APPENDIX A

DATING TECHNIQUES

A.1. INTRODUCTION

River deposits contain a long, albeit discontinuous, record of fluvial landscape evolution (Stokes and Walling 2003). As such, they hold the key to understanding how a fluvial system has responded to past disturbances, and how it may respond in the future. Deciphering this record, then, is an important component of the geochemical-geomorphological approach in that it provides insights into the precise mechanisms through which contaminated particles were distributed and where they are currently stored within the watershed. In order to fully exploit this record, it is essential to date the alluvial sequence and determine which of the deposits correspond to periods of sediment-borne trace metal influx. The importance of these relations stem, of course, from the fact that trace metal concentrations are likely to vary closely with the history of contaminant releases in the watershed, as was demonstrated for floodplains and terraces in Chapters 6 and 7, respectively. For most sites, a detailed geomorphological history of the watershed will not be available prior to site assessment, and will therefore need to be constructed as part of the characterization and assessment program. Reconstructing a history of geomorphological events is a difficult process that requires a considerable amount of experience in examining and characterizing alluvial deposits. It is therefore best performed by one who is trained in the analysis of alluvial stratigraphy and geomorphology. In general, the analysis involves four basic steps: (1) the delineation, characterization, and mapping of fluvial landforms, including those that may serve as contaminant sinks, (2) determining the relative and absolute age of the landforms and their deposits, (3) correlating sediment-borne trace metal concentrations to landforms, deposit age, and deposit sedimentology, and (4) combining the temporal and spatial data to construct a geomorphic history of the system that depicts the timing and nature of contaminant movement through the river valley. One of the more difficult aspects of this process is determining the age of specific stratigraphic units that comprise floodplains and terraces.

Historically, two types of dating were generally recognized: relative and absolute (see Stokes and Walling 2003 for a different classification of dating methods). Relative dating compares the ages of two or more stratigraphic units to determine

which is younger and which is older. The dating methods are founded on a set of principles involving basic logic, and typically rely on the spatial relationships of the units to one another. Two of the more important concepts include the principle of superposition and the principle of cross-cutting relationships. The former states that sediment is deposited on top of earlier, older deposits. Thus, the younger deposits within any alluvial sequence will be found at the top, whereas the older deposits will be found at the bottom. The principle of cross-cutting relationships states that a disrupted or eroded deposit is older than the cause of the disruption. For example, the cross-cutting relationship indicates that terrace deposits truncated during a period of channel entrenchment must be older than the period of downcutting. Moreover, the truncated deposits must be older than the deposits found abutting the eroded truncation surface and which are found at a lower elevation. It follows, then, that younger terraces and their deposits are positioned at lower elevations than older terraces (although a few minor exceptions have been reported in the literature) (e.g., Kochel et al. 1987). When working with alluvial sequences, other approaches have been used to assess the relative age of the deposits, including the analysis of soil profile development and the degree of mineral or rock weathering. These types of techniques compare changes in the character of landforms and/or their sediments to develop a relative sequence of ages (see, for example, Birkeland 1999).

Absolute dating methods generally rely on a physiochemical parameter that changes at a constant rate through time; they can therefore be used to estimate the age of the material with which they are associated on an absolute (i.e., numerical) time-scale. A wide range of absolute dating methods have been developed since the 1960s (Table A.1), each of which vary in their time of applicability, the precision and accuracy of the resulting age estimates, and the nature of the event being dated (Stokes and Walling 2003). Unfortunately, only a handful of these can be used to date recent alluvial deposits. In the sections below, we will briefly examine the theory behind these methods, and the age range for which the techniques may be applied, to provide insights into the methods that may be used at a contaminated site. Additional information can be obtained from a number of discussions on the subject, including Mahaney (1984), Carroll and Lerche (2003), and Stokes and Walling (2003).

A.2. SHORT-LIVED RADIONUCLIDES (Pb-210 and Cs-137)

In Chapter 3, it was shown how various short-lived radionuclides, such as ^{210}Pb and ^{137}Cs, could be used to estimate the rates of upland erosion and deposition. The primary method with which we were concerned was the measurement of the total nuclide inventory for an undisturbed or reference site, and its comparison to other localities for which sedimentation or erosion had occurred. The magnitude of erosion or deposition could then be estimated as a function of the negative or positive change in the inventory, respectively. Although minor variations in the method are required, the procedure can also be applied to determine the rates and spatial patterns in sedimentation on floodplains and terraces (Stokes and Walling

Table A.1. Summary of selected dating methods applicable to Quaternary alluvial deposits

Method	Approximate age range (years)	Basis of method
Dendrochronology	10^0 to 10^4	Counting of annually produced tree rings and correlation to sedimentary deposit
Varve chronology	10^1 to 8×10^3	Counting of seasonally deposited layers back from present
Radiocarbon (C-14)	10^2 to 5×10^4	
Cosmogenic nuclides		
^{10}Be	10^4 to 10^7	Formation and decay of nuclides in rocks exposed to cosmic rays
^{38}Cl	5×10^3 to 5×10^5	
^{3}He	5×10^2 to 10^6	
^{14}C	5×10^3 to 3×10^4	
Potassium-argon; argon-argon	10^4 to 5×10^7	Radioactive decay of K in K-bearing minerals
Lead-210	0 to 150	Radioactive decay of Pb-210
Cesium-137	0 to 1950	Accumulation and decay of Cs-137
Uranium series	0 to 5×10^5	Measurement of radioactive decay of U and U-daughter produces in sedimentary minerals
Uranium-lead; thorium-lead	10^4 to 4×10^7	Measurement of Pb enrichment due to decay of U and Th
Fission Track	3×10^3 to 4×10^7	Measurement of damage trails due to U fission decay
Luminescence (TL, OSL, IRSL)	0 to 10^6	Measurement of electron accumulation in crystal defects
Obsidian hydration	0 to 10^6	Increase in thickness of hydration rind on obsidian particles
Lichenometry	0 to 10^4	Growth of lichens on bare rock surfaces
Paleomagnetism, secular variations	0 to 7.5×10^3	Secular variations in Earth's magnetic field
Paleomagnetism, reversal stratigraphy	5×10^5 to 2.5×10^6	Reversal of Earth's magnetic field
Tephrochronology	0 2.5×10^6	Correlation and dating of tephra layers

Adapted and modified from Stokes and Walling (2005)

2003). An alternative to the total inventory approach, which is of interest here, is to date surficial sediment by determining the distribution of the nuclides with depth. This typically involves the collection of a sediment core, its subsectioning into 15–20 units, and their analysis, generally for ^{210}Pb and ^{137}Cs.

