The use of historical data and artifacts in geomorphology

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**Abstract:** Historical data and artifacts, as commonly used in historical geography, can provide powerful tools for dating geomorphological processes over the past century or more and applications can range from months to millennia. Investigations in geomorphology and environmental management can be greatly enhanced by the use of historical techniques. The approach is useful for tracing human-induced changes as well as for those occurring naturally. Several primary techniques are introduced in this essay.

**Key words:** historical artcrafts, historical data, historical techniques, histriography.

1 Introduction

Although commonly used in cultural-historical geography, historical data and techniques are becoming increasingly important in ascertaining changes of the physical environment. This importance stems from the fact that (1) understanding processes in historical time gives important insights to processes in geologic time and (2) the knowledge of processes and trends of the past century or so allows more effective environmental management.

New impetus to this trend has been given by the question that increasingly faces stream and wetland restoration: restore to what? For example, a large Georgia swamp pronounced by authorities as ‘primeval’ was shown to have been prime agricultural land in the nineteenth century which had been transformed to swamp by human action (Trimble, 1970a). On the other hand, some Australian lakes and rivers commonly thought to have been radically transformed by human action were shown to have changed relatively little and those changes may have had more natural than human causation (Finlayson, 1984; Finlayson and Brizga, 1995).

An earlier overview and keen critique and analysis of the historical approach is given by the outstanding work of Hooke and Kain (1982), especially the use of British sources, and is required reading for anyone using historical data. Historical data as used here (and in most other papers cited) primarily concern cultural data and artifacts. While more natural or scientific dating methods

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such as dendrochronology, anthropogenic pedogenesis, stratigraphy, and isotopic dating are touched on, full coverage is not appropriate.

Among the first to use historical data in geomorphology was George Perkins Marsh (1864). While usually most appropriate to the last few centuries, data and landscape artifacts from classical civilizations were used by Vita-Finzi (1969) to date stream processes over a much longer period, a timescale perhaps archaeological rather than historical. While historical data are most often used to study human-induced geomorphic changes, they sometimes may be used to measure changes that may be occurring quite naturally (Schmudde, 1963; Alexander and Nunnally, 1972). Indeed, some of the most scholarly, not to mention most fascinating, works of this genre are those by Parry (1978), and especially by Grove (1966; 1972; 1988).

For the United States, a timescale of about three centuries, Trimble and Cooke (1991) have amassed and critiqued historical data sources for geomorphic change. But a much broader and comprehensive ecosystem approach is that of Egan and Howell (2001). This fuller environmental scale is used by Whitney (1995) in a magisterial work that may be the most comprehensive and compelling use of historical data yet. Conzen et al. (1993) have regionally cataloged studies of the historical geography of the USA and Canada. Such source lists and bibliographies for other regions would be most useful.

For Britain, a delightful and instructive volume edited by Higgitt and Lee (2001) not only encapsulates geomorphological changes AD 1000–2000, but also implicitly includes many techniques covered in this paper. Essays are by D. Brunsden, D. Jones, B. Rumsby, J. Hooke, E. Lee, D. Higgitt, J. Warburton, M. Evans and I. Foster.

II Some basic techniques
While it is possible to identify some general principles of using historical data, it is impossible to give clinical directions on their use because every application is different. Instead, this essay presents some applications of historical data and analysis to the study of geomorphological forms and processes. Several specific approaches or techniques are presented with examples. The reader is also directed to Thornes and Brunsden (1977), Gregory (1979; 1987), Hooke and Kain (1982), Grove (1988), Cooke and Doornkamp (1990), Trimble and Cooke (1991), Trimble (1998; 2001), Collins and Montgomery (2001), Vita-Finzi (2002), Brown et al. (2003), Gurnell et al. (2003) and references given therein. An examination of examples and the sources themselves can often give insight and inspiration for a particular application and that is the approach of this paper.

For this review, most emphasis will be placed on geomorphic effects (form and process), but two sections (climate and land use) deal with causes. It is, however, important to note that effects in one place may act as causes elsewhere. The organization herein loosely follows that adopted by Trimble and Cooke (1991).

1 Instrumented topographic surveys
While not available for many locations, topographic surveys are often the best baseline data to be obtained. Costa (1978), for example, was able to reconstruct bankfull discharge back to 1858 for a stream in Denver, Colorado. When available, data reposited in the Vigil Network are extremely useful because they are developed by geomorphologists and are designed for restudy (Leopold and Emmett, 1965; Emmett and Hadley, 1968; Emmett, 1974; Osterkamp et al., 1990). For the USA, it is hard to overemphasize the utility of detailed topographic surveys by the US Army Corps of Engineers (COE) on many US streams over the last century or so. Longitudinal and cross-sectional profiles by COE were essential to Adler (1980) and James (1989) who studied the movement of erosional debris from hydraulic
mining in California. Also in California, Kondolf and Curry (1986) used COE profiles to show channel migration, while Kesel et al. (1992) used them to establish a sediment budget for the lower Mississippi River. Carson (2003) used detailed COE topographic surveys of the upper Mississippi River floodplains to show that inundation from low navigation dams actually enhanced fluvial processes on the old floodplains. At a much more local (brook) scale, Federico (2003) used detailed COE maps to measure channel erosion resulting from urbanization in southern California.

Detailed maps are sometimes available in unexpected times and places and may show unexpected details. In Russia, Golosov and Panin (2006) used a series of maps from the 1780s to show how stream networks had shrunk in response to climate and land-use changes. In Poland, Zygmunt (2003) was able to demonstrate the narrowing of a stream over a 270-year period.

