6) and bare sediment was visible on the inside of many of the meander bends in the photographs. In 1955, extensive channel modification took place from above the South Boulder Canyon Ditch headgate to south of U.S. 36. The channel was relocated east of its previous position and straightened, and a lateral dike was constructed on the west side of the channel for much of this length. Access roads, equipment staging areas and bare ground are visible on the west side of the creek in the 1955 photographs. Channel straightening also occurred several hundred meters south of Baseline Road. Channel position has not changed appreciably since 1955 with the exception of a small meander forming approximately 100 m below the Shearer Ditch headgate.

It is likely that flood attenuation and reduction of peak flows due to the operation of Gross Reservoir has limited channel migration since 1955, although a direct causal relationship was beyond the scope of this study. Other studies, however, show meandering rates decrease as a result of reduced peak flow. Johnson (1992) found river meandering rates decreased substantially following damming of the Missouri River in North Dakota. Bradley and Smith (1984) reported a decrease in meander rates from 1.8 to 0.4 m/year below Fresno Dam on the Milk River, Alberta.

Some of the decline in forest abundance from 1937 to 1955 can be attributed to direct removal of trees during channelization. Channelization also increases stream gradient and can lead to downcutting and subsequent lowering of the water table (Hupp 1992). Water table decline has been demonstrated to affect adult cottonwood survival. Scott et al. (in press) found a gravel mining induced ground water decline of approximately 2 m caused from 15 to 75 percent mortality of cottonwoods on Coal Creek in Jefferson County after two years. In an experimental study on the effects of ground water pumping on cottonwoods along the South Platte River near Denver, Cooper and D'Amico (in press) related a ground water decline of 0.5 m to stem and leaf death and cavitation in plains cottonwoods. Channelization also reduces the formation of bare moist sites suitable for seedling establishment by at least temporarily eliminating channel meandering.

SEEDLING ESTABLISHMENT

Data from seed traps demonstrate that seed dispersal is occurring throughout the study area (Table 1). Several sites showed low seed densities which can be attributed to the stochastic nature of wind dispersal and the individual placement of traps. Although only one seed was caught on Trap #2, it represents a density of 100 seeds per square meter. Cottonwood seeds are also dispersed by water (Engstrom 1948, Everitt 1968, Johnson 1994) as they are carried downstream and deposited along the shoreline. Using seed traps to capture airborne seeds does not provide information on waterborne dispersal, which may be an important form of dispersal.

Seed trap data also indicate dispersal of cottonwood seeds on South Boulder Creek occurs throughout the month of June and into early July (Table 1). The highest density of seeds was recorded on 8 June and seed dispersal had ended by 15 July. This is similar to the 1 June to 10 July dispersal period reported by Bradley and Smith (1986) on the Milk River in southern Alberta and northern Montana. It also corresponds to when Shafroth et al. (1995) collected seeds of plains cottonwood in Larimer County, Colorado. On Boulder Creek, Friedman et al. (1995) recorded a slightly earlier seed rain occurring from late May to early June.

Despite widespread and abundant seedfall, cottonwood seedlings did not occur on 16 of the 24 bars surveyed (Table 2). Most of these bars are located low in the channel and are nearly continuously inundated except during low flows which typically begin in late summer and continue through April. For example, bar 15 is flooded until late July (Well 5, Figure 7), long after seeds have ceased dispersing. Seeds of cottonwoods are dispersed over several weeks in early summer and remain viable for only 1-2 weeks (Moss 1938, Fenner et al.1985, Scott et al. 1993) in which time they must come into contact with suitable germination sites. On South Boulder Creek, this occurs from early June to July. Thus, these bars are not amenable to cottonwood establishment because they are not exposed during seed dispersal.

Several other factors make these bars ill-suited for cottonwood growth. First, because they are low in the channel, these surfaces are subject to intense energy from high flows and ice scouring, both of which can uproot young seedlings (Bradley and Smith 1986, Rood et al. 1994). Second, the soils are saturated for much of the growing season and anaerobic soil conditions likely occur. While cottonwood trees are facultative wetland species, they are intolerant of the reducing conditions in anaerobic soil (Hosner 1960, Segelquist et al. 1993, Auble et al. 1994).

Bars which did not support cottonwoods but had at least part of their surfaces exposed during seed dispersal were densely shaded by alder, coyote willow or prairie cordgrass (*Spartina pectinata*). Several bars also had dense litter covering the bare sediment. Both of these conditions have been shown to be deleterious to cottonwood seed germination (Walker et al. 1986, Friedman et al. 1995).

Other bars which did not support cottonwoods or had only a few scattered individuals had a deep water table during seed dispersal. For example, wells 3, 4, 6, 7 and 8 on bars 23, 21, 13, 11, and 10, respectively, had water tables 0.44 m to 0.63 m deep from 8 June to 4 July (Figure 7). Given the coarse soil texture of the bars, lack of adequate soil moisture is likely the predominant reason seeds failed to germinate at these sites. Coarse sand, gravel and cobble have limited capillarity and water holding capacity (Klute 1986) and may not hold adequate moisture to allow seeds to germinate or grow past the cotyledon stage if not in contact with the water table. Moisture for seed germination is typically provided by high spring and early summer flows which saturate the coarse alluvium. As flow recedes and the water table drops, seedling roots follow the declining water table to obtain water (Scott et al. 1993). Seedling mortality due to lack of sufficient soil moisture and desiccation has been demonstrated in other studies (Mahoney and Rood 1991, Segelquist et al. 1993).

The seedlings on bars with deep water tables were located along the water line during low flows in July and August. For example, the 16 seedlings on bar 10 were arranged in a linear row several centimeters above and parallel to stream flow. These seedlings will be exposed to the scouring of spring flows next year and will likely suffer high mortality (Auble et al. In press). The lack of seedlings from the previous year's flood supports this assumption. Seedlings were most common on point bars on the inside of meanders and less common on lateral bars in straight stream sections.

Bar 24 was the only bar where extensive seedling establishment took place. Plot 1 is located on the inside of the bar and was inundated by the peak discharge of 21.5 m^3/s in 1995 but was not flooded in 1996 (Figure 8). Plot 2 was flooded in both years. In late July, 1996, Plots 1 and 2 contained 80 and 365 seedlings of the year, respectively (Table 3). By 24 September, 13 seedlings of the year remained in plot 1 while 49 remained in plot 2. Seedlings of the previous year also occurred in July in plots 1 and 2 at densities of 105/m^2 and 10/m^2 , respectively. When the plots were resurveyed on 24 September, 82 remained in plot 1 and 10 remained in plot 2.

In both plots, more than 80 percent of the new seedlings died between July and August (Table 3). This is consistent with the reported reproductive strategy of cottonwoods whereby a large number of small, short lived seeds are dispersed into a heterogeneous environment and only a small percentage survive and grow.

In general, many of the alluvial bars studied along South Boulder Creek do not provide appropriate conditions for cottonwood seedling establishment. Suitable germination sites are moist, free of vegetation and exposed to full sunlight (Read 1958, Shopmeyer 1974, Hupp 1992). While many of the bars on South Boulder Creek satisfy these conditions, they do not occur during seed dispersal in early summer.

VEGETATION

The most abundant tree species in the study area is narrowleaf cottonwood (Figure 9). Plains cottonwood is the next most common species followed by alder, which is found only along the stream bank or on low bars with high water tables. Low densities of crack willow, peach-leaf willow, cottonwood hybrids and box elder were also recorded. Russian olives are uncommon possibly due to Open Space management efforts to eradicate this species from their properties.

Most plains cottonwoods were greater than 30.48 cm (12 in.) dbh (Figure 10). Many appeared very old and had diameters greater than 75 cm. No plains cottonwoods in the 2.54 cm (1 in.) size class were observed in any of the plots.

In contrast, most narrowleaf cottonwoods were in the first two size classes and measured less than 7.62 cm (3 in.) in diameter (Figure 11). Only four narrowleaf cottonwood trees greater than 30.48 cm (12 in.) were recorded.