The vertical distribution of ^{210}Pb and ^{137}Cs differ significantly from one another as a result of the differing sources. In the case of ^{137}Cs, the profile typically observed in

upland areas is characterized by a peak in concentration which occurs just below the ground surface, and which then decreases to non-detectable levels within a few tens of centimeters in depth (Fig. 3.17 of Chapter 3). The ^{137}Cs profiles constructed for floodplain deposits are also characterized by a peak in concentration. However, the peak typically occurs at a greater depth than is the case for the uplands. Moreover, the total inventory and the depth over which it is distributed tend to be significantly greater than that found at an upland reference site (Fig. A.1). The difference in the observed profiles occurs because the upland soils receive ^{137}Cs solely by means of atmospheric deposition. In contrast, ^{137}Cs within the floodplain deposits is derived both from the atmosphere and from the deposition of ^{137}Cs bound to particles which are deposited on the floodplain during overbank flooding. In the latter instance, the ^{137}Cs represents radiocesium which was atmospherically deposited over the watershed and was subsequently eroded and transported downstream as part of the river's load (Stokes and Walling 2003). It follows, then, that the observed peak in ^{137}Cs represents the floodplain surface at the time of peak fallout (i.e., 1963 in the northern hemisphere and 1964/1965 in the southern hemisphere). The maximum depth to which ^{137}Cs occurs represents its first occurrence in the environment in the 1950s (Popp et al. 1988; Ely et al. 1992). The depth to which these horizons occur represents the thickness to which sediment has accumulated since the horizons were

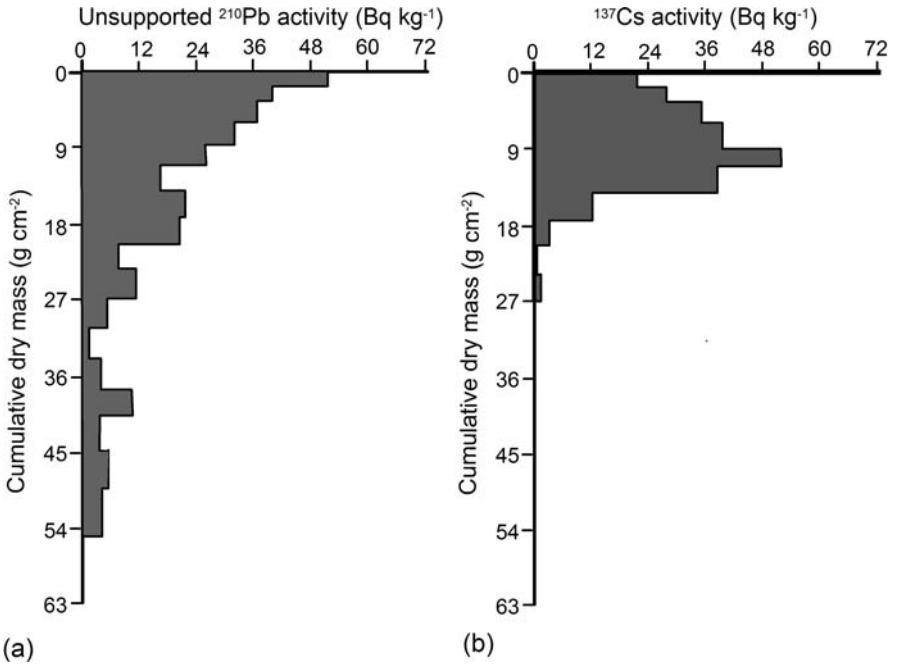

Figure A.1. Excess ^{210}Pb (A) and ^{137}Cs (B) profiles for two sediment cores extracted from the floodplain of the river Culm (Modified from Stokes and Walling 2005)

formed. Because the thickness of sediment deposition is known for a specific time interval, it is possible to calculate an average rate of floodplain aggradation. Such calculations, however, assume that sedimentation is essentially a continuous process (Stokes and Walling 2003). Moreover, the estimates must consider the possibility of the post-depositional redistribution of ^{137}Cs in the profile. As a result of this latter concern, most investigations use the peak in ^{137}Cs to calculate rates of sedimentation rather than its deepest occurrence. This follows because the position of the peak is less likely to be affected by post-depositional processes than the maximum depth to which ^{137}Cs first appears in the sediment record.

Lead-210 occurs naturally as one of the many radionuclides found within the ^{238}U decay series. It is most closely linked to the decay of ^{226}Ra in the soil to ^{222}Rn, the latter of which escapes to the atmosphere. ^{222}Rn subsequently decays through a series of short-lived radionuclides to ^{210}Pb before it is redeposited across the landscape by precipitation or dry deposition (Appleby 2001). This atmospheric ^{210}Pb is commonly referred to as the unsupported or excess ^{210}Pb in the soil and sediment because it represents the ^{210}Pb that occurs in excess of that which is found in equilibrium of ^{226}Ra. It is this excess ^{210}Pb this is used to date sedimentary deposits, and is typically determined by subtracting the supported activity, estimated from the analysis of ^{226}Ra, from the total ^{210}Pb activity.

The potential advantages of using ^{210}Pb over ^{137}Cs are (1) its potential to cover longer-time frames, and (2) its ability to be used in parts of the world, particularly the southern hemisphere, where bomb-derived fallout was limited (Stokes and Walling 2003). Unlike ^{137}Cs, the atmospheric flux of ^{210}Pb to the ground surface is assumed to be constant when considered over a period of a year or more. The near constant flux eliminates the occurrence of a peak in ^{210}Pb activity at depth within the sediment cores. Rather, ^{210}Pb activity is highest at the surface where sediment has been most recently exposed to the atmosphere, and decreases downward in materials that have been buried and removed from the atmospheric inputs (Fig. A.1). The downward decline in activity is associated with the progressively older age of the deeper sediment and radioactive decay such that the total ^{210}Pb activity can be defined by:

$$(1) \qquad C_{tot} = C_{tot}(0)e^{-\lambda t} + C_{sup}(1 - e^{-\lambda t})$$

where C_{sup} is the supported ^{210}Pb activity, λ is the ^{210}Pb radioactive decay constant and $C_{tot}(0)$ is the total ^{210}Pb activity of the sediment at the time that it was buried (Appleby 2001). In most cases, the total ^{210}Pb activity and the ^{226}Ra activity occurs after six to seven half-lives, allowing the dating of sediment over a period of 130–150 years (Appleby 2001). Where the initial ^{210}Pb concentrations are low, or the ^{226}Ra concentrations are high, a distinction between the supported and unsupported ^{210}Pb activity cannot be determined in sediment older than 60 to 90 years (three to four half-lives).

Within lake and floodplain environments, the surficial sediment may exhibit unsupported ^{210}Pb concentrations that are significantly different from that expected from the local atmospheric flux. These differences are predominately related to

inputs associated with the erosion and transport of ^{210}Pb enriched sediment from the catchment, and losses from the water column, particularly in lakes, via outflow and depositional focusing of sediment accumulation. Where these processes are essentially constant, it can be assumed that each layer of sediment will have the same initial unsupported ^{210}Pb concentration. It is therefore a relatively simple matter to estimate sediment age and the rates of sediment accumulation on the basis of the measured variations in the unsupported ^{210}Pb content of the sediment with depth. For example, the mean sedimentation rate (r) can be determined from the slope of the line created by plotting the unsupported ^{210}Pb activity versus sediment depth (usually measured as cumulative dry mass, g/cm^2) (Fig. A.2.) The age of each layer can then be determined by:

$$t = m/r \qquad (2)$$

where t is the age of the layer and m is the depth of the layer below the ground surface. In most cases, however, sediment accumulation rates vary through time, making the estimation of deposit age more difficult. For these types of sites, a number of models have been developed, the two most common of which are the constant rate of ^{210}Pb