Brizga and Finlayson (1994) used a series of nine profiles surveyed by an Australian agency between 1920 and 1988 to discount sustained channel change on the lower Snowy River, while Thoms and Walker (1992) used a government survey of the lower Murray River as a baseline for determining the effects of a weir system. Detailed nineteenth-century surveys of European rivers allow comprehensive planning for restoration (e.g., Kern, 1992). Assani and Petit (2004) used a series of precise surveys to show the downstream effects of a reservoir in Belgium, while Thomas et al. (2004) found archived baseline studies of a gully in Iowa and were able to precisely show subsequent changes. Pieguy et al. (2004) used surveys of the Rhone River dating from 1835 to document later changes of channel form. In using topographic surveys, one should always check to see if level lines are closed and, if so, to what level of precision. Measuring vertical increments of centimetres across a broad floodplain may be inaccurate unless 3rd- or 4th-order survey standards are maintained and many older transits or theodolites were not capable of that precision.

Coastlines have been mapped to increasingly precise standards over the past two to three centuries (Carr, 1980). Such surveys have been used to excellent advantage to measure estuarine sedimentation (Gottschalk, 1945; Figure 1), coastal erosion (Dolan and Bosserman, 1972; Figure 2), shoreline evolution (Robinson, 1966; El-Ashry and Wanless, 1968; Engstrom, 2006), long-term harbour changes (Robinson, 1955; Bird, 1987) and growth of a delta (Ren, 1985). Detailed harbour plans date from 1800 in the UK (Hooke and Kain, 1982) and the mid-nineteenth century in the USA (Trimble and Cooke, 1991).

Older stage-discharge rating records for stream gauging stations can be indispensable. For the United States, some of these were begun in the nineteenth century and were sometimes revised frequently. Each successive revision entailed at least one surveyed cross-section which may be contained in the archival records and such series have been used by Cooke and Reeves (1976), Williams and Wolman (1984), James (1997), van Steeter and Pitlick (1998), and Erskine and Warner (1999) to study channel changes. Gauging stations sometimes include control structures, such as weirs or flumes, which also can be used for dating (Trimble, 1975a).

Topographic maps, although at a lower resolution, can be important sources. Maps and travel accounts were used by Butzer (1971) to document lake levels and delta growth, 1888–1930, in Lake Rudolf, Ethiopia. Drawn without the benefit of aerial photography, older topographic maps require caution but are still valuable (Lewin, 1978; Werritty and Ferguson, 1980; Hooke and Kain, 1982; Hooke and Harvey, 1983; Lewis and Lewin, 1983; Lawler, 1993; Surian, 1999; Pasternack et al., 2001; Liebault and Pieguy, 2002; Pisut, 2002; see Blakemore and Harley, 1980, and Downward, 1995, for concepts of accuracy using old topographic maps). Graf (1983a), for example, was able to show channel...
migration of the Salt River near Phoenix, Arizona, from 1868 onward, while Madej et al. (1994) used a large-scale topographic map to measure bank erosion on the Merced River in California. Erskine et al. (1992) documented channel cutoffs from 1879 in SE Australia, while Gregory and Ovende (1980) used the same approach to demonstrate increases of drainage density in the Southern Pennines. Land use in the UK from as early as 1776 was reconstructed from Ordnance Survey maps in order to understand erosion and sedimentation trends (Foster et al., 1997; 2000; Foster and Lees, 1999). Meandering and channel migration since the nineteenth century has been investigated by Sundborg (1956), Mosley (1975), Hooke (1977; 2004), Lewin and Brindle (1977), Hooke and Harvey (1983), Hooke and Redmond (1989) and Surian (1999). Perhaps the longest-term study using topographic maps is the four-century evolution of embanked floodplains in the Netherlands (Middelkoop, 1997). Soil maps dating to the nineteenth century are often at a larger scale and include many features of interest to the geomorphologist (Trimble, 1970a). Because the training of soil scientists was quite similar to that of physical geographers, the narrative of soil surveys should also be consulted.

Studies of flooding have been published by various governmental agencies over the past century or more (Trimble and Cooke, 1991). One such study was used by Cooke (1984) to delineate flooded zones and flood deposits for the 1914 floods in Los Angeles County (Figure 3).

Unusual landscape features are more likely to be documented. Hence, Niagara Falls, New York, was surveyed several times, beginning in 1678, which made it feasible to determine the recession rate (Philbrick, 1970). US rivers were commonly given relatively frequent and precise surveys by the US Army

![Figure 1](image_url)

**Figure 1** Estuarine sedimentation sequence, Chesapeake Bay, Maryland, based on detailed topography from US Army Corps of Engineers and US Coast and Geodetic Survey

*Source:* Adapted from Gottschalk (1945).
Figure 2  Shoreline erosion of Roanoke Island, North Carolina. The shorelines of 1851 and 1903 are from coastal surveys prepared by the US Army Corps of Engineers and by the US Coast and Geodetic Survey. The projected 1585 shoreline is extrapolated from the average erosion rates of 1851–1970.

Source: Adapted from Dolan and Bosserman (1972).

Corps of Engineers which have been too little utilized by geomorphologists (Trimble and Cooke, 1991).