In three stands with high densities of narrowleaf cottonwoods less than 7.62 cm (3 in.) in diameter, roots were excavated to determine the extent of clonal reproduction of this species. All stems had shallow, horizontal roots, most of which could be directly traced to other stems (Figure 12). No vertical (tap) roots were observed coming from the small stems. However, larger trees could have tap roots which would suggest they are non-clonal and germinated from seed (Rood et al. 1994).

Plains cottonwoods did not appear to clonally reproduce. Evidence of this was deduced from the lack of high densities of small stems. Trees in the 2.54 - 7.62 size class were not found in high densities to suggest interconnection among stems. It is possible that the larger trees are or were once connected. However, if this were true, it would suggest that although clonal reproduction occurred in the past, it no longer occurs. Also, where tree roots were exposed along the creek banks due to high flows or bank sloughing, plains cottonwoods did not exhibit stem sprouting from these roots while narrowleaf cottonwood did.

Twenty-two plains cottonwoods between 2.54 and 15.24 cm (1-6 in.) diameter were recorded on Bar 24. Recent beaver cutting was evident on nearly all of these small trees and based on the presence of older beaver cut stumps and multi-stemmed trees, herbivory by beaver had occurred in the past. Coppicing (i.e., shoot production from decapitated trees) represents shoot regrowth rather than the production of new shoots and does not result in lateral spreading of stems. Although the occurrence of this form of asexual reproduction was confined to plains cottonwoods on this bar only, it also contributes to the population structure of the cottonwood forest.

Asexual reproduction in the form of root suckering is currently and may have historically been an important form of reproduction and riparian forest maintenance along South Boulder Creek. This study shows that it occurs almost exclusively in narrowleaf cottonwoods. Sexual reproduction was documented for plains cottonwoods, but it was limited by the lack of suitable germination surfaces. Although a direct causal relationship was not demonstrated, a combination of channelization and hydrologic alterations with corresponding reductions in channel meander are likely to be the primary causes. Sexual reproduction was likely more prevalent prior to these impacts.

Plains cottonwoods reach their distributional limit at mountain front streams (McGregor and Barkley 1977) and may never have been the most abundant *Populus* species along South Boulder Creek. In contrast, narrowleaf cottonwoods are a significant component of this system due to their ability to clonally reproduce and because of their preference for high gradient, higher elevation, course substrate streams.

MANAGEMENT RECOMMENDATIONS

Management efforts should be directed at developing and maintaining conditions that will promote vegetative as well as sexual reproduction of riparian cottonwoods. This will allow both plains cottonwood and narrowleaf cottonwood to regenerate and contribute to the forest structure along South Boulder Creek. Several recommendations are outlined below.

1. Develop a water management plan that encourages high early summer flows which promote channel meandering, transport and deposit sediment in low energy areas and provide sites suitable for cottonwood establishment and long-term forest maintenance. Although instream flows studies and stream enhancement projects have addressed habitat for non-native trout on South Boulder Creek, these strategies typically emphasize channel stabilization and minimum winter base flows. Purchasing or transferring water rights to ensure adequate flows should be considered. The City should also work towards developing public/private and intergovernmental agreements to achieve this goal.

2. Continue current irrigation practices in the meadows adjacent to the creek. Maintenance of flood irrigation in the floodplain meadows likely ameliorates some of the effects of water diversions that remove water from the stream and transport it out of the basin. Flood irrigation helps to maintain a high water table (D'Amico 1995) and

reduces water stress and possible tree mortality.

3. Restore channel meanders by removing lateral dikes and installing engineered structures (i.e., wing deflectors, boulders) to deflect flow and initiate lateral channel movement. This would eventually create point bars on the inside of meander bends where seedling establishment could occur. This would be most appropriate between the South Boulder Canyon Ditch headgate and U.S. 36 where extensive channelization has occurred in the past. The benefits of this type of restoration would likely not be evident for a decade or more but would continue without continuous effort indefinitely.

4. Examine the effects of grazing on cottonwood reproduction. Cattle browse and trample seedlings and small trees (Hanson et al. 1988, Krueper 1995). Although rotational grazing is practiced along South Boulder Creek, its long- and short term effects on riparian trees is poorly understood. Grazing exclosures should be erected and monitored yearly to determine the influence on the plant communities in the riparian area. Control plots should also be established for experimental control.

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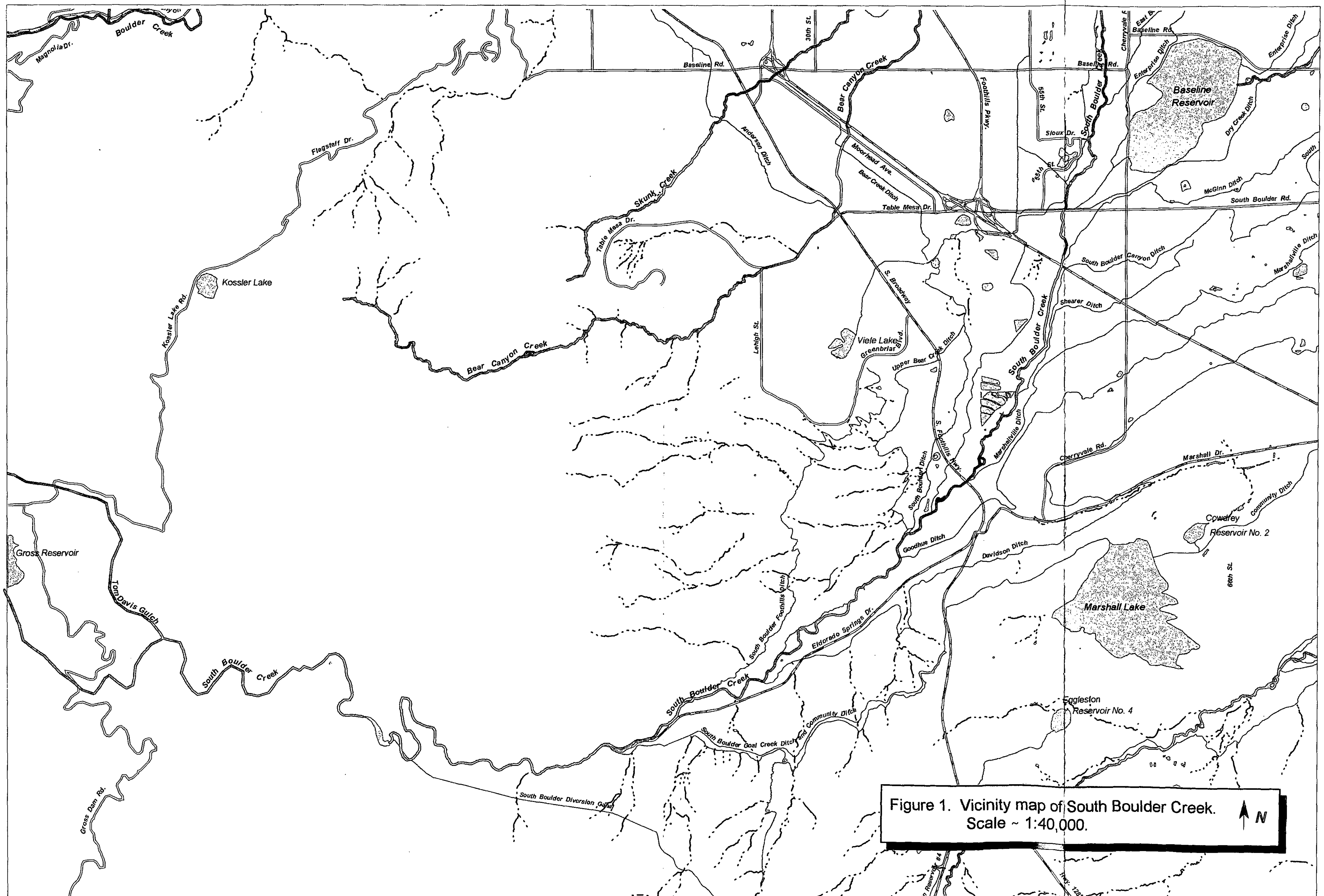

Figure 1. Vicinity map of South Boulder Creek.
Scale ~ 1:40,000.