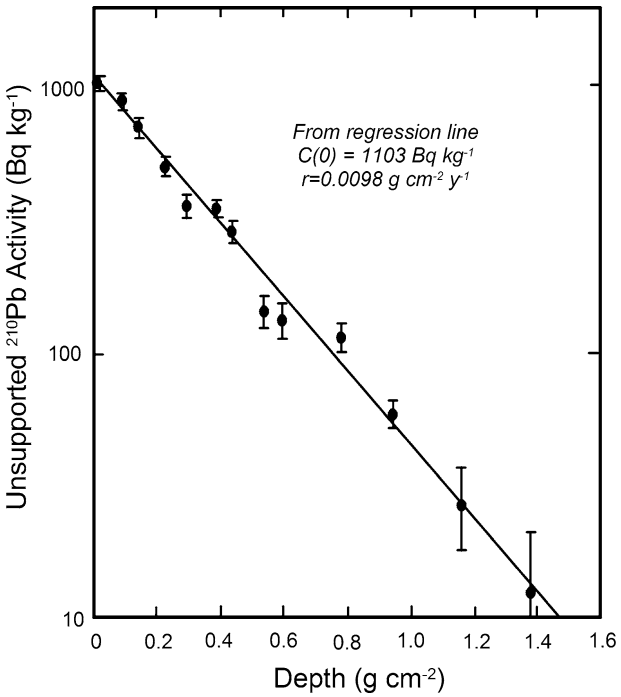

Figure A.2. Regression of unsupported ^{210}Pb activity versus sediment depth in a lake core from Øvre Neadalsvatn, Norway (From Appleby 2001)

supply (CRS) (Appleby and Oldfield 1978; Robbins 1978; Appleby et al. 1979) and the constant initial concentration (CIC) (Appleby and Oldfield 1992).

Lead-210 dating of sediment has been most extensively and effectively applied to reservoir, lake, and wetland environments. In the case of floodplains, He and Walling (1996) suggested that any attempt to date specific horizons in a sediment core was unlikely to yield reliable results. The difficulties arise from (1) the deposition of sediment during infrequent runoff events, (2) variations in depositional rates during overbank flooding as a result of variations in flood magnitude and frequency, and (3) the post-depositional remobilization of sediment which may complicate the vertical distribution of ^{210}Pb in the sediment profile. He and Walling (1996) argued, however, that average long-term, annual rates of sedimentation can be estimated by ^{210}Pb using a constant initial concentration, constant sedimentation rate (CICCS) model. Although the method will not provide continuous ages through the core, it possesses the important advantage of only requiring the measurement of the total ^{210}Pb inventory from the deposits, rather than the measurement of ^{210}Pb in multiple subsections (Stokes and Walling 2003).

A.3. RADIOCARBON (C-14)

The most widely used method for dating deposits greater than approximately 100 to 150 years, but less than about 35 to 50 thousand years of age, is radiocarbon or ^{14}C. ^{14}C is the product of the continual bombardment of ^{14}N in the atmosphere by high-energy cosmic rays. The ^{14}C produced is unstable and decays back to ^{14}N at a constant rate described by its half-live, estimated to be 5,730 $+/-$ 40 years. In other words, half of the ^{14}C within any given reservoir or medium will be converted back to ^{14}N in about 5,730 years.

A certain amount of ^{14}C, along with ^{12}C, is incorporated in CO_2, which allows both isotopes to be accumulated in plants until equilibrium is reached with the atmosphere (Smol 2002); animals also accumulate ^{14}C as they consume organic matter in which it resides. Upon death of the plant or animal, ^{14}C replenishment ends and its levels within the organic materials decline as it decays to N. It follows, then, that the time since the plant or animal died can be determined provided that the initial ^{14}C :^{12} C ratio and the decay rate are known.

Oddly enough, the true half-life of ^{14}C is not used to determine the age of an organic carbon bearing substance. Rather, the half-life of ^{14}C originally determined by William Libby (sometimes referred to as the conventional half-life) of 5,568 years is used to keep all of the radiocarbon dates which have been determined since the 1950s consistent.

Originally, it was assumed that the production of ^{14}C was a constant, but the radiocarbon dating of tree rings (the age of which is precisely known) showed that it was not. Variations in ^{14}C production can be caused by a range of factors including changes in solar activity, the geomagnetic flux, fluctuations in CO_2 uptake by the oceans and human activity (Brown 1997). As a result, the determination of age in terms of calendar dates requires a calibration process which is conducted on a

regional basis. The correction factors are based on a number of parameters including tree rings, ^{14}C dated marine sediments, and ^{14}C/U-Th dated corals (Stuiver et al. 1998; Smol 2002). For a larger number of studies, uncalibrated ages can be used, in which case the dates are reported in years before present (YBP) where the present is set at 1950 AD.

As with any technique there are a number of problems that can affect the results. One of the most important issues is that of contamination. Contamination can occur through a host of processes including rootlet penetration, fungal growth, and the infiltration of humic acids containing younger organic carbon from overlying horizons. Older organic carbon may also contaminate the material, particularly in areas containing calcareous soils or bedrock. In these areas, plants may not only accumulate ^{14}C from the atmosphere, but carbon in the water that was derived from rocks millions of years old. This so-called "hard-water" effect will lead to dates that are significantly older than the material's actual age (MacDonald et al. 1991).

It is important to recognize that the date derived for a particular alluvial stratigraphic unit using ^{14}C is based on the date derived from some organic carbon bearing particle or substance within the deposit. In other words, the method is dating substances contained within the deposit, not the actual time of deposition. An important assumption, then, is that the death of the plant or animal from which the date is derived corresponds very closely with the time of deposition of the sediment in which it resides. This is not always the case, however. For example, charcoal reworked from older deposits can significantly pre-date the timing of deposition, thereby leading to erroneous age estimates. This reworking problem tends to be less significant with the dating of non-woody macrofossils of local origin and which exhibit limited degrees of abrasion (Brown 1997). One of the means which is now being used to overcome the problem of old in-washed carbon from water, contamination by rootlets, and reworked materials is the dating of carbon-bearing materials by accelerator mass spectrometry (AMS). AMS uses very small quantities of material, such as individual macrofossils, which are known to be of local origin. In addition, the ^{14}C content of the material is directly measured, rather than its radioactivity, allowing for a rather precise estimation of the material's age for samples containing as little as 1 to 3 mg of carbon (Hedges 1991).

A.4. LUMINESCENCE TECHNIQUES (TL, IRSL, AND OSL)

Grains of sediment buried within an alluvial deposit are continuously bombarded by very low levels of ionizing radiation as a result of radioactive substances which exist within the sediment mixture. This bombardment leads to the trapping of electrons within individual minerals that accumulate over time in a predictable manner. Upon erosion and exposure to sunlight, the trapped electrons are released within a short-period of time (seconds to minutes) in a process referred to as bleaching. Thus, it is theoretically possible to determine the time since a well-bleach grain was buried

provided that the amount of built up electrons can be measured and the ionizing dose rate is known. Mathematically, the age of burial (B_{age}) is expressed as:

$$(3) \qquad B_{age} = De/Dr$$

where De is the measured equivalent dose for a grain or group of grains, and Dr is the dose rate provided by the ionizing radiation. The dose rate (Dr) can be estimated by determining the concentration of radioactive elements in surrounding materials, usually by mass spectrometry or high-resolution gamma spectrometry (e.g., Olley et al. 2004). The equivalent dose can be determined by measuring the amount of excess energy released in the form of photons, called *luminescence*, as the trapped electrons return to their ground state. The various methods depend on the mechanism used to release the trapped electrons. When luminescence is initiated by thermal stimulation it is called *thermoluminescence* (TL). Luminescence produced by optical stimulation is called *optically stimulated luminescence* (OSL), and infrared stimulation is referred to as *infrared stimulated luminescence* (IRSL). It is probably fair to say that TL and OSL are most widely used methods. TL relies on the application of heat to release the electrons. As the electrons are emitted, an extra amount of light is given off which reflects the quantity of stored electrons. The amount of extra light that is emitted can be determined by re-heating the mineral grains. Since all of the electrons were released the first time the grains were heated, there will be no extra light emitted during repeated heating of the particles. In the case of OSL, visible light is used to stimulate luminescence in quartz, while infra-red radiation is used for feldspars. Again the amount of "extra" light is measured.

