A Little Flood Geology

Part I: Importance of Flood Geology

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Abstract

Floods are a key category of geologic processes. Creationists often refer to "Flood geology," while those who try to emphasize evidence for intelligent design without any reference to the Bible often avoid geology entirely, and those with traditional old earth beliefs sometimes downplay the effects of floods. Floods observed in today's world make important analogues to megafloods, including the Deluge of Noah's day. This paper provides some examples of geologic work by floods and related processes in Central Montana as experienced by the author and also provides ideas about how these may apply to the study of earth history. It is important to recognize the limitations of analogues, especially effects of scale with these episodic events. Part I introduces flood geology and provides data and interpretations related to observed floods, starting with basic open channel flow equations and principles of scour analysis. Initial scour estimates for a flood in the study area are presented. Scour analysis is complex and beset by much uncertainty, but it is still very useful since science must be constrained by real world data.

The Importance of Flood Geology

Geologists universally recognize the importance of floods, but the larger the scale, the larger the controversy. When the traditional view of earth history was popularized by James Hutton, Charles Lyell, and others, the goal was to explain away nearly all unusual events, especially those mentioned in the Bible (Rudwick, 2005). Several researchers have made important contributions to our understanding of how belief in an ancient earth and uniformitarianism has provided justification in the minds of many to reject the Bible (Milton, 1997; Morris, 1989; Mortenson, 2004; Reed, 2001) and other ancient historical sources, just as Hutton, Lyell, and many of their influential contemporaries intended. A global flood is entirely incompatible with the naturalistic world history needed to deny God's judgment on sin, and so many notable individuals followed Lyell's example in attempting to explain geologic features through slow, presently observable geologic processes. Obviously, the sentiment behind these developments was not motivated by a humble, detached, objective search for

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truth! Enlightenment intellectuals denied the reliability of all ancient records and proclaimed their inherent superiority over previous generations (Ruse, 2011). Unfortunately for uniformitarians, science has been very unkind to them. Floods do occur, and the importance of flood geology often hits close to home.

Geotechnical engineers and engineering geologists frequently estimate scour depths of rivers to determine whether bridges are adequately supported, or other structures protected from natural disasters. "During the 20th century, floods were the number-one natural disaster in the United States in terms of number of lives lost and property damage" (Perry, 2000, p.1). Property damage of some of these floods was valued in the billions of dollars (Perry, 2000), and the total annual flood damage in the United States is several billion dollars (O'Connor and Costa, 2003). While God promised never to destroy the earth again with a *mabbul* (or *mabbuwl*, translated "flood" in Genesis 9:11), He never promised that local floods—some very large—would not occur, some of which have been very destructive (Figure 1). Flood scour may be the single most common cause of bridge failure (New York State Department of Transportation, 2016).

Figure 1. The Busy Bee Café in early June 2011. During the flood, the water was at least to the top of the tables. Photograph courtesy City of Roundup.

The Mechanics of Floods

A rule of thumb in geology is that most geologic work by rivers occurs during infrequent floods, with the majority of time accomplishing very little. The reason for this is simple: energy. Erosion is largely governed by stream flow (hence stream power or bed shear stress), the nature of the bed materials, and the slope of the bed. This is known as the "stream power law," written on a unit basis (Costa, 1983) as:

$$\omega = \gamma_f D S \mathbf{v} \qquad (1)$$

Where ω is the unit stream power vector, γ_f is fluid density (or unit weight), D is flow depth, S is bed slope, and **v** is mean velocity. There are some basic relationships evident in the stream power law. Water density increases with sediment load. For a given reach, bed slope is generally nearly constant, and stream power is proportional to it. Stream power is proportional to depth and velocity. Depth and velocity are related, and velocity can be inferred from depth. In most cases, as depth increases, velocity does too, following a parabolic distribution since the boundary layer where shear stresses resist movement remains at the stream bed. (The exception to this depth-velocity proportionality is when velocity exceeds critical flow or hydraulic jump occurs.)

For a stream bed armored with gravel or bedded in sand (i.e. cohesionless materials), a shear stress threshold must be reached before the rocks or sand (or silt) grains begin to move. Above this value, more of them move faster, while below this value, they do not move at all. The unit rate of erosion can be described thus (Benito, 1997):

$$q_e = k(\omega - \omega_c)^n \qquad (2)$$

Where q_e is the rate of erosion per unit width, k is a material-specific constant, ω is the magnitude of unit stream power, and ω_c is the critical stream power or erosion threshold. Below a unit stream power of ω_c, negligible erosion will take place. As stream power increases above ω_c, dramatic changes can take place. For example, the inferred intensity of the Missoula Flood was greater than the Bonneville Flood despite the fact that the Bonneville Flood is believed to have released five times the total potential energy (Benito, 1997). Critical stream power is a key variable; virtually no geologic work occurs until ω_c is exceeded. Equation (2) shows that unit erosion is related to the excess stream power (stream power greater than ω_c) by a power relationship; it is nonlinear.