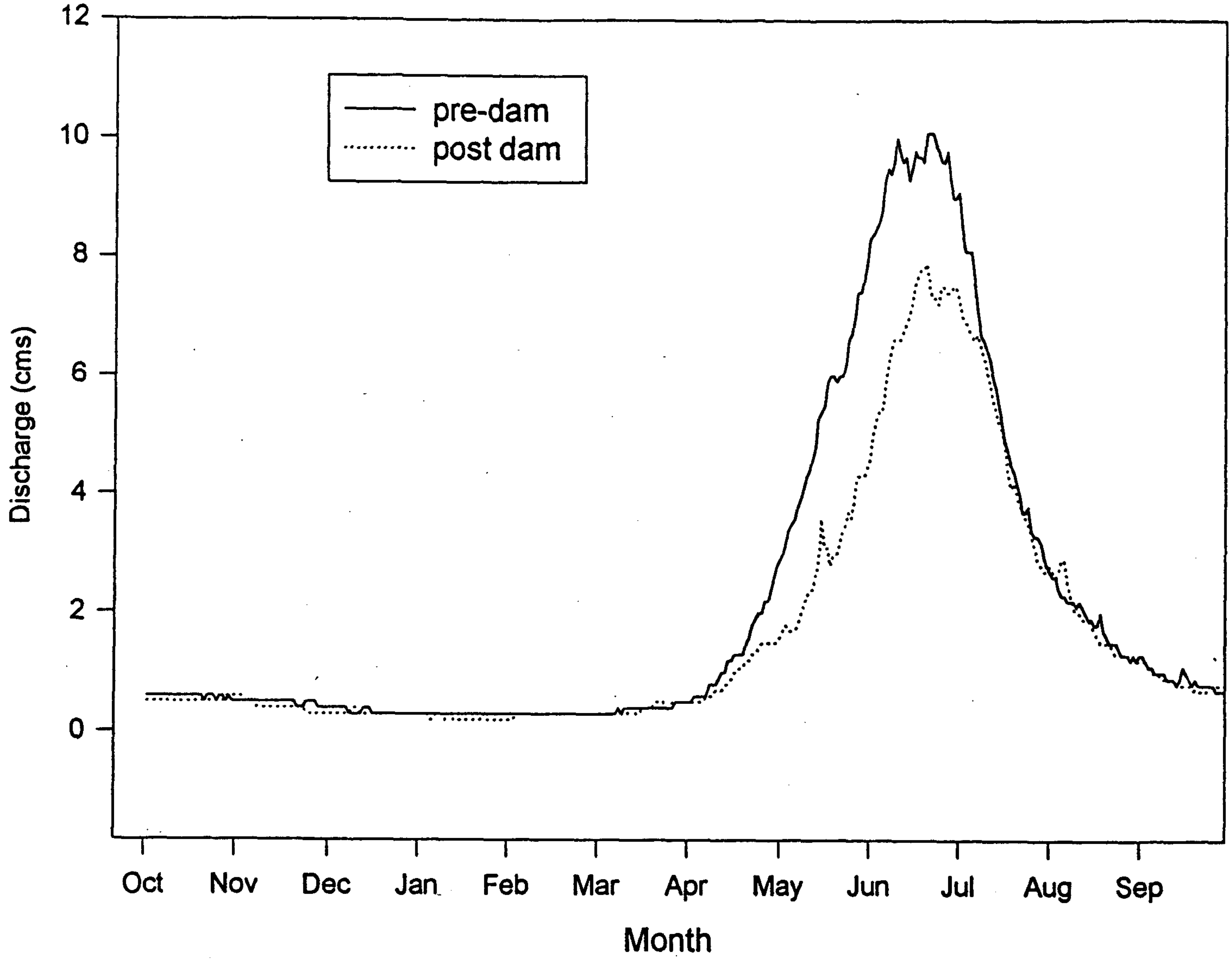

Figure 2. Average daily flows on South Boulder Creek at Eldorado Springs before and after Gross Reservoir began operation. Pre-dam is 1897-1953. Post-dam is 1954-1995.

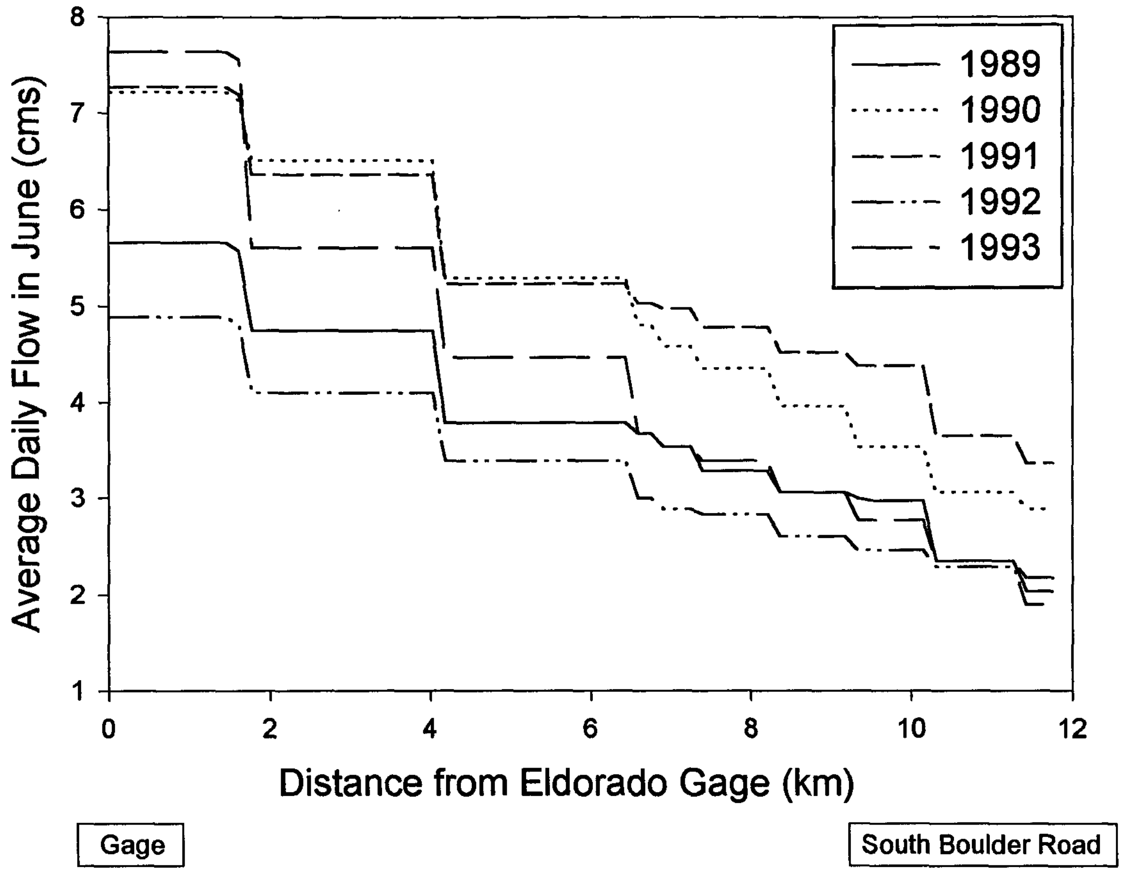

Figure 3. Flow depletions caused by numerous diversions from South Boulder Creek from the Eldorado Gage to South Boulder Road. June flows from 1989 to 1993 are shown. (After Hydrosphere, 1994, with permission).