As might be expected, a large number of factors can affect the accuracy of the obtained dates, including grain mineralogy, the nature of the ionizing radiation (which is affected by water content of the sediment), the occurrence of surface coatings on grains, and the degree of bleaching before burial. The latter is particularly important in river systems as early studies questioned whether short periods of exposure of sediment to light during transport (particularly in turbid waters) were sufficient to completely bleach the particles, a requirement of obtaining accurate dates (Berger 1984; Bailiff 1992). However, TL has generated ages in some locations which are consistent with other dating methods (Nanson and Young 1987; Nanson et al. 1991). Perhaps more importantly, recent advances in OSL dating, including the measurement of the equivalent dose for individual grains, indicate that it may be a particularly powerful tool for dating deposits in fluvial environments (Murray and Olley 2002; Olley et al. 1999, 2004), particularly in larger catchments, provided an appropriate methodology is used (Stokes and Walling 1993).

A.5. MARKER BEDS (TEPHRA, TRACE METALS)

In many instances it is possible to use one or more distinct horizons that have been deposited nearly instantaneously (at least on the geological time scale) as an indicator of sediment age. Such layers, commonly referred to as *marker beds*, can

be particularly useful because they provide a time-line that may cross-cut multiple depositional environments, thereby allowing for a determination of landscape morphology and character at a specific instant in the past. In addition, their occurrence in a sedimentary package can be used to correlate terraces and other alluvial deposits along a river channel, while their absence indicates that the deposits are either younger or older than the identified horizon. Perhaps the most commonly used and easily recognizable marker beds are composed of tephra (Fig. A.3). Tephra consists of a wide range of pyroclastic material ejected during a volcanic eruption, including pieces of pumice and scoria, glass fragments, and both felsic and mafic minerals. In general, tephra of basaltic composition is black, those of andesitic origin are grey, and rhyolitic materials are white (Turney and Lowe 2001). The particle size of the tephra also varies considerably, ranging from blocks and bombs (>64 mm), lapilli (2–64 mm), and ash (<2 mm). Grain size of the tephra, and its thickness, normally decrease with distance from the source of the volcanic eruption (Turney and Lowe 2001).

Interest in the use of tephra as an age dating tool, referred to as *tephrochronology*, has grown significantly in the past three decades because (1) tephra is deposited nearly instantaneous from the atmosphere over large areas, and therefore provides a precise timeline that cross-cuts multiple depositional environments, (2) multiple tephra units may occur in a region of volcanic activity allowing for the relative or

Figure A.3. Tephra layer (light-colored sediment in center of photo) positioned in alluvial terrace along the Rio Pilcomayo, Bolivia

absolute dating of deposits spanning a wide range of ages, and (3) individual tephra units can readily be identified in stratigraphic sequences. Historically, fingerprinting of tephra relied on the morphology of glass shards, but subsequent studies have demonstrated that shard shape and color are rarely adequate to identify individual eruptive events because their general morphology may be common to other tephras of similar composition (Turney and Lowe 2001). As a result, tephra identification has utilized other parameters including its mineralogy and chemical composition. By themselves, tephra beds can only be used to correlate alluvial deposits; they therefore represent a relative age dating tool. However, tephra beds can be dated using a variety of methods including $^{40}K/^{40}Ar$, $^{40}Ar/^{39}Ar$, thermoluminescence, and fission track analysis (Berger 1992). The age of the tephra units can also be determined indirectly by dating the deposits in which they are contained. Once the age of a tephra unit is adequately constrained, it becomes a powerful absolute dating tool because tephra are time-parallel units (i.e., exhibit a spatially similar age across the landscape), and, thus, a determination of their age at one location is sufficient to determine the tephra's age at all other locations.

Clearly, the fingerprinting and dating of tephra beds is a significant effort. Fortunately, regional chronological sequences have been established for a large number of areas where tephra is commonly found. In addition, there are now a number of labs to which samples can be sent for analysis by tephrachronologists, dramatically simplifying their use as a correlation and dating tool.

In addition to tephra, zones of trace metal enrichment have been used as marker beds. In most instances, horizons distinguished on the basis of elemental concentration are associated with rivers impacted by mining operations. From this perspective, the contaminant character of the deposits provides information on the geomorphic processes within the river. These types of marker beds (i.e., those defined on geochemistry) are more difficult to use than tephra because they are usually not visibly identifiable in the field, and the dispersal of contaminated sediment may require considerable periods of time. Their age, then, may vary with distance from their source. Nonetheless, a number of studies have been able to correlate one or more horizons of elevated trace metal content to specific periods of mining activity, thereby providing an absolute age for the material (Lewin and Macklin 1987; Popp et al. 1988; Macklin and Dowsett 1989). Such geochemical marks have been shown to be particularly useful for floodplain and terrace sediment deposited by vertical accretion processes.

A.6. DENDROCHRONOLOGY

Dendrochronology refers to the science of assigning calendar dates to the annual growth rings in trees (Stokes and Smiley 1968). Its basic principles were developed by an astronomer, Andrew Ellicott Douglass, during the first three decades of the 1900s. Since that time, it has been applied to a growing list of fields including archaeology, climatology, forest ecology, hydrology, seismology, and

geomorphology. It has also been linked to the geochemical analysis of the wood to provide a wealth of information regarding environmental change. One of the areas of growing interest is in the development of *dendrogeomorphic analysis* which refers to the use of dendrochronology to estimate the timing of important geomorphic events (e.g., floods and mass movements) and the rates at which erosional and depositional processes function. The latter involves the dating of recent unconsolidated deposits, the methods of which fall into two broad categories. The first involves the determination of the time at which a geomorphic surface became stabilized by dating the period of germination of the oldest woody species growing on the surface. The technique is based on the realization that zones of deposition or scour are generally devoid of vegetation because the reworking of the surface materials either inhibits germination or rapidly destroys any woody species that germinates before they can be firmly established. At some point, however, the frequency of surface disruption by erosional or depositional processes will slow to the point where they can become rapidly colonized by woody plants (Everitt 1968; Johnson 1994; Scott et al. 1997). The minimum age of surface stabilization can then be determined by dating the oldest trees and shrubs on the surface using dendrochronologic methods (Hupp and Bornette 2003). A common feature to which this method has been applied along meandering rivers is point bars. In these areas, point bars are characterized by bands of woody plants which increase in age with distance from the channel. The maximum age of each band can be determined and used to both date the point bar deposits and estimate the rates of lateral channel migration. This method may be particularly useful in relating point bar and floodplain deposits to periods of contaminant influx along meandering channels.