2 Stream and sediment discharge records
For the United States, stream discharge data go back to about 1850, are quite plentiful for this century, and most are easily available (Trimble and Cooke, 1991). Knox et al. (1975) were able to construct the annual flood series in the Upper Mississippi River for the period after c. 1850 showing an amelioration around the turn of the century. Costa (1978) reconstructed flood records for Denver, Colorado, going back to 1864. Trimble et al. (1987) used streamflow records dating from 1900 to show that reforestation had decreased streamflow for 10 large basins in the southeastern USA. Potter (1991) showed that annual floods had decreased in southwestern Wisconsin after 1940 and suggested that land treatment (rather than land use) accounted for the change. Price (1998) showed that flood regimes on the Southern Piedmont, c. 1905–1975, had been moderated by improved land-use and conservation practices. Price (1998) also corroborated the lag of hydrologic response behind changes of land use earlier shown by Trimble and Lund (1982) and Potter (1991). Van Steeter and Pitlick (1998) demonstrated that dams and diversions moderated the
flood regime of the Colorado River during the period 1917–1965. Wasklewicz et al. (2004) used stage records as surrogates for changes of flow characteristics on the Mississippi River, while Juracek (2004) used gauging station data to show changes of bed elevation in Kansas.

In the UK, data are less plentiful than in the USA, but have improved greatly since about 1950 (Hooke and Kain, 1982). Using historical techniques, the Institute of Hydrology has lengthened the flood record for Britain (Hooke and Kain, 1982). In addition, at least two other excellent guides to historical streamflow in the UK have appeared (Jones et al., 1984; Sutcliffe, 1987).

The USA has collected sediment discharge data from the early twentieth century, and both quantity and quality of sampling has increased (Trimble and Cooke, 1991). Such records were used by Meade and Trimble (1974) to show the decrease of sediment yield along the eastern seaboard of the USA between 1910 and 1970 as a result of (1) better land use, and (2) reservoir construction (see also Meade, 1982; Meade and Parker, 1985). Trimble (1975b; 1977) compared these same sediment yields to upland erosion rates based on historical soil profile truncations to show that streams were not in steady state. Hadley (1974) showed that decreases of sediment yield on the Colorado River 1926–1960 were not related to decreases of grazing. Using reservoir deposition rates plus unit runoff data, Trimble and Carey (1984) demonstrated how historical stream sediment concentrations could be retrodicted. Bierman et al. (2005) used historical stream sediment records to contrast erosion rates and sediment yields in the southwestern USA, while Ferrier et al. (2005) did a similar study in northern California.

**Figure 3** Areas of flooding and sedimentation in 1914 and areas flooded before 1914 in southern Los Angeles County, California

*Source:* Original data from Los Angeles County Board of Supervisors. Adapted from Cooke (1984).
3 Permanent landscape features
Common, but permanent, landscape features can sometimes act as gauges to measure physical landscape change. Considered here are: bridges; dams, mills, reservoirs, fords and fish traps; roads, canals, causeways and buildings.

a Bridges: Inspection of older bridges by a practised eye can often yield immediate information about stream processes. Aggrading streams are often indicated by reduced stream openings (Happ et al., 1940; Trimble, 1970b; Costa, 1978) and by the burial of structural members (eg, wingwalls) which are usually exposed to the stream. Degrading streams, on the other hand, can often be diagnosed from old water lines left on structural members, by exceptionally large openings, and by the exposure of structural members (eg, footings, pilings) which are usually placed beneath the surface. The remains of an old bridge were used by Williams (1978) to show changes of channel form on the North Platte River in Nebraska, while bridges were useful in showing channel changes in the River Severn, UK (Lewin, 1979), and on the Bega River of New South Wales (Brooks and Brierley, 1997).

Often of greater value are bridge plans, usually obtained from governmental agencies. In the USA, townships, counties and states usually archive bridge plans. These will usually include a stream and valley cross-section surveyed before bridge construction which can be resurveyed for comparison (Figure 4). In comparing profiles, it must be ensured that the present bridge has not induced local scour or deposition which would thus make comparison difficult or invalid.

Figure 4  Historical stream and valley sedimentation based on a railroad bridge profile, Hurricane Creek, Lafayette County, Mississippi. Aggradation between 1911 and 1936 was about 2 m
Source: Adapted from Happ et al. (1940).
Often, plans will include a detailed topographic map of the stream reach and some may also include surveyed cross-sections at some distance upstream or downstream. The latter surveys are particularly valuable because they are less affected by scour or dam effects induced by some bridges.

Often, a succession of bridges has been located at the same site. Highway bridge plans in the USA often go back to the turn of the century and railroad plans to the mid- to late nineteenth century. These were put to good use by Happ et al. (1940) and by Cooke and Reeves (1976). In the UK, bridge, highway and railroad plans are usually available from the early nineteenth century (Hooke and Kain, 1982). Fortunately, the same vertical datum is normally used for successive bridges at a site so that resurveys of century-old profiles are facilitated. Bridge surveys were used to great effect in showing channel changes from 1861 in southeastern Australia (Erskine, 1999; Erskine and Warner, 1999). Even when datum changes, parts of the old bridge may be excavated to re-establish elevations (Trimble, 1998).

Bridges are usually inspected periodically by government agencies. The resulting reports usually include considerable description and measurements of site conditions, and often include photographs which allow time-lapse photography.

**Dams, mills, reservoirs, fords and fish traps:** Changes in streams often create severe problems in the operation of mills and reservoirs and such problems may have been documented or can be established (Trimble, 1998). Trimble (1970a; 1970b) used mill dams, fish traps, and stream fords, in part, to document the aggradation and degradation of streams on the Georgia Piedmont. That work has been recently extended by Ferguson (1997a; 1997b) who has used subsurface radar and magnetometer surveys to establish the presence of datable landscape features buried beneath the floodplain and thus establish accretion rates, and by Ruhlman and Nutter (1999) who used Trimble’s 1960s field data as a baseline. Other types of low dams, such as weirs and irrigation diversions, are similarly useful to gauge stream changes (Gilbert, 1917; Thornthwaite et al., 1942; Vita-Finzi, 1969; Cooke and Reeves, 1976; Thoms and Walker, 1993). Limbrey (1983) points out the enticing possibility of locating Anglo-Saxon mills and paved Roman fords in the UK as a means of dating fluvial processes.