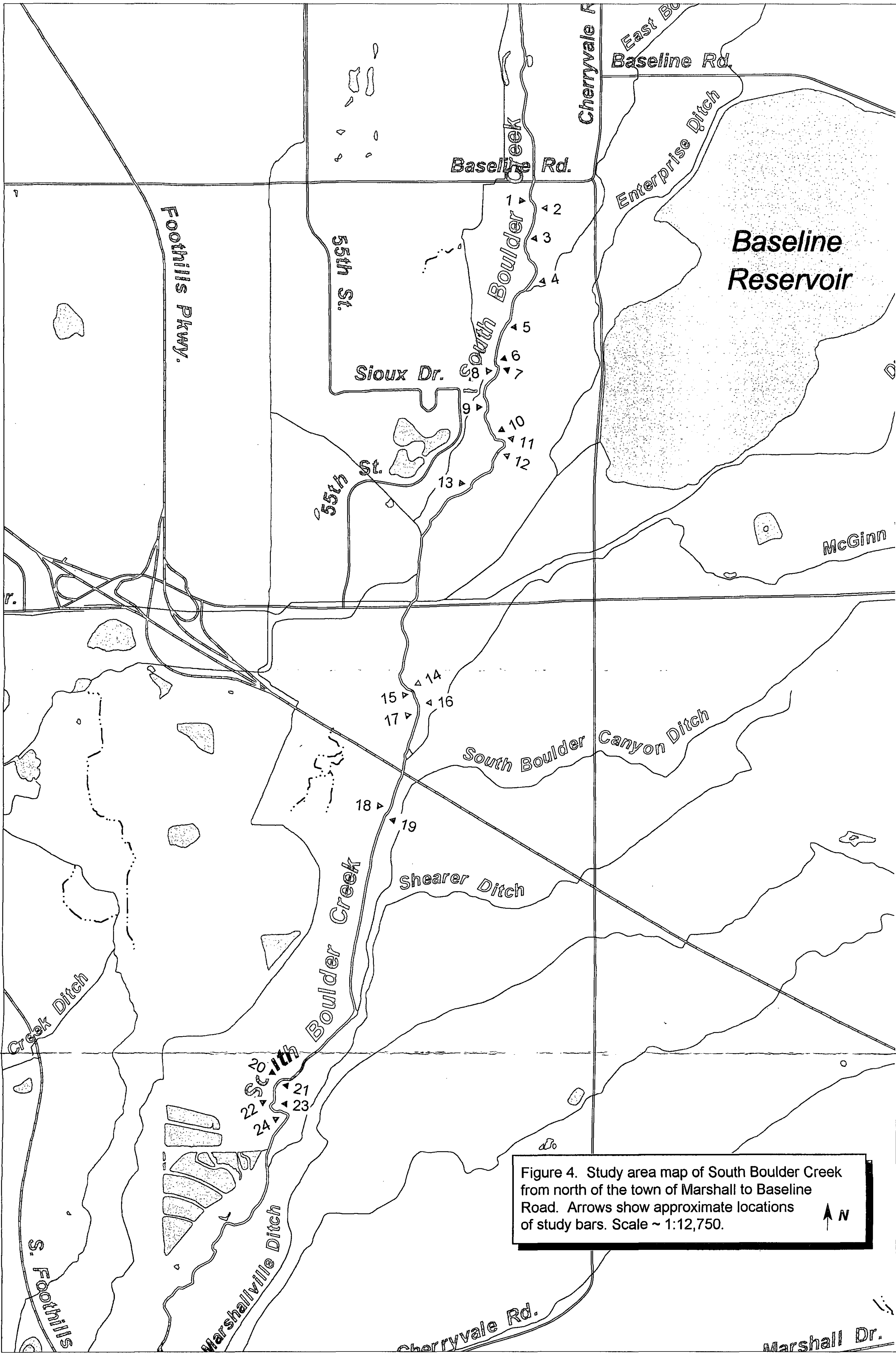

Figure 4. Study area map of South Boulder Creek from north of the town of Marshall to Baseline Road. Arrows show approximate locations of study bars. Scale ~ 1:12,750.

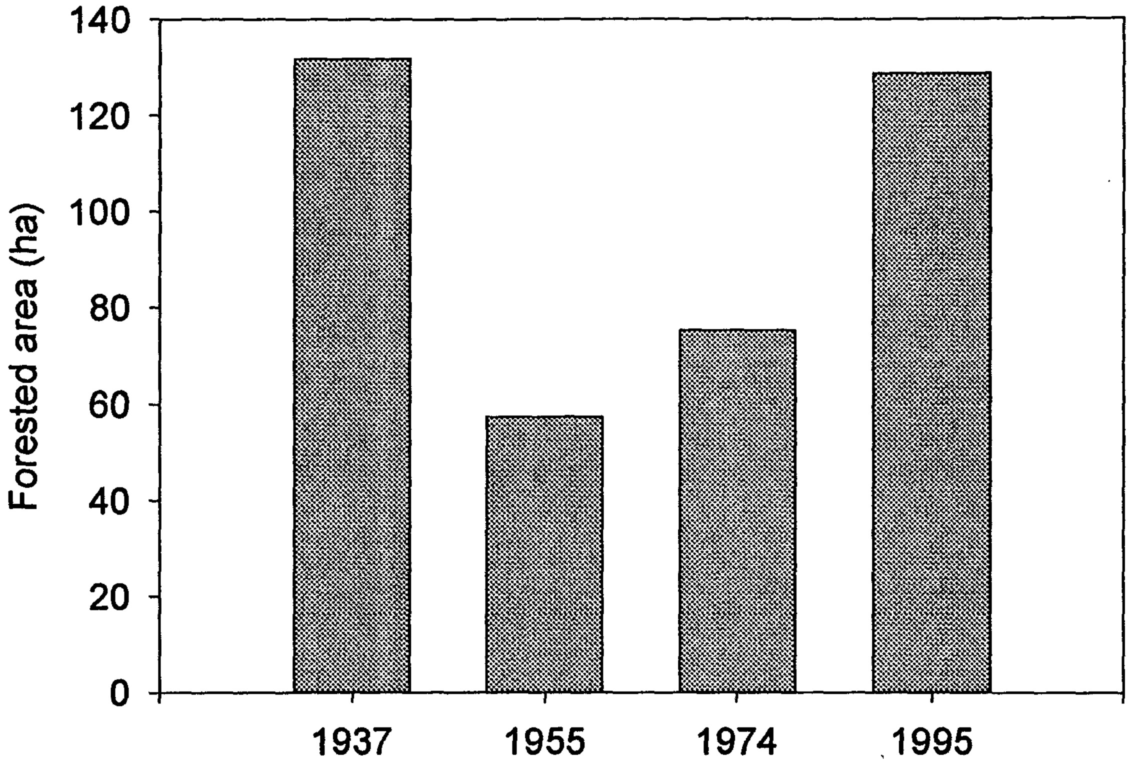

Figure 5. Area of South Boulder Creek forested in 1937, 1955, 1974 and 1995.