The second method which is commonly used to date alluvial deposits applies to trees that have been buried by sediment, particularly those growing on floodplains which have been subjected to the periodic deposition of suspended materials during overbank flooding. At the time of germination, tree roots grow just below the ground surface where they are close to sources of water and nutrients. With time, a network of roots will develop which radiates out from the point of germination, creating a basal root flare. This basal root flare, or collar, then, represents a marker of the original ground surface at the time of germination (Fig. A.4). Subsequent deposition, however, may bury the basal root flare, imparting a straight or telephone looking appearance to the tree-trunk at the ground surface (Hupp and Bornette 2003). Burial of the basal roots allow average rates of deposition to be determined by (1) measuring the depth to which the basal root flare is buried, (2) determining the time of germination by dendrochronologically dating an increment core or slab taken near the ground surface, and (3) dividing the depth of burial by the age of the tree. In most instances, numerous trees will need to be analyzed to filter out local site variations. This general approach has been modified to determine temporal trends in sedimentation rates by organizing the collected data into specific age categories ranging from the youngest to the oldest trees present. Average depositional rates can then be determined for each age class, such as a decade, and used to determine changes in depositional rates through time (Hupp and Morris 1990; Hupp and Bazemore 1993).

Figure A.4. Adventitious roots on a Sycamore tree in Southern Illinois buried in response to massive aggradation following forest clearing near the turn of the 20th century. Tree could be dated using dendrochronology to determine the onset of aggradation and the rates of sedimentation

In some cases, basal root flares are associated with buried soils (Fig. A.4). Given that soil formation requires a stable geomorphic surface, the determined ages are likely to indicate the onset of a period of channel instability (i.e., the timing of a threshold crossing event). Thus, dating of the trees not only provides an average rate of deposition for the overlying sediment, but the time at which increased rates of deposition on the surface began. Unfortunately, in many cases, buried paleosurfaces are devoid of living trees. However, a procedure referred to as cross-dating can be used to determine the approximate timing of germination for trees associated with the paleosurface and which are no longer living. Cross-dating essentially matches the pattern of tree-ring widths in the dead and exhumed tree-trunks to that of an existing tree-ring chronology, thereby allowing the age of the trees in question to be determined. Orbock Miller et al. (1993), for example, found a large number of tree stumps buried beneath post-settlement alluvial in the Drury Creek watershed of southern Illinois (Fig. A.5). The basal root flares of these stumps were associated with a buried paleosol. Using cross-dating techniques, they were able to determine the approximate time at which a significant period of channel aggradation began in response to land-uses changes in the watershed at the end of the 1800s and the beginning of the 1900s.

Figure A.5. Buried tree stump in Southern Illinois. Cross-dating allowed the stumps to be dated, thereby allowing a determination of the onset of valley aggradation

The use of dendrochronology and dendrogeomorphology has thus far been highly underutilized in contaminant studies. Nonetheless, one would suspect that these and other biogeomorphic methods will be applied much more frequently to contaminated sites in the future because they are relatively inexpensive, and have been shown to provide accurate results in comparison to data from repeated cross-sections (Hupp and Bazemore 1993).

APPENDIX B

UNIT CONVERSIONS AND ELEMENTAL DATA

Table B.1. List of unit abbreviations

English unit	Abbreviation	SI unit	Abbreviation
Acre	ac	Hectare	Ha
Fahrenheit	F	Celsius	C
Inches	in.	Centimeters	cm
Yards	yd	Meters	m
Ounces	oz	Grams	gm
Pounds	lb	Kilograms	kg
Gallons	gal	Liter	l
		Milliliter	ml

Table B.2. Common conversions

Distance/Length	Area
$1\,\text{nm} = 10^{-9}\,\text{m}$	$1\,\text{ft}^2 = 9.280 \times 10^{-2}\,\text{m}^2$
$1\,\mu\text{m} = 10^{-6}\,\text{m}$	$1\,\text{acre} = 0.4046$ hectares
$1\,\text{mm} = 10^{-3}\,\text{m}$	$1\,\text{mi}^2 = 2.5899\,\text{km}^2$
$1\,\text{cm} = 10^{-2}\,\text{m}$	
$1\,\text{km} = 10^{3}\,\text{m}$	
$1\,\text{mile} = 1.609\,\text{km}$ or $1{,}609.34\,\text{m}$	
$1\,\text{in.} = 25.4\,\text{mm}$ or $2.54\,\text{cm}$	
Flow/Volume	Mass/Weight
$1\,\text{ml} = 10^{-3}\,\text{L}$	$1\,\text{pg} = 10^{-12}\,\text{g}$
$1\,\text{L} = 1000\,\text{cm}^3$	$1\,\text{ng} = 10^{-9}\,\text{g}$
$1\,\text{gal} = 3.785\,\text{L}$	$1\,\mu\text{g} = 10^{-6}\,\text{g}$
$1\,\text{quart (US)} = 0.9463\,\text{L}$	$1\,\text{mg} = 10^{-3}\,\text{g}$
$1\,\text{ft}^3 = 0.0283\,\text{m}^3$	$1\,\text{kg} = 10^{3}\,\text{g}$
$1\,\text{cfs} = 28.32\,\text{L/s}$ or $0.0283\,\text{m}^3/\text{s}$	$1\,\text{metric ton} = 10^{3}\,\text{kg}$
	$1\,\text{short ton} = 2{,}000\,\text{lbs}$ or $907.184\,\text{kg}$
	$1\,\text{lb} = 453.592\,\text{g}$
	$1\,\text{troy oz} = 31.1035\,\text{g}$

(Continued)

Table B.2. (Continued)

Radioactivity	Pressure
1rad (absorbed dose) $= 10^{-2}$ J/kg	1 bar $= 10^5$ Pa or 0.9869 atm
1pCi $= 10^{-12}$ Ci or 0.037 Bq	1 Pa $= 10^{-5}$ bar
1curie $= 3.7 \times 10^{10}$ dps	1 atm = 760 mm Hg or 1.01325×10^5 Pa
1becquerel (Bq) = 1.0 dps	

Table B.3. Units of concentration

Concentrations (volume)		Concentrations (weight)	
Unit	*Symbols*	*Unit*	*Symbols*
moles per liter	mol/L or M	moles per kg	mol/kg
millimoles per liter	mmol/L or mM	milliequvalents per kilogram	meq/kg
micromoles per liter	μmol/L or μM	micrograms per kg or ppb	μg/kg or ppb
micrograms per liter	μg/L	milligrams per kg or parts per million	g/kg = ppm

Table B.4. Load calculation constants

Units of concentration	Units of flow	Constant
μg/L	m^3/s	0.000864
mg/L	m^3/s	0.0864
g/L	ft^3/s	86.4
μg/L	ft^3/s	0.000002447
mg/L	ft^3/s	0.002447
g/L	ft^3/s	2.447

Adapted from Richards (2001)
Load = constant × concentration × flow

Table B.5. Elemental data

Element	Symbol	Atomic number	Atomic weight
Hydrogen	H	1	1.0079
Helium	He	2	4.0026
Lithium	Li	3	6.941
Beryllium	Be	4	9.0122
Boron	B	5	10.811
Carbon	C	6	12.011
Nitrogen	N	7	14.007
Oxygen	O	8	15.999
Fluorine	F	9	18.998
Neon	Ne	10	20.180
Sodium	Na	11	22.980
Magnesium	Mg	12	24.305
Aluminum	Al	13	26.982