While nearly all small water-powered mills had reservoirs, most of these were channel-type pools which had low trap efficiency for sediment. Some mills and later hydroelectric and flood-control dams have a large volumetric capacity in relation to their drainage area and thus have a high trap efficiency so that sediment yield can be measured with some confidence (Brune, 1953; Trimble and Bube, 1990). Data from large reservoirs may be useful on a decadal timescale (Eakin, 1936; Trimble and Lund, 1982; Petts, 1984; Petts and Foster, 1985; Foster et al., 1990; Labadz et al., 1991; Trimble and Carey, 1992; McManus and Duck, 1993). These data have the advantage of often being long-term and of including normally unmeasured sediment (eg, bedload) but caution must be exercised lest lake sedimentation rates be inflated by shoreline erosion.

Erosion and sediment yield studies based on lakes and reservoirs have blossomed in the UK during the last two decades (Oldfield, 1977; Burt et al., 1984; Petts, 1984; Foster et al., 1985; 1986; 1990; McManus and Duck, 1985; Petts and Foster, 1985; Duck and McManus, 1987; 1990; Stott, 1987; Stott et al., 1988; Labadz et al., 1991; Dearing and Foster, 1993; McManus and Duck, 1993). While using many dating techniques not under the purview of this paper, some of these studies establish sediment yields well back into the nineteenth century. A comprehensive survey of 28 reservoirs in the Southern Pennines, for example, yielded data from as early as 1840 (Butcher et al., 1993).
Estate lakes in the UK, such as built by ‘Capability’ Brown or Humphrey Repton, for example, are extraordinary and relatively untapped data sources, some of which date well into the eighteenth century. Estate records of construction and maintenance along with modern dating techniques (eg, Foster et al., 1985) should together give some extremely good long-term records of sediment yields under varying land-use and climatic conditions.

Many reservoirs are given continuing surveys which sometimes must be obtained from repositories, but compendia are periodically published, usually by governmental agencies (eg, Dendy and Champion, 1978; US Geological Survey, 1983). Forty-five years of such data (1925–70) from a large reservoir system, the Tennessee Valley Authority, were used by Trimble and Bube (1990) in a cascade optimization analysis to construct trap efficiency rates for sediment coming directly into reservoirs and also for sediment which had already passed through upstream reservoirs (Figure 5). The data were also used to establish long-term rates of sediment accumulation, yields and fluxes in a stream basin of 113,000 km².

c Roads, canals and causeways: Roads (including railroads) and causeways serve as benchmarks to measure changes of stream morphology and process. An example is from Coon Creek in the Driftless Area of Wisconsin (Figure 6). The 1852 surface is the pre-agricultural soil as determined from borings (McKelvey, 1939). Before the availability of isotopic dating, McKelvey (1939)

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**Figure 5**  Sediment trap efficiency ratings for reservoirs based on sedimentation rates in Tennessee Valley Authority reservoirs, 1925–70

*Source:* Adapted from Trimble and Bube (1990).
and Happ (1944) dated the pre-agricultural soil of this region by cultural artifacts. In another location, the sedimentary contact of the floodplain soil and the fill of a railroad embankment was used to establish the 1904 floodplain surface (Trimble and Lund, 1982). The 1922 surface in Figure 6 is a roadway abandoned when the bridge was relocated 100 m downstream. This roadway was described by an eyewitness as being maintained level with the floodplain until the time of abandonment. It was located by dug holes and borings, the diagnostic feature being crushed limestone gravel at a uniform level. The 1938 profile was surveyed just upstream by a governmental agency and the 1976 profile was surveyed using the 1938 datum (Trimble, 1981; 1983; Trimble and Lund, 1982). It will be noted that the rate of floodplain aggradation increased significantly from the first period (70 years) to the second period (16 years) when vertical accretion rates averaged about 15 cm per year (Trimble and Lund, 1982). A 1993 re-survey (not shown, but see Trimble, 1999) showed about 4–15 cm accretion in 17 years. These five dated floodplains furnish a remarkable record of the rates of accelerated sedimentation in a highly impacted basin.

Lateral movement of streams or gullies can also be gauged with the help of roads and canals (Ireland et al., 1939). When the former position of a road or canal in relation to the stream can be determined from documentary evidence such as old maps or aerial photographs, its present location will allow an average rate of lateral migration to be calculated. Significant stream migration usually takes place on the timescale of decades or centuries, but on occasion it occurs in a few years, or even months (Lawler, 1993). Authorities will normally take whatever measures are necessary to protect a road or canal impinged upon by a laterally migrating

Figure 6  Stream and valley aggradation sequence, Coon Creek, Wisconsin, based on various historical techniques (see text). Sediment yields during the 1930s were about 3000 tkm⁻²

Source: Adapted from Trimble and Lund (1982).
stream. Some sort of documentation is normally prepared, often with plans and maps. Structures put into place then act as benchmarks to measure future stream movement. In Wisconsin, for example, a roadbank reinforcement installed in 1947 later showed that the cut bank had advanced about 10 m in five years (Trimble, 1975a). Other road-protection structures useful for future measurement are dikes, levees and rip-rap. Additionally, roads are often raised above normal flooding or aggrading floodplains by fill, and the level of the old road beneath may be ascertained from construction plans, borings or excavations.