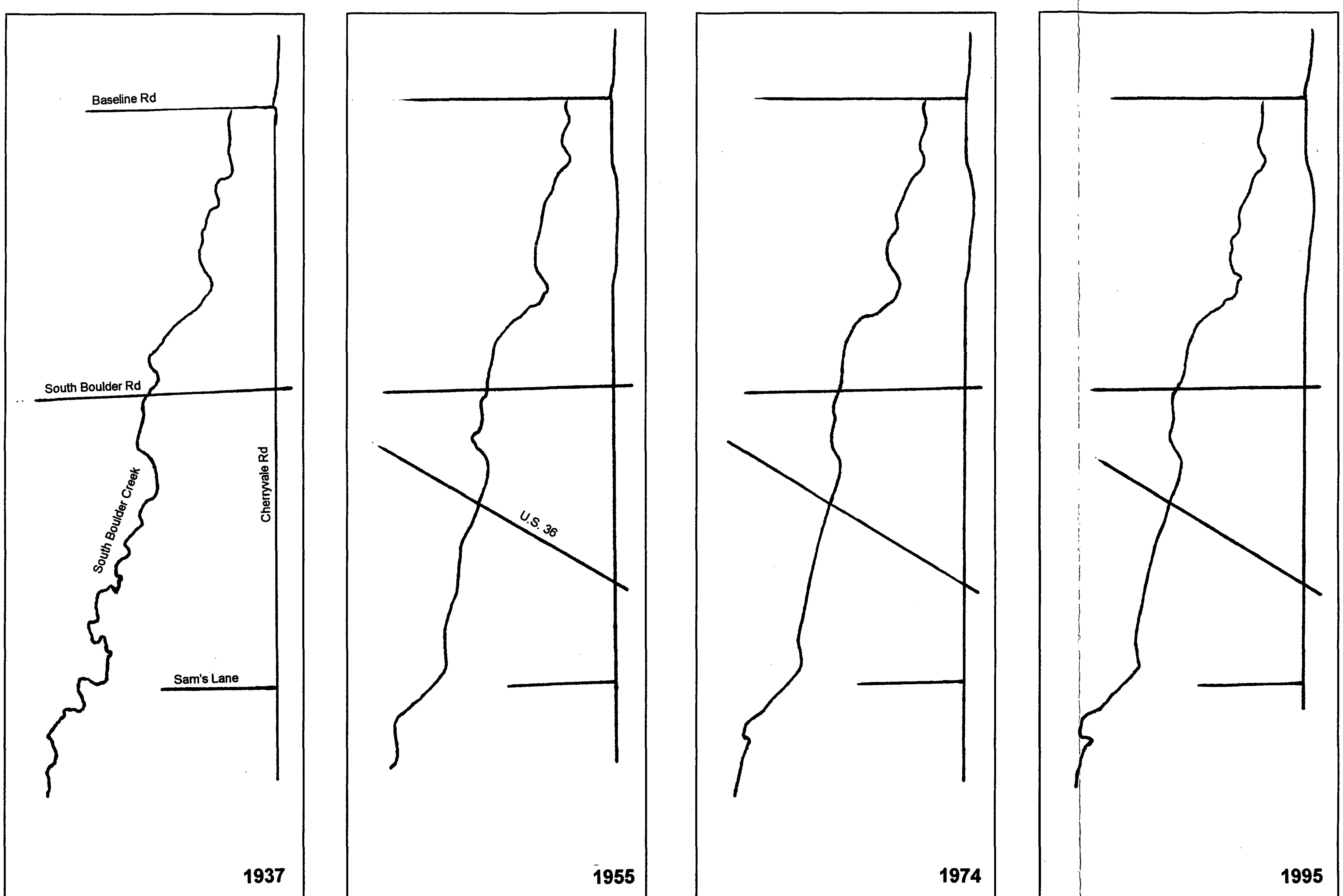

Figure 6. Location of South Boulder Creek channel in 1937, 1955, 1974 and 1995. Extensive channelization around 1955 resulted in a straighter and shorter channel.

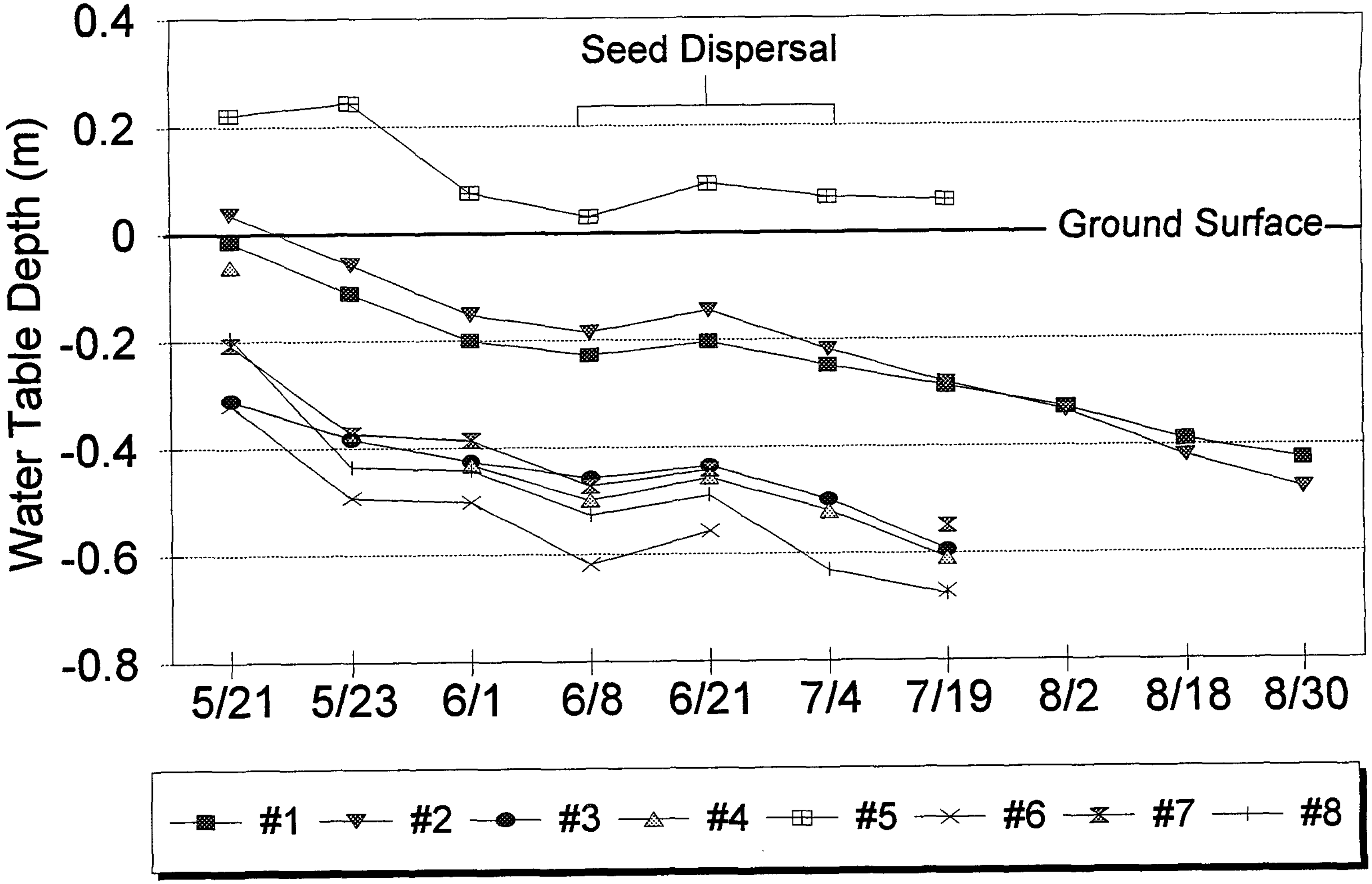

Figure 7. Water table depths in monitoring wells on seven of the study bars. Period of cottonwood seed dispersal and ground surface elevation are also displayed. Note well 5, located on bar 15, is flooded during seed dispersal. Wells 3, 4, 6, 7, and 8 have a deep (>40cm) water table during this period. Wells 1 and 2 on bar 24 have a shallow water table within 20 cm of the ground surface.