Silicon	Si	14	28.086
Phosphorus	P	15	30.974
Sulfur	S	16	32.065
Chlorine	Cl	17	35.453
Argon	Ar	18	39.948
Potassium	K	19	39.098
Calcium	Ca	20	40.078
Scandium	Sc	21	44.956
Titanium	Ti	22	47.867
Vanadium	V	23	50.942
Chromium	Cr	24	51.996
Manganese	Mn	25	54.938
Iron	Fe	26	55.845
Cobalt	Co	27	58.693
Nickel	Ni	28	58.693
Copper	Cu	29	63.546
Zinc	Zn	30	65.39
Gallium	Ga	31	69.723
Germanium	Ge	32	72.84
Arsenic	As	33	74.922
Selenium	Se	34	78.96
Bromine	Br	35	79.904
Krypton	Kr	36	83.80
Rubidium	Rb	37	85.468
Strontium	Sr	38	87.62
Yttrium	Y	39	88.906
Zirconium	Zr	40	91.224
Niobium	Nb	41	92.906
Molybdenum	Mo	42	95.94
Technetium	Te	43	(98)
Ruthenium	Ru	44	101.07
Rhodium	Rh	45	102.91
Palladium	Pd	46	106.42
Silver	Ag	47	107.87
Cadmium	Cd	48	112.41
Indium	In	49	114.82
Tin	Sn	50	118.71
Antimony	Sb	51	121.60
Tellurium	Te	52	127.60
Iodine	I	53	126.90
Xenon	Xe	54	131.29
Cesium	Cs	55	132.91
Barium	Ba	56	137.33
Lanthanum	La	57	137.91
Cerium	Ce	58	140.12
Praseodymium	Pr	59	140.91
Neodymium	Nd	60	144.24
Promethium	Pm	61	(145)
Samarium	Sm	62	150.36
Europium	Eu	63	150.96
Gadolinium	Gd	64	157.25
Terbium	Tb	65	158.93

(Continued)

Table B.5. (Continued)

Element	Symbol	Atomic number	Atomic weight
Dysprosium	Dy	66	162.50
Holmium	Ho	67	164.93
Erbium	Er	68	167.26
Thulium	Tm	69	168.93
Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.97
Hafnium	Hf	72	178.49
Tantalum	Ta	73	180.95
Tungsten	W	74	183.84
Rhenium	Re	75	186.21
Osmium	Os	76	190.23
Iridium	Ir	77	192.22
Platinum	Pt	78	195.08
Gold	Au	79	196.97
Mercury	Hg	80	200.59
Thallium	Tl	81	204.38
Lead	Pb	82	207.2
Bismuth	Bi	83	208.98
Polonium	Po	84	(209)
Astatine	At	85	(210)
Radon	Rn	86	(222)
Francium	Fr	87	(223)
Radium	Ra	88	(226)
Actinium	Ac	89	(227)
Thorium	Th	90	232.94
Protactinium	Pa	91	232.04
Uranium	U	92	238.03
Neptunium	Np	93	(237)
Plutonium	Pu	94	(244)
Americium	Am	95	(243)
Curium	Cm	96	(247)
Berkelium	Bk	97	247
Californium	Cf	98	(251)
Einsteinium	Es	99	(252)
Fermium	Fm	100	(257)
Mendelevium	Md	101	(258)
Nobelium	No	102	(259)
Lawrencium	Lr	103	(262)
Rutherfordium	Rf	104	(261)
Dubnium	Db	105	(262)
Seaborgium	Sg	106	(266)
Bohrium	Bh	107	(264)
Hassium	Hs	108	(265)
Meitnerium	Mt	109	(267)
Ununnilium	Uun	110	285
Ununbium	Uub	112	285
Ununquadium	Uuq	114	289

(xxx) – The mass number of the longest-lived isotope of the element

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GLOSSARY

Absorption: The incorporation of ions into the crystal structure of a mineral or other substrate.

Accuracy: Degree to which an observation or measurement corresponds to the true value.

Action Levels[1]: (1) The existence of a contaminant concentration in the environment high enough to warrant action or trigger a response.

Acute Exposure[1]: A single exposure to a toxic substance which results in severe biological harm or death. Acute exposures are usually characterized as lasting no longer than a day.

Acute Toxicity[1]: The ability of a substance to cause poisonous effects resulting in severe biological harm or death soon after a single exposure or dose. Can also refer to any severe poisonous effect resulting from a single short-term exposure to a toxic substance.

Adsorption: A process referring to the removal of dissolved species from solution and their accumulation on a particle surface without the formation of a distinct, three-dimensional molecular structure.

Aerobic[1]: Processes or life forms that require, or are not destroyed by, the presence of oxygen.

Aggradation: Long-term accumulation of sediment on the channel bed, forming a new base level.

Alluvial Channel: A channel whose bed and banks are composed of unconsolidated materials.

Alluvial Sediment: Sediment composed of unconsolidated material deposited by a river or running water.

Alluvium: Unconsolidated sediment deposited by a river or running water.

Alpha Particle[1]: A positively charged particle composed of two neutrons and two protons released by some atom undergoing radioactive decay. The particle is identical to the nucleus of a helium atom.

Anaerobic[1]: A process or life form that occurs in, or is not destroyed by, the absence of oxygen.

Aquifer[1]: An underground geological formation, or group of formations, containing usable amounts of groundwater that can supply wells and springs.

Aromatic: Substance characterized by the presence of at least one benzene ring.

Assessment: The means for determining the nature, extent and levels of existing contamination at a site, and the actual or potential risk(s) that the contaminant poses to human or ecosystem health.

Attenuation[1]: The process by which a compound is reduced in concentration over time, through adsorption, degradation, dilution, and/or transformation.

Bacteria[1]: (Singular: bacterium) Microscopic living organisms.

Base Level: Theoretical level to which a river can erode. The ultimate base level is sea level.

Bedload: Material that is transported close to the channel bottom by rolling, sliding, or bouncing (saltating).

Bed Material Load: Particles found in appreciable quantities on the stream bed, but which may be moved as bedload or in suspension.

Benthic Organism (Benthos)[1]: A form of aquatic plant or animal life that is found on or near the bottom of a stream, lake or ocean.

Beta Particle[1]: An elementary particle emitted by radioactive decay that may cause skin burns. It is halted by a thin sheet of paper.

Biodegradable[1]: The ability to break down or decompose rapidly under natural conditions and processes.

Biofilm: A dense, gelatinous coating on sediment produced by a wide range of microorganisms; often highly reactive and composed of hydrated exopolysaccharide and polypeptide polymers.

Biomagnification: A process whereby a substance increases in concentration up the food chain.

Biota[1]: All living material in a given area.

Biotic Community[1]: A naturally occurring assemblage of plants and animals that live in the same environment and are mutually sustaining and interdependent.

Cap[1]: A layer of clay, or other highly impermeable material installed over the top of a landfill or contaminated area to prevent entry of rainwater and minimize production of leachate.

Capacity: Maximum amount of sediment that a river is capable of transporting.

Carcinogen[1]: Any substance that can cause or contribute to the production of cancer.

Cation Exchange Capacity: The propensity for a given substance to exchange cations with those in a chemically defined solution.

Channelization[1]: Straightening and deepening of a stream so water will move faster; typically used as a flood-reduction or marsh-drainage measure that can interfere with waste assimilation capacity and disturb fish and wildlife habitats.

Chronic Toxicity[1]: The capacity of a substance to cause long-term poisonous human health effects.

Cleanup[1]: Actions taken to deal with a release or threat of release of a hazardous substance that could affect humans and/or the environment. The term "cleanup" is sometimes used interchangeably with the terms remedial action, removal action, response action, or corrective action.

Coliform[1]: Microorganisms found in the intestinal tract of humans and animals. Their presence in water indicates fecal pollution and potentially dangerous bacterial contamination by disease-causing microorganisms.