Cultural artifacts of harbours relate to both coastal and fluvial phenomena. Finding harbour features such as mooring cleats several km from open water, for example, allowed Gottschalk (1945) to establish the rate of advance for a prograding delta in the Chesapeake Bay of Maryland. For the UK, Limbrey (1983) points out the possibility of locating Roman harbour features as well as riverine features such as causeways, bridges, and fords. It appears that the evolution of the great cuspate foreland of Kent known as Dungeness was cartographically reconstructed for AD 300 by Cunliffe (1980) partially on the basis of Roman relicts and, for later periods, based partially on Anglo-Saxon chronicles.

d Buildings: The work of archaeologists relating to buildings in the present context is highly instructive (Butzer, 1964; Butzer and Hansen, 1968; Vita-Finzi, 1973; 1978; 2002; Limbrey, 1983). Thieme and Schuldenrein (1998) used archaeological sites for age control in Pennsylvania. In Ethiopia, Butzer (1971) used a ruined fort to gauge long-term lake fluctuations. In Switzerland, Heim (1989[1932]) used buildings to calibrate characteristics of landslide, both potential and active. Coates (1979) used buildings and other structures to measure subsidence. Other examples are given by Hooke and Kain (1982). Except for occasional mills, buildings are rarely constructed on active floodplains, and even when close to streams, they are usually sited on terraces. Thus, when a structure is affected by sediment, it often indicates important changes of stream or sediment regime. Generally, when a building is significantly impacted by water and/or sediment, steps are taken to move or raise the building if possible. If not, the building is usually dismantled, leaving only the foundation, which itself can serve as a benchmark (Trimble, 1998). Once the foundation has been covered with sediment, however, the location must be established from old maps, land plats or perhaps eyewitness testimony although Ferguson (1997a; 1997b) has used subsurface radar. Likewise, the chronology must be established from such sources as maps and land survey plats, tax records, or eyewitness accounts. Unlike roads and causeways which may be located by borings, it is best to excavate around as much of the building as possible because it is necessary to see how the building’s occupants interfaced with the stream. For example, did an entrance face the stream? Artifacts between the building and the stream such as steps, walks, fences (McKelvey, 1939) and small outbuildings would imply that the area was frequented by people at one time, thus implying low frequency of flooding. In studying the buried village of Village Creek, Allamakee County, Iowa, for example, Trimble found a buried chicken house between a dwelling house and the stream which allowed him to infer that the site flooded infrequently at the time of construction.

Buildings may be occasionally useful for measuring stream channel erosion. The work of Bryan (1925), Cooke and Reeves (1976), Womack and Schumm (1977) and others in studying arroyos (gullies) in the western United States has relevance. In parts of Europe (eg, Germany), older buildings have historic flood levels marked, sometimes back to the Middle Ages, so that high flood discharges can be calculated and a long-term flood series reconstructed. Such markings
were also used by Madej et al. (1994) in California. In many places, flood stages were often marked on buildings and bridges. Werrity et al. (2006) used flood marks on a bridge in Perth Scotland to corroborate sedimentary flood dating, thus reconstructing almost two centuries of flood record.

4 Land (cadastral) surveys
Although they refer only to the plan view, land surveys can often supply important information to the fluvial geomorphologist. Although they relate more to vegetation, outstanding guides to North American original land surveys are given by Whitney (1995) and Wang (2005). The original land surveys have been used to establish pre-agricultural floodplain conditions in the USA (Trimble, 1970a; 1970b; Shankman and Smith, 2004), upland vegetation (Trewartha, 1940; Knox, 1977) and stream widths (Cooke and Reeves, 1976; Knox, 1977; Eschner et al., 1981; Brooks and Brierley, 1997; Fitzpatrick et al., 1999). In California, Kondolf and Curry (1986) used surveys of Spanish land grants to estimate channel changes, while Trimble (2003) used them to show the virtual absence of natural streams before European settlement on bahadas that are now densely urbanized. In British Columbia, Church (1983) used the cadastral survey of 1889–93 to fix the route of the Bella Coala River. In other areas and more recent periods, ongoing land resurveys sometimes give useful descriptions of geomorphological interest.

Related sources are estate maps, tithe maps and enclosure maps (Hooke and Kain, 1982). Tithe maps have been used to date river meanders from 1840 (Lewin et al., 1977; Lewin, 1978; Hooke and Harvey, 1983; Lewis and Lewin, 1983), while a detailed map of 1749 provided qualitative information about stream braiding (Werrity and Ferguson, 1980). An exceptional study of this genre used deeds, private papers, and local maps to reconstruct aspects of the River Trent back to AD 1200 (Petts et al., 1992). Tax maps and tax records are particularly valuable and underused sources (Trimble and Cooke, 1991). Tax records were used to establish the advance and retreat of glaciers in Norway (Hoel and Werenskiold, 1962; Grove, 1972; 1988) and in the Alps (Grove, 1966; 1988). Sundborg (1956) used tax records to show stream channel migration in Sweden. Land rent assessments in Norway allowed Grove (1972) to reconstruct the incidence of Little Ice Age mass movement and other natural hazards. Local records, also in Sweden, were used by Dearing (1979) to reconstruct ploughed area and sheep population. These were then related to sedimentation rates in a local lake.