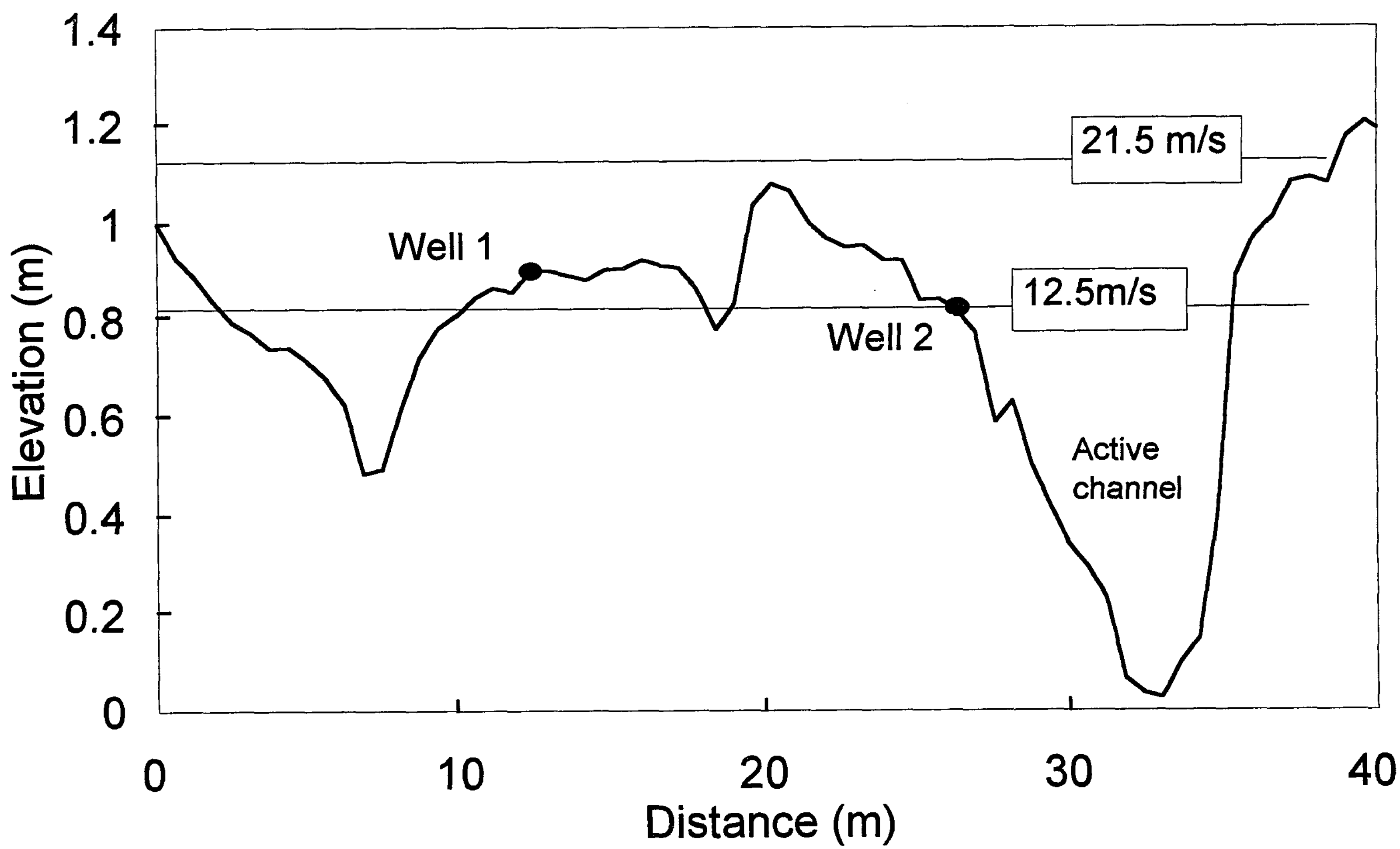

Figure 8. Cross section of Bar 24 looking downstream with locations of monitoring wells which were centered on vegetation plots. Horizontal line at 12.5 m^3/s indicates stage at maximum average daily flow in 1996 and surfaces that were inundated at this discharge. 21.5 m^3/s indicates maximum average daily flow in 1995.

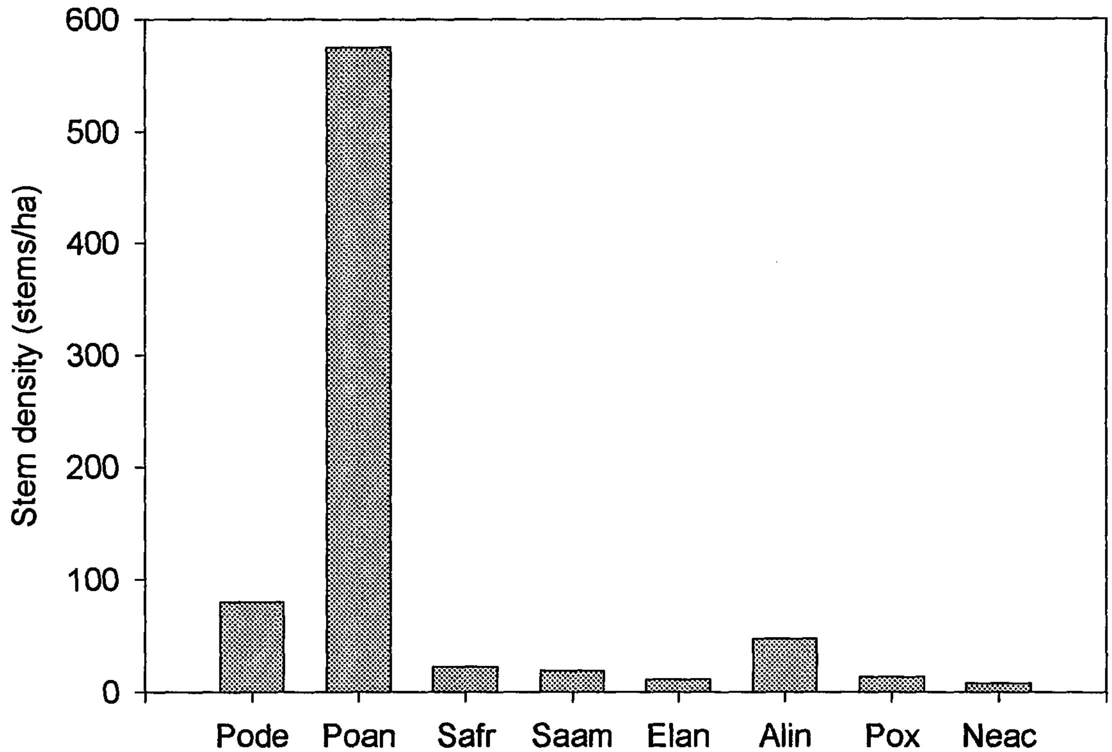

Figure 9. Stem denstiy of trees in 20m x 20m vegetation plots. Species abbreviations are: Pode=*Populus deltoides*, Poan=*Populus angustifolia*, Safr=*Salix fragilis*, Saam=*Salix amygdaloides*, Elan=*Eleagnus angustifolia*, Alin=*Alnus incana*, Pox=*Populus x acuminata*, Neac=*Negundo aceroides*.