Common Ion Effect: The lowering of the solubility of a mineral as a result of the occurrence of one of its reaction products from another source.

Competence: The size of the largest particle that a river can carrier under a given set of hydraulic conditions.

Composite Sampling: (1) The collection of the water and sediment continuously over a relatively long period of time, (2) The collection of multiple, instantaneous samples which are combined prior to analysis, (3) Collection and mixing of multiple samples from geographically different areas prior to analysis. The intent is to reduce the number of samples that must be analyzed, while obtaining a more accurate, average concentration of the constituent for that particular increment of time.

Contaminant[1]: Any physical, chemical, biological, or radiological substance or matter that has an adverse affect on air, water, or soil.

Curie[1]: A quantitative measure of radioactivity equal to 3.7×10^{10} disintegrations per second.

Degradation: Long-term erosion of channel bed, thereby lowering base level.

Detachment: Surface process that increases the susceptibility of individual particles of a geologic substrate at the ground surface to movement by the breaking of chemical and physical bonds.

Diagenesis[2]: Physical or chemical process affecting a sedimentary unit or rock after it has been deposited, excluding those processes occurring at sufficiently high temperatures to be considered metamorphic.

Diffuse Flow: Movement of water through a network of interconnected pores in the sediment.

Discharge: The volume of water that passes a given cross section in the channel (or subsurface) during a specified time interval. In rivers, it is usually expressed in units of cubic feet per second or cubic meters per second, and can be expressed mathematically as the product of width, depth, and velocity.

Disposal[1]: Final placement or destruction of toxic, radioactive, or other wastes; disposal may be accomplished through use of approved secure landfills, surface impoundments, land farming, deep well injection, ocean dumping, or incineration.

Direct Runoff: The quantity of water that flows into a stream channel in direct response to a precipitation event.

Dolomite[2]: A mineral ($CaMg(CO_3)_2$), or rock composed primarily of that mineral.

Drainage Basin. The discernible, finite land area which is drained by a trunk channel and all its interconnected network of tributaries and streams. Represents a fundamental unit of the landscape through which solutes, sediments, and contaminated particles are collected, transported, and stored. Used interchangeable with watershed.

Dredging[1]: Removal of sediment from the bottom of a water body.

Ecological Impact[1]: The effect that a man-made or natural activity has on living organisms and their non-living (abiotic) environment.

Ecosystem[1]: The interacting system of a biological community and its non-living environmental surroundings.

Effluent[1]: Wastewater – treated or untreated – that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.

Entrainment: All of the processes involved in initiating motion of a particle from a state of rest.

Estuary[1]: Regions of interaction between rivers and nearshore ocean waters, where tidal action and river flow create a mixing of fresh and salt water. These areas may include bays, mouths of rivers, salt marshes, and lagoons.

Facies: The characteristics of a sedimentary package or rock unit that usually reflect the location or conditions of its origin.

Feasibility Study[1]: (1) Analysis of the practicability of a proposal; e.g., a description and analysis of the potential cleanup alternatives for a site or alternatives for a site on the National Priorities List. The feasibility study usually recommends selection of a cost-effective alternative. It usually starts as soon as the remedial investigation is underway; together, they are commonly referred to as the "RI/FS". The term can apply to a variety of proposed corrective or regulatory actions, (2) In research, a small-scale investigation of a problem to ascertain whether or not a proposed research approach is likely to provide useful data.

Fecal Coliform Bacteria[1]: Bacteria found in the intestinal tracts of mammals. Their presence in water or sludge is an indicator of pollution and possible contamination by pathogens.

Felsic Rock[2]: A light-colored rock usually consisting of feldspars and or quartz.

Fluvial: Pertaining to or produced by a river.

Food Chain[1]: A sequence of organisms, each of which uses the next, lower member of the sequence as a food source.

Fresh Water[1]: Water that generally contains less than 1,000 milligrams-per-liter of dissolved solids.

Fungi[1]: (Singular, Fungus) A group organisms that lack chlorophyll (i.e., are not photosynthetic) and which are usually non-mobile, filamentous, and multicellular. Some grow in the ground, others attach themselves to decaying trees and other plants, getting their nutrition from decomposing organic matter. Some cause disease, others stabilize sewage and break down solid wastes in composting. Includes molds, mildews, yeasts, mushrooms, and puff-balls.

Fungicide: Pesticides which are used to control, prevent, or destroy fungi.

Gamma Radiation[1]: Gamma rays are true rays of energy in contrast to alpha and beta radiation. The properties are similar to x-rays and other electromagnetic waves. They are the most penetrating waves of radiant nuclear energy but can be blocked by dense materials such as lead.

Groundwater: Loosely defined as all subsurface water, as distinct from surface water.

Habitat[1]: The place where a population (e.g., human, animal, plant, microorganism) lives and its surroundings, both living and non-living.

Half-life: Time required for a radioactive material to loose half of its radioactivity.

Hazardous Substance[1]: Any material that poses a threat to human health and/or the environment. Typical hazardous substances are toxic, corrosive, ignitable, explosive, or chemically reactive.

Hazardous Waste[1]: By-products of society that can pose a substantial or potential hazard to human health or the environment when improperly managed. Waste possesses at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity).

Heavy Mineral: A mineral generally possessing a specific gravity of greater than 2.85. Usually found as a minor constituent ($<1\%$) of common rocks. Includes magnetite, ilmenite, zircon, rutile, kyanite, garnet, sphene, apatite, and biotite, among others.

Holocene: An epoch in the Quaternary period extending from approximately ten thousand years ago to the present.

Hydrograph: A graph depicting changes in stage or discharge of water through time.

Humic Substances: Nonliving, partially decomposed and visually unidentifiable materials that are characterized by extreme heterogeneity in chemical composition and structure.

Hydraulic conductivity: A measure of the rate at which water flows through a unit cross section under unit hydraulic gradient.

Hydrogeology[1]: The geology of groundwater, with particular emphasis on the chemistry and movement of water.

Hydrology[1]: The science dealing with the properties, distribution, and circulation of water.

Hydrophilic: Having an affinity for water.

Hydrophobic: Having an attraction or affinity for particulate matter. Generally refers to contaminants that are associated with particles, and for which the dissolved concentrations are extremely low.

Incision: A process in which a channel lowers it bed elevation through downward erosion. Used interchangeably with entrenchment.

Influent Flow: Movement of water into the ground from a surface water body.

Inorganic Chemicals[1]: Chemical substances of mineral origin, not of basic carbon structure.

Infiltration: Portion of precipitation that is absorbed into the underlying materials.

Infiltration capacity: The rate at which infiltration occurs, usually measured in mm per hour.

Interflow: See throughflow.

Interception: Process by which precipitation is caught by vegetation and is returned to the atmosphere before reaching the ground.

Ion: An electrically charged atom or group of atoms.

Isotope[1]: A variation of an element that has the same atomic number but a different weight because of a different number of neutrons.

Isotopic ratio: Ratio of abundance of any two isotopes.

Knickpoint: Point of abrupt change in the longitudinal profile (slope) of a stream. Slope is often nearly vertical.

Lacustrine: Pertaining to, produced by or formed within a lake.

Landfills[1]: (1) Sanitary landfills are land disposal sites for non-hazardous solid wastes at which the waste is spread in layers, compacted to the smallest practical volume, and cover material applied at the end of each operating day, (2) Secure chemical landfills are disposal sites for hazardous waste. They are selected and designed to minimize the chance of release of hazardous substances into the environment.