5 Aerial photographs
Aerial photographs dating from as early as 1917 have been used to document and date fluvial changes along with the land-use changes that were responsible (Rozin and Schick, 1997). The general coverage of stereographic aerial photography in the USA dates from 1937–38, but limited coverage exists from c. 1925 (Trimble and Cooke, 1991). Air photos generally date from the mid-1940s in the UK (Hooke and Kain, 1982) where Thornes and Brunsden (1977) have shown the utility of repetitive coverage to monitor mass movements. The value of aerial photography is a function of scale, photographic quality, and the availability of stereographic coverage. With optimum conditions, Hoag (1983) was able to use standard photogrammetric methods to quantify channel erosion in Orange County, California, from 1938 to 1983. Significant decreases of stream response in Wisconsin have been inferred from striking decreases in drainage density as measured from air photos (Trimble and Lund, 1982; Fraczek, 1987; Figure 7), but Knighton et al. (1992) showed that tidal creek channel networks were expanding after 1943 in northern Australia. Air photos are extremely useful in establishing rates of channel migration and channel change (Schumm and Lichty, 1963; Williams, 1978; Thorne and Lewin, 1979;

Stream and valley aggradation is difficult to detect on air photos, but some attendant effects such as the creation of backswamps and vegetational changes can be seen and measured (Trimble, 1970b). On upland areas, air photos have also been used to quantify land use and consequent erosion (Trimble and Lund, 1982; Rowntree et al., 1991). New methods of processing data from historical photographs give more precision and possibility of replication (Chandler and Cooper, 1989; Chandler and Brunsden, 1995; Brunsden and Chandler, 1996). Using air photo coverage spanning the period 1918–2000, Zviely and Klein (2004) demonstrated the rapid retreat of cliffs along the Israeli Mediterranean coastline, while Guthrie and Evans (2004) used air photos to document 201 separate debris slides between 1950 and 1996 in British Columbia.

Ground-based oblique photography

Ground-based oblique photography has been used to date geomorphological processes dating back to 1864 (Costa, 1978). Although not systematically available as aerial photography, ground-based photography has existed longer and generally offers better scale. Some major American sources are given by Trimble and Cooke (1991), but queries should always be addressed to museums, libraries, and individuals living in the region being investigated. By far the most valuable coverage is sequential photos at the same place, known as time-lapse photography (Hastings and Turner, 1965; Malde, 1973; Rogers et al., 1984). Graf (1979a) has used such imagery to show land use and consequent development of channels in montane valleys, arroyo filling and vegetational stabilization (Graf, 1982), changes of bed material in the Salt River, Arizona (Graf, 1983a), and stabilization by vegetation of sediment deposits along the Rio Grande River (Graf, 1994). Brizga and Finlayson (1994) demonstrated similar stabilization along the Snowy

Figure 7 Decrease of drainage density, upper Coon Creek basin, 1938–78, as reconstructed primarily from US Department of Agriculture aerial photographs. Analysis of drainage density and other data suggests that present flood peaks are only a fraction of those of the late 1930s

Source: Adapted from Fraczek (1987).
River in Australia. Trimble and Lund (1982) showed the formation and subsequent healing of hillside gullies in Minnesota and also demonstrated the transformation of tributaries from sediment sinks to sediment sources as stream response increased, while Trimble and Crosson (2000) showed how tributaries had improved in condition as the result of better land use since the 1930s (Figure 8). Ground imagery has been used by Williams (1978) and Eschner et al. (1981) to show changes of channel size and form for the Platte and North Platte Rivers in the central USA, while Williams and Wolman (1984) demonstrated channel scour downstream of dams. Goudie (1992) used time-lapse photography to show changes in UK beaches as the result of offshore shingle mining and of jetty building. Trustrum and DeRuse (1988) were able to date landslides in New Zealand, while the destructive effects of debris flows were documented in California by DeGraff (1994). Enzel and Wells (1997) used photographs in conjunction with

Figure 8  Time-lapse photography showing improvement of tributary stream channel conditions in the unglaciated region of Wisconsin. (A) Photo made by S.C. Happ in 1940 to depict a ‘typical’ tributary of the period. Note the eroded, shallow channel composed of gravel and cobbles with coarse sediment, much of it sand, deposited on floodplains by frequent overflows. Such tributaries were described as resembling ‘gravel roads’. (B) Remake by S. Trimble in 1974. The stream channel is narrower, smaller, and more stable. The coarse sediment has been covered with fine material, and the floodplain is vegetated to the edge of the stream which has continued to narrow. This condition has continued and improved since the early 1970s

railroads and buildings to show the change of playa water levels in California.

Photogrammetric techniques can also be used with oblique photography, making it possible to obtain precise measurements in some cases (Graf, 1979b; Lawler, 1993). Using photogrammetry in conjunction with planimetric maps, Hoel and Werenskiold (1962) were able to measure glacier thicknesses in Norway. Oblique aerial photography is also available for some areas but does not lend itself easily to photogrammetric methods (Trimble and Cooke, 1991).

Some investigators have used paintings to extend time-lapse analysis to the scale of centuries. Messerli et al. (1978) and Grove (1988) have used pictures to study glacial advance and retreat over the past four centuries. Indeed, Vita-Finzi (2002: 83–84) states that “The acceptance of a Little Ice Age in about 1550–1850 initially owed much to engravings of Swiss settlements overwhelmed by glaciers”. Lamb (eg, 1982) and Ladurie (1971) routinely used sketches and paintings in their historical analyses of climate. More recently, Cooper (1994) used a detailed painting to establish the 1847 morphology of the Mvoti River estuary, South Africa, and Madej et al. (1994) used old paintings of the Merced River in Yosemite Park, California, to estimate long-term bank erosion.