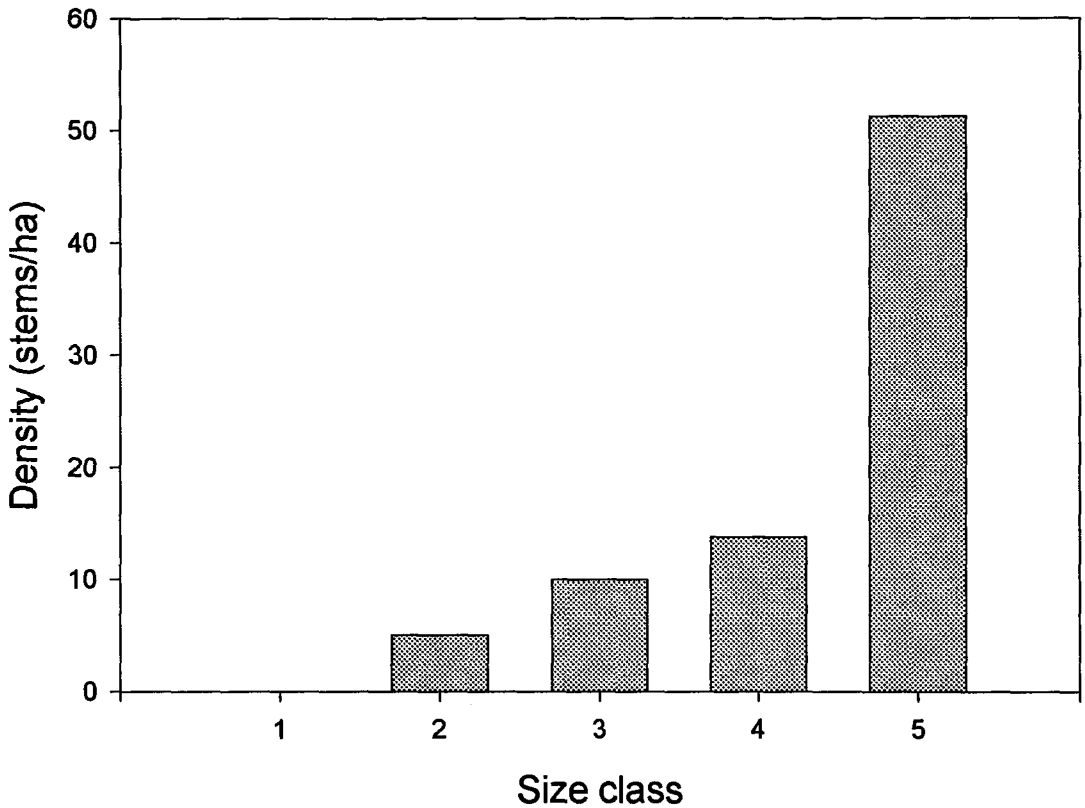

Figure 10. Size class distribution of *Populus deltoides*. Size classes are: 1, <2.54 cm (1 in.); 2, 2.55-7.62 cm (1-3 in.); 3, 7.63-15.24 cm (3-6 in.); 4, 15.25-30.48 cm (6-12 in.); 5, >30.48 cm (12 in.).

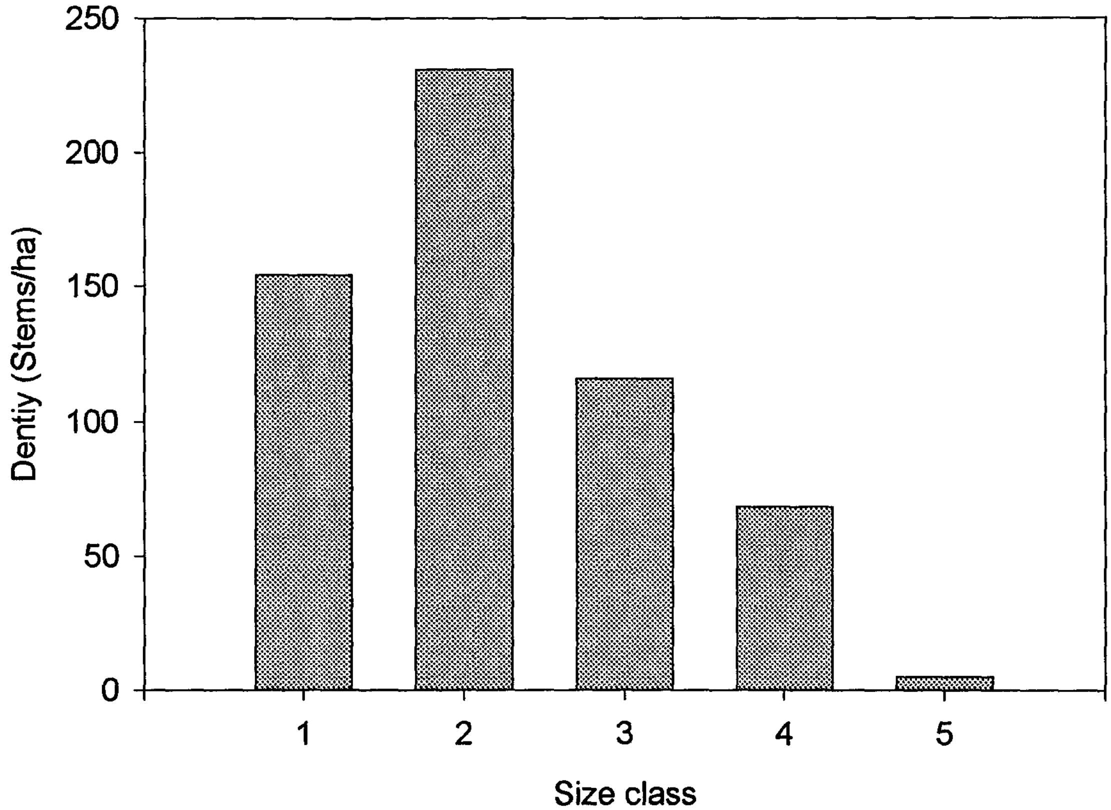

Figure 11. Size class distribution of *Populus angustifolia*. Size classes are: 1, <2.54 cm (1in.); 2, 2.55-7.62 cm (1-3 in.); 3, 7.63-15.24 cm (3-6 in.); 4, 15.25-30.48 cm 6-12 in.); 5, >30.48 cm (12 in.).