Landform: A physical, recognizable feature of the Earth's surface possessing a characteristic shape and which is produced by natural processes.

Leachate: A liquid resulting from the percolation of water or other fluid through wastes, contaminated materials, or other substance.

Lithology: Mineral composition of rock or sedimentary unit.

Load: The mass of material that passes a given point in the channel. The timeframe is not explicitly stated, but must be obtained from the context in which it is used. Load is given in units of mass (tons, kg, etc.).

Mafic Rock[2]: A usually dark-colored rock having a high proportion of ferromagnesian minerals.

Mass Movement: Movement of Earth material downslope under the influence of gravity.

Media[1]: Specific environments – air, water, soil – which are the subject of regulatory concern and activities.

Microbes[1]: Microscopic organisms such as algae, animals, viruses, bacteria, fungus, and protozoa, some of which cause diseases (see microorganism).

Mitigation[1]: Measures taken to reduce adverse impacts on the environment.

Model: A working representation of a phenomenon or process that cannot be precisely observed or described.

Monitoring[1]: Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things.

National Priorities List (NPL)[1]: USEPA's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial action under Superfund. A site must be on the NPL to receive money from the Trust Fund for remedial action. The list is based primarily on the score a site receives from the Hazard Ranking System.

Non-ionic: Materials possessing no charge on its surface-active ion(s).

Non-point source: The delivery of pollutants to a river from a diffuse area, such as an agricultural field or an urban center.

Oxidation: (1) A chemical process in which electrons are removed from an atom, (2) The addition of oxygen to break down organic waste or chemicals such as cyanides, phenols, and organic sulfur compounds by bacterial and chemical means.

Pathogenic[1]: Capable of causing disease.

Permeability: Capacity of a rock or sedimentary unit to transmit a fluid. Typically used to indicate the ease with which the fluid can move through a material under conditions of unequal pressure.

Phase: Physical or chemical composition of the material with which the constituents are associated.

Pleistocene[2]: A time period roughly corresponding to the ice ages (10,000–2 million years before present). Represents the time period before the recent (Holocene).

Point Source: Discharge of contaminants from a specific location, such as the end of a pipe or canal.

Precision: Describes the ability to reproduce the results of a measurement; if there is little difference between replicate measurements, then the method used in making the measurement is called precise.

Process: Action through which one feature or item is produced from something else.

Quaternary: Period of geologic time extending from approximately two to three million years ago and extending to the present.

Radiation[1]: Any form of energy propagated as rays, waves, or streams of energetic particles. The term is frequently used in relation to the emission of rays from the nucleus of an atom.

Radioactive Substances[1]: Substances that emit radiation.

Radionuclide[1]: Radioactive element characterized according to its atomic mass and atomic number which can be man-made or naturally occurring. Radioisotopes can have a long life as soil or water pollutants, and are believed to have potentially mutagenic effects on the human body.

Reagent: A substance, chemical, or solution involved in a chemical reaction. Often used to detect, measure or otherwise examine other substances, chemicals or solutions.

Recharge[1]: The process by which water is added to a zone of saturation, usually by percolation from the soil surface, e.g., the recharge of an aquifer.

Record of Decision (ROD)[1]: A public document that explains which cleanup alternative(s) will be used at National Priorities List sites where, under CERCLA, Trust Funds pay for the cleanup.

Reduction: A chemical reaction in which an atom gains one or more electrons.

Refractory: A material characterized by a high melting point.

Remedial Action[1]: The actual construction or implementation of site cleanup that follows remedial design.

Remedial Design[1]: A phase of remedial action that follows the remedial investigation/feasibility study and includes development of engineering drawings and specifications for a site cleanup.

Remedial Investigation[1]: An in-depth study designed to gather the data necessary to determine the nature and extent of contamination at a site; investigation establishes criteria for cleaning up the site and identifies preliminary alternatives for remedial actions. Also supports technical and cost analyses of the alternatives. In the case of the U.S. Superfund Program, the remedial investigation is usually done with the feasibility study. Together they are usually referred to as the "RI/FS".

Remediation: The application of methods that prevent, minimize, or mitigate the damage to human health or the environment by a contaminant; it can involve any method that removes, contains, destroys, or reduces the exposure of pollutants to biota.

Residual[1]: Amount of a pollutant remaining in the environment after a natural or technological process has taken place.

Restoration: The return of a riverine ecosystem to a more natural working order that is sustainable over the long-term, while creating a river that is more productive, aesthetically appealing, and valuable.

Return flow: Type of overland flow in which water that has infiltrated the sediment, flows downslope, and subsequently returns to the surface before entering a stream channel.

Riparian Habitat[1]: Areas adjacent to rivers and streams that have a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

Risk Assessment[1]: The qualitative and quantitative evaluation performed in an effort to define the risk posed to human health and/or the environment by the presence or potential presence of specific pollutants.

River Stage: Height of the water surface in a stream above some arbitrary datum.

Saturation Overland Flow: Movement of water over the ground surface where the water table intersects the ground surface, or when water accumulates above a relatively impermeable horizon. It consists of two components: return flow and direct precipitation on saturated areas.

Saturated Zone[1]: A subsurface area in which all pores and cracks are filled with water under pressure equal to or greater than that of the atmosphere.

Sorption: The accumulation of constituents dissolved within river or pore waters on particle surfaces; occurs through a combination of mechanisms, including absorption, adsorption, and precipitation.

Subsurface Stormflow: The combined effects of enhanced groundwater flow and throughflow to a river channel.

Superfund[1]: A program in the U.S. operated under the legislative authority of CERCLA and SARA that funds and carries out the USEPA solid waste emergency and long-term removal remedial activities. These activities include establishing the National Priorities List, investigating sites for inclusion on the list, determining their priority level on the list, and conducting and/or supervising the ultimately determined cleanup and other remedial actions.

Surface Water: All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, impoundments, seas, estuaries, etc.).

Surfactant: A soluble compound which reduces surface tension in liquids, and/or reduces interfacial tension between liquids or a liquid and a solid.

Suspended Load: The downstream movement of fine-grained particles transported within the water column. Particles are held in suspension by short, but intense, upward deviations in the flow as a result of turbulent eddies.

System: Interconnected group of features or forces.

Tectonic: Pertaining to the forces that deform rocks and sediment, and result in structural features such as faults and joints. Often associated with mountain building processes.

Throughflow: Movement of water above the water table through locally saturated materials during and after a precipitation event.

Toxic Pollutants[1]: Materials contaminating the environment that cause death, disease, birth defects in organisms that ingest or absorb them.

Unsaturated Zone[1]: The area above the water table where the soil pores are not fully saturated, although some water may be present.

Wash Load: Particles so small that they are absent from the channel bed sediment. The implication is that after these particles have been eroded, they are transported through the river system without ever coming to rest within the channel.

Watershed[1]: The land area that drains into a stream.

Volatile: A substance that evaporates readily.

Water Table: Surface along which the groundwater pressure is equal to atmospheric pressure, and which separates the zone of saturation from the zone of aeration.

Zeolite[2]: A group of hydrated aluminosilicate minerals which are chemically similar to feldspars plus water, plus/minus silica. Some zeolites have a high cation-exchange capacity. Some also are used in industry as molecular sieves.

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[1] Terms from the Glossary of Environmental Terms and Acronym List, U.S. Environmental Protection Agency, August 1988

[2] Terms after from Drever (1988)

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CHAPTER 3

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CHAPTER 5

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