7 Litter
The classic work on using litter in geomorphological investigations was done by C.B. Hunt (1975) who worked in the American desert. Litter includes mobile artifacts such as tools, vehicle parts, bottles, cans, package wrappers and any other datable artifacts. Although litter may be precisely dated in some cases, its location can only give an earliest possible date. For example, a beer can datable to 1939 may have been dumped into a stream in 1950 where it was later buried in

Figure 8  (continued)
a point bar in 1952. The point bar may have eroded away in 1960 and the can buried 20 cm deep on a downstream floodplain. The only allowable conclusion, in the absence of more information, is that there has been a minimum accretion of 20 cm at the final location since 1939. However, finding several items at similar levels with similar dates might allow a stronger inference, as when an intact dump is located beneath a floodplain (Costa, 1975).

A related method of tracing fluvial sediments and surfaces is by use of anthropogenically produced materials such as radionuclides, heavy metals and other wastes (e.g., Davies and Lewin, 1974; Lewin et al., 1977; Wolfenden and Lewin, 1978; Bradley, 1982; Macklin, 1985; Knox, 1987; Marron, 1989; Walling et al., 1992; Rowan et al., 1999; see also the excellent review in Graf, 1994).

8 Contemporary descriptions
Geomorphological changes in China have been dated back as far as 2000 years using written accounts (Ren, 1985; Yang, 1998). For example, Zhang and Yang (1998) used contemporary descriptions to show that over a two-millennium period the Yellow River did not entirely lose surface runoff until 1972, the result largely of upstream dams. Xu (2004) was able to explain that decrease based on climate and flow diversions. On the Yangtze River, Wang et al. (2005) were able to investigate channel forms and processes from 1644. The utility of written accounts takes two basic forms. The first is a description of past events or changes, while the second is the description of contemporary or baseline conditions useful for later comparisons. For veracity, one must consider (1) the scientific credentials of the observer, and (2) the stage of scientific development at time of observation. An example of an erroneous observation would be a nineteenth-century observer attributing erratic rocks to the currents of the biblical flood.

As an example of contemporary change by a qualified scientist, one can do no better than the famed English geologist, Sir Charles Lyell, who in 1845 observed the early fluvial consequences of agricultural settlement on the Piedmont of Georgia, pointing out that a stream from the settled areas was turbid but that one from the primeval area was clear, even during floods (Lyell, 1849).

The American surveyor and naturalist David Dale Owen (1847) furnishes an example of a baseline scientific observation. Before extensive agricultural settlement in the upper midwestern USA, he could observe fish and stream bottom formations in streams up to several metres deep. This, of course, would have been impossible during most of the period since agriculture began. Observations of John C. Fremont and G.K. Gilbert were used by Atwood (1994) to establish the early levels of Great Salt Lake in Utah, USA. Accounts from scientific observers such as these tend to be dependable and are often extremely helpful. Observations from less-qualified people also can be helpful, but may need more qualification or interpretation (Hooke and Kain, 1982). Travel accounts of ordinary people were used to reconstruct the size and condition of glaciers in Norway during the eighteenth and nineteenth centuries (Hoel and Werenskiold, 1962) and in the Alps during the seventeenth century (Ladurie, 1971). Liebscher (1991) gives an excellent account of attempts to reconstruct river flood stages and lake and ocean levels based in part on historical narratives. Trimble and Cooke (1991) and Whitney (1995) give many useful sources for travel accounts in the United States and Canada.

Somewhat less valuable sources are contemporary newspapers, periodicals, books, government records and unpublished manuscripts. Wooley (1946) used newspaper reports to establish numbers of floods in Utah, 1850–1938, and related these to population increases. Kondolf and Curry (1986) used newspaper accounts to study channel migration in California, while Knox (1987) and Fitzpatrick et al. (1999) used them to establish historical floods in Wisconsin.
Trimble (1974) used newspapers and periodicals to trace the progress and effects of soil erosion on the Southern Piedmont during the nineteenth century. Using newspaper and other contemporary accounts, Nuttli (1973) was able to construct an isoseismal map of the Mississippi Valley (New Madrid) earthquake of 1811–12. Newspapers were used to document mass movements in the southern Appalachian highlands by Clark (1987) and in Puerto Rico by Larson and Simon (1993). James (2004) used local histories to show the effects of tailing fans from hydraulic mining in California. In Switzerland, Heim (1989[1932]) used local history to chronicle major landslides back to AD 1563.

9 Weather events and climate
Recorded climatic records, especially regular records kept by governmental agencies, are often of exceptional value to geomorphologists. Official climate records sometimes go back to the mid-nineteenth century in the USA and Europe, but scattered records were collected earlier. Cooke and Reeves (1976), in their analysis of arroyos in the southwestern USA, were able to use early climate records from US Army posts. Trimble and Lund (1982) used official records to analyse precipitation trends back to 1865 in the upper Mississippi Valley, showing that climate was distinctly out of phase with the human-driven hydrologic and geomorphic processes shown to be occurring. Hoel and Werenskiold (1962) were able to show that glacial advance and retreat in Norway were in accord with climatic controls. An exemplary study by Rumsby and Macklin (1994) correlates climate and channel changes from 1700 to the present in the River Tyne, UK, while Merrett and Macklin (1999) did the same for the Yorkshire Dales. Using 110 years of climate data, Mountain and Jones (2006) were able to forecast and hindcast the frequency of extreme flows on the River Wye in Wales. Hooke and Kain (1982) list private diarists going back to 1337 who periodically recorded British weather. H.H. Lamb (eg, 1977; 1982; 1988) has been resourceful and ingenious in reconstructing past climates from highly varied historical sources including official records when possible. His synthesis of these techniques serves as a model. The work of Parry (1978) is also excellent. Workers in the UK are fortunate in having much of the climate over the past two centuries or so synthesized and quite accessible to use (eg, Lamb, 1972; Kington, 1976; Lawler, 1987; Favis-Mortlock et al., 1997). See also the review in Goudie (1992).