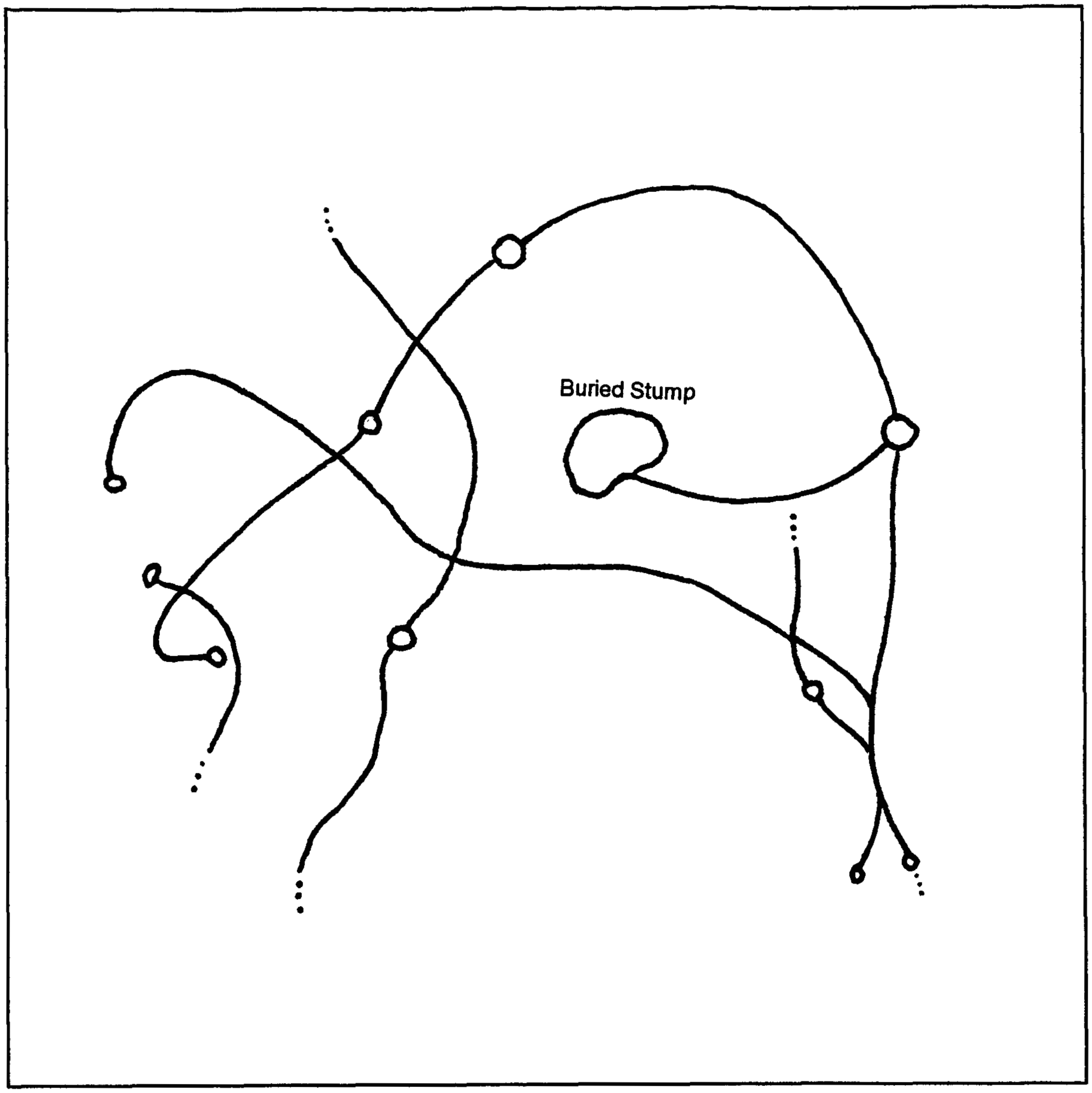

Figure 12. Drawings from excavations of narrowleaf cottonwood roots showing interconnected roots and clonal reproduction. Site is south of Baseline Road between Bars 1 and 8. Aerial stems are represented by circles. Scale ~ 1:25.

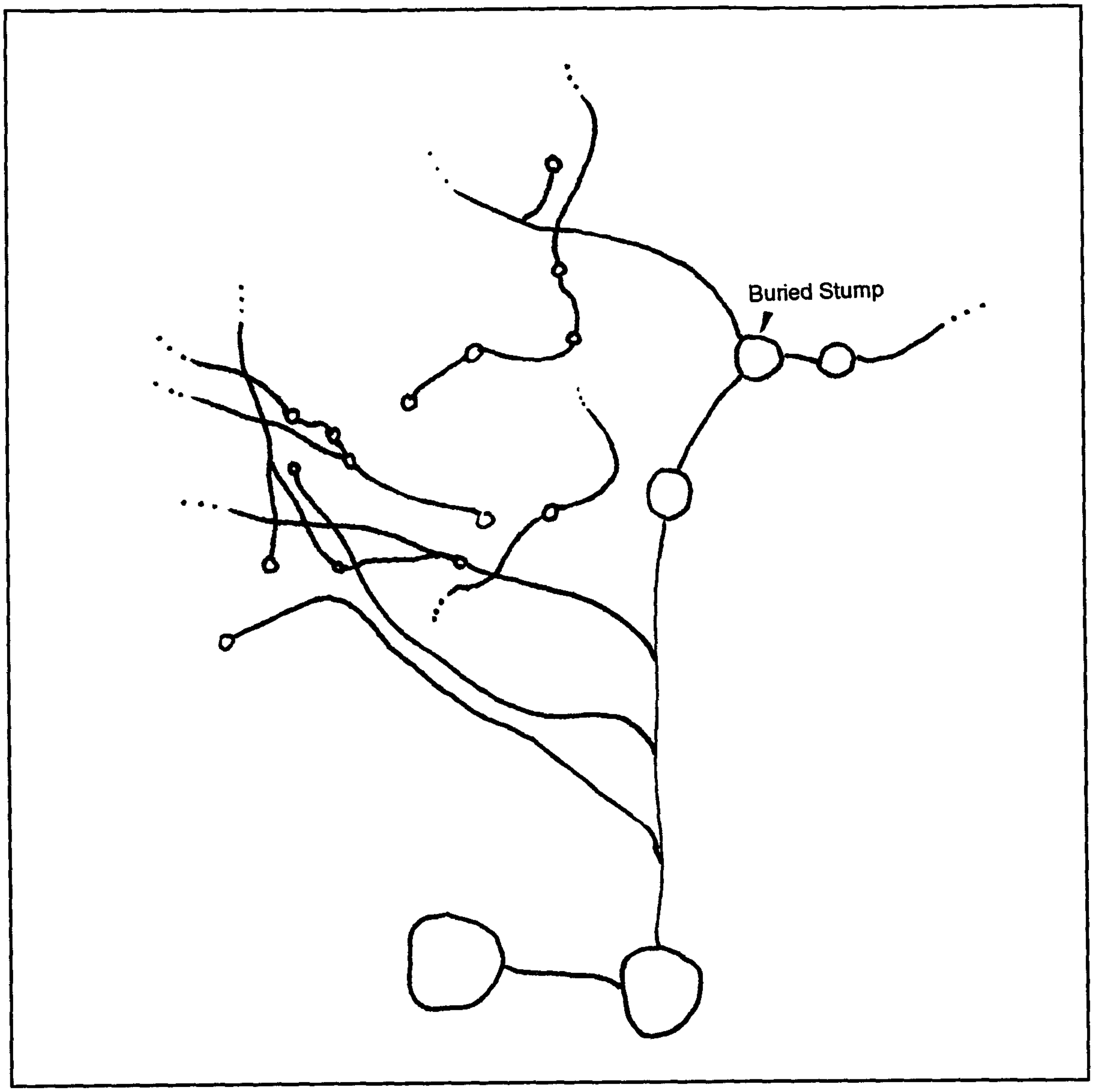

Figure 12 (Continued). Site is 200 m south of previous site. Scale ~ 1:25.

Trap #	1 June	8 June	21 June	4 July	15 July	Total
1	0	2	10	1	0	13
2	0	0	1	0	0	1
3	0	0	0	3	0	3
4	0	5	0	2	0	7
5	0	21	6	0	0	27
6	0	6	1	0	0	7
7	1	8	5	3	0	17
8	0	2	2	1	0	5
9	0	8	2	2	0	12
10	0	0	0	2	0	2
Mean Density (seeds/100cm^2)	0.1	5.2	2.7	1.4	0	9.5

Table 1. Cottonwood seeds captured on 10 - 100 cm^2 seed traps.

bar	# seedlings	shade	substrate	elevation	notes
1	0	5	sand/ gravel	low	*Salix fragilis, Alnus incana*
2	0	5	fine sand	low	*Alnus incana*
3	0	3	sand/cobble	low	*Alnus incana*
4	31	1	sand/gravel/cobble	med	bare
5	0	5	gravel/cobble	med	*Alnus incana*, litter
6	0	3	sand/cobble	low	bare
7	0	5	sand	med	*Alnus incana*, litter
8	0	3	cobble	low	bare
9	0	4	sand	med	*Spartina pectinata*
10	16	1	sand/gravel	med	bare
11	0	1	sand/gravel	high	*Pascopyrum smithii, Panicum virgatum*
12	18	3	sand/cobble	med	*Spartina pectinata*
13	0	4	gravel/cobble	med	*Salix exigua, Thlaspi arvense*
14	0	4	sand	low	bare
15	0	4	gravel/cobble	low	bare
16	0	3	sand	low	bare
17	13	1	gravel/cobble	med	bare
18	0	3	sand	low	bare
19	0	2	sand/gravel	low	bare
20	4	1	gravel	low	*Thlaspi arvense, Poa compressa*
21	0	5	gravel	med	*Salix exigua*
22	3	1	gravel	low	bare
23	12	1	sand/gravel	med	bare
24	see text	1	sand/gravel	med	bare

Table 2. Cottonwood seedling numbers and environmental data from 24 bars surveyed on South Boulder Creek. Bars with high shade values and low plant cover (i.e., bars 14 and 15) were shaded by large trees adjacent to the bar.

	Plot 1		Plot 2	
	30 July	24 Sept	30 July	24 Sept
1995 seedlings	105	82	10	10
1996 seedlings	80	13	365	49

Table 3. Seedling counts from 1 m^2 plots on bar 24 on 30 July and 24 September 1996.