Particular storms may have significant geomorphologic effects locally or over larger areas. Engstrom (1994; 1996; 2006) has reconstructed some major storms for California showing some of the geomorphologic consequences. From written records of an earthquake that struck Japan in 1700, Satake et al. (1996) were able to reconstruct the general dimensions of an earthquake.

Historical reconstruction of precipitation has been extremely important in explaining the historical formation or demise of arroyos (Graf, 1983b). Examined have been long-term annual trends, seasonality, frequency, intensity, and, more recently, connections with the Southwestern Monsoon and El Niño–Southern Oscillation events (eg, Bryan, 1925; 1928; Thornthwaite et al., 1942; Leopold, 1951; Cooke and Reeves, 1976; Hereford, 1984; 1993; Balling and Wells, 1990; Webb and Betancourt, 1990; Hereford and Webb, 1992; Betancourt and Turner, 1993; Bull, 1964; 1997).

10 Land use
Land use has been increasingly recognized as a major causal factor in geomorphology. For the UK, tithe, topographic, county and Land Utilization Survey maps, some of which go back to the early 1700s, are given excellent coverage by Hooke and Kain (1982). For the USA, Trewartha (1940) and Knox (1977) used original plats of survey to establish primeval
vegetation in southwestern Wisconsin, while Trimble (1970a) used them to study early floodplain conditions in Georgia, showing their genesis to wetlands. Graf (1979a) used photography to reconstruct land use for a basin in Colorado, 1859–1974, and then related land-use changes to hydrologic and geomorphic changes, specifically channel incision. In the perennial and ongoing attempt to explain arroyos in the southwestern USA, Denevan (1967) and Cooke and Reeves (1976) splendidly reconstructed livestock numbers by census reports, travel accounts and other sources. Both studies concluded that animals were important but only one of many causal factors.

Land-use reconstructions need to be as precise as possible because (1) increasingly sophisticated information about the hydrologic and geomorphic effects of different land uses and treatments is available, and/or (2) we may be able to correlate historical land use with contemporaneous geomorphic phenomena in model building. An example of the latter is Graf’s (1979a) study which related land use to channel incision. Another example is the study of reforestation and water yield decreases in the Southern Piedmont by Trimble et al. (1987) who were able to use relatively precise census data. Their long-term results of 10 large basins, together with available short-term experimental data, permitted a model which explains 50% of water yield variance in humid areas as a result of reforestation or deforestation and is presently the standard stochastic model (Maidment, 1993). Potter (1991) was able to show a decrease in the annual flood series of the Pecatonica River in southeastern Wisconsin even though land use held relatively constant. He attributed the reduction of flooding to improvement of land treatment with resulting decreases of drainage density. Potter’s pioneering work was followed by similar analyses in the same region by Gebert and Krug (1996) and Knox (1999). While controlling for climate with historical climatic data, Price (1998) used historical land-use data to show that an amelioration of streamflow regime on the Georgia Piedmont was culturally rather than physically caused.

Detailed land-use reconstructions from census data have been used to analyse historical soil erosion and associated hydrologic changes in the USA (Trimble, 1974; Price, 1998) and Canada (Wilson, 1989). Trimble and Lund (1982) were able to show a lag of hydrologic and geomorphic processes so that there was a hysteretic relationship between land use and the dependent variables of erosion and sedimentation. The lag was attributed to cumulative temporal changes in soil condition.

Agricultural census data are complex and confusing because categories and definitions often change from one census to the next. For the US census, at least, county enumerations are for ‘land in farms’ only and sometimes cover only fractional parts of counties. Where available, the census manuscripts, rather than the published reports, give far more detailed information (Conzen, 1969). Another major problem is that areas of enumeration units change with time so that the boundaries and areas must also be reconstructed (Trimble, 1974: Appendix F). Unfortunately, there are as yet no guides to the use of census data in reconstructing historic land use, and a great need clearly exists. Despite all these problems and limitations, Waisanen and Bliss (2002) have recently succeeded in mapping by GIS much of the agricultural land use for the USA since 1850. Such mapping may fore-shadow modelling of historical geomorphic and hydrologic processes.

Urban land use is increasingly recognized as a geomorphic factor. Cooke et al. (1982) and Cooke (1984) have shown the relation between urban expansion and increased geomorphological activity. Trimble (1997; 2003) showed that historical stream channel erosion in southern California was associated more with channel construction and agricultural land use than with urban expansion.
Surrogates can sometimes be used to extend land-use data beyond the effective dates of the census. Thus, historic sheep populations were estimated from the weight of wool clipped each year (Noble and Tongway, 1986) and erosive land use was extended back in time by calibrating from densities of slave and non-slave populations (Trimble, 1974). Such surrogate retrodictions might be used for other historical data, but caution must be used.

III Summary and conclusions
Although not always precise, historical data and techniques can provide powerful tools for dating processes over the past few centuries and particularly during the last few decades. This is important not only to more traditional theoretical applications, but also to considerations in environmental management. Historical techniques can be criticized (Richards, 1984), but the recognition of their importance is shown by their increased use and the fact that they are now featured in standard texts (e.g., Cooke and Doornkamp, 1990; Ward and Trimble, 2004). While this short paper has touched on most major techniques used by historical geographers, there are often variants of each not covered here. Geomorphologists would do well to acquaint themselves with the literature and techniques of both historical geography and archaeology for their areas of interest if they wish to extend their chronologies beyond the few decades spanned by instrumental records.

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