Based on conservation of energy, it is possible to estimate the amount of energy available for erosion. Since conservation of energy means energy is neither created nor destroyed but only changed in form, the total of potential energy and kinetic energy at one cross-section must be equal to this sum plus any tributary additions at a downstream cross-section, subtracting any dissipative losses. Dissipative losses are lumped together as *head loss* due to friction, and these include frictional heating of the water, noise, and geologic work. Geologic work includes erosion (physical weathering and transport) and deposition. As found in any fluid mechanics textbook, this relationship can be expressed as:

$$h_f = LS_f + C(\alpha_2 v_2^2 - \alpha_1 v_1^2)/2g \qquad (3)$$

where h_f is head loss due to friction, L is the length of the study reach, S_f is the frictional slope (related to Manning's roughness coefficient or the similar Chezy equation coefficient), C is the energy loss coefficient related to channel uniformity, α_1 and α_2 are velocity head coefficients for the upstream and downstream cross-sections, respectively, v_1 and v_2 are mean velocities for the upstream and downstream cross-sections, and g is the acceleration due to gravity. From equation (3), one can see that the effect of velocity is to the second power. The relationship between head loss and velocity is nonlinear.

Alluvial channels tend to reconfigure through erosion and deposition to achieve an equilibrium with minimal energy loss (Chang, 1979). Floods sometimes cut off meanders, smooth out irregularities in bed slope, and provide other examples of Chang's hypothesis.

Practical Application

This head loss equation is the basis for the HEC-RAS computer program produced by the U.S. Army Corps of Engineers and widely used to model stream behavior. HEC-RAS is commonly used in hydraulic engineering studies of streams. The Corps of Engineers has the primary national responsibility for wetland, flood, and river management in the United States.

The primary flood geology interest of the Federal Highway Administration has been scour: bridge pier scour, contraction scour where roadways limit channel widths, and abutment scour where bridge abutments encroach on flood plains or stream channels. There are three levels of analysis (Holnbeck and Parrett, 1997): Level 1 is qualitative, Level 2 is quantitative, and Level 3 is site specific modeling. Level 2 analysis typically uses standard programs such as HEC-RAS, HEC-2, and WSPRO. These are simplified one-dimensional analyses. It is seldom economically justified to develop a Level 3 analysis, which demands not only laborious finite element or finite difference modeling but also departs from most of the simplifying assumptions used with common flood geology and hydraulic engineering equations.

Two of the most important simplifying equations are uniformity and steadiness. Unsteady flow waxes and wanes, and this is the nature of floods. However, this assumption is usually appropriate since the peak flow is what is normally the matter of interest. Uniformity is more difficult. When a stream channel is sinuous, with changes in width and depth, it is nonuniform. Uniformity can be approximated as the limit of the reach length is reduced (a la calculus or finite element modeling). Results are often difficult to predict. Sometimes uniformity can be adequately approximated with a change in roughness coefficient or some other simple modification; sometimes it is not so simple. Obstructions, such as boulders and bridge piers, are deviations from uniformity (Figure 2). During floods, flow across a flood plain may exceed flow in the channel. Flood geology can be complex, both in terms of hydraulic processes (transport) and sedimentation (removal and deposition of sediment).

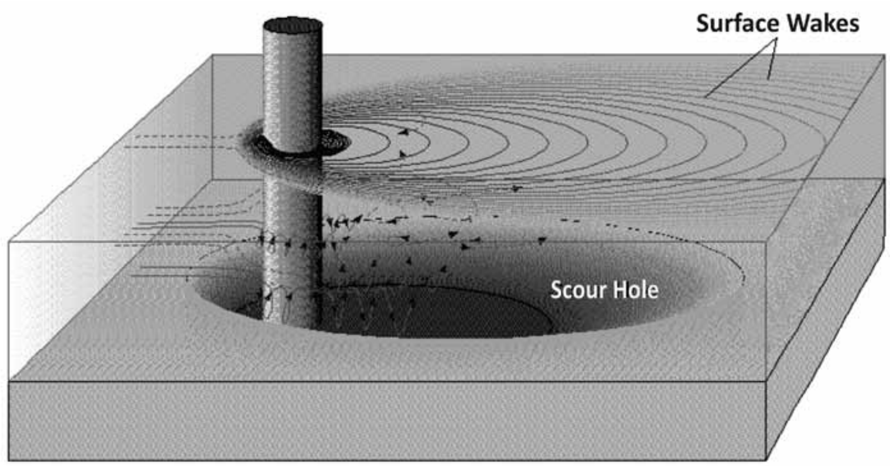

Figure 2.

A specific example from the Judith River of Montana (Figures 3 and 4) will be presented in Part II of this series. HEC-RAS was used to model flood flows in 2011, but river geometry and the changes in stream channel configuration during and after the 2011 flood posed challenges. Applying the simplified Level 2 method (Holnbeck and Parrett, 1997) to an approximate channel and flood plain configuration based on survey data and field estimates produced the initial estimates of contraction scour shown in Table 1.

These estimates are generally conservative (Holnbeck and Parrett, 1997) and intended to overpredict scour to provide a margin of safety, but actual scour that occurred in 2011 was locally greater. Since the foundations were undermined or moved laterally, scour proximate to the damaged piers was at least 11 feet (3.3 m) deep in these areas. This was from a stream that is typically easy to wade across.

The scour function is clearly nonlinear. The last column shows the ratio of approach depth (y_{app}) to depth at the bridge section (y_{brg}) which is a 5/3-power function to obtain the variable for matching with the scour curve. At first, the scour nearly doubles with a doubling of water depth, but then drops off as flow gets deeper; however, the 5/3-power function shows that the *difference* in flow depth governs. The response of scour depth to flow depth is highly dependent on channel geometry. Another factor at this site is the presence of bedrock 18 feet (5.5 m) below the streambed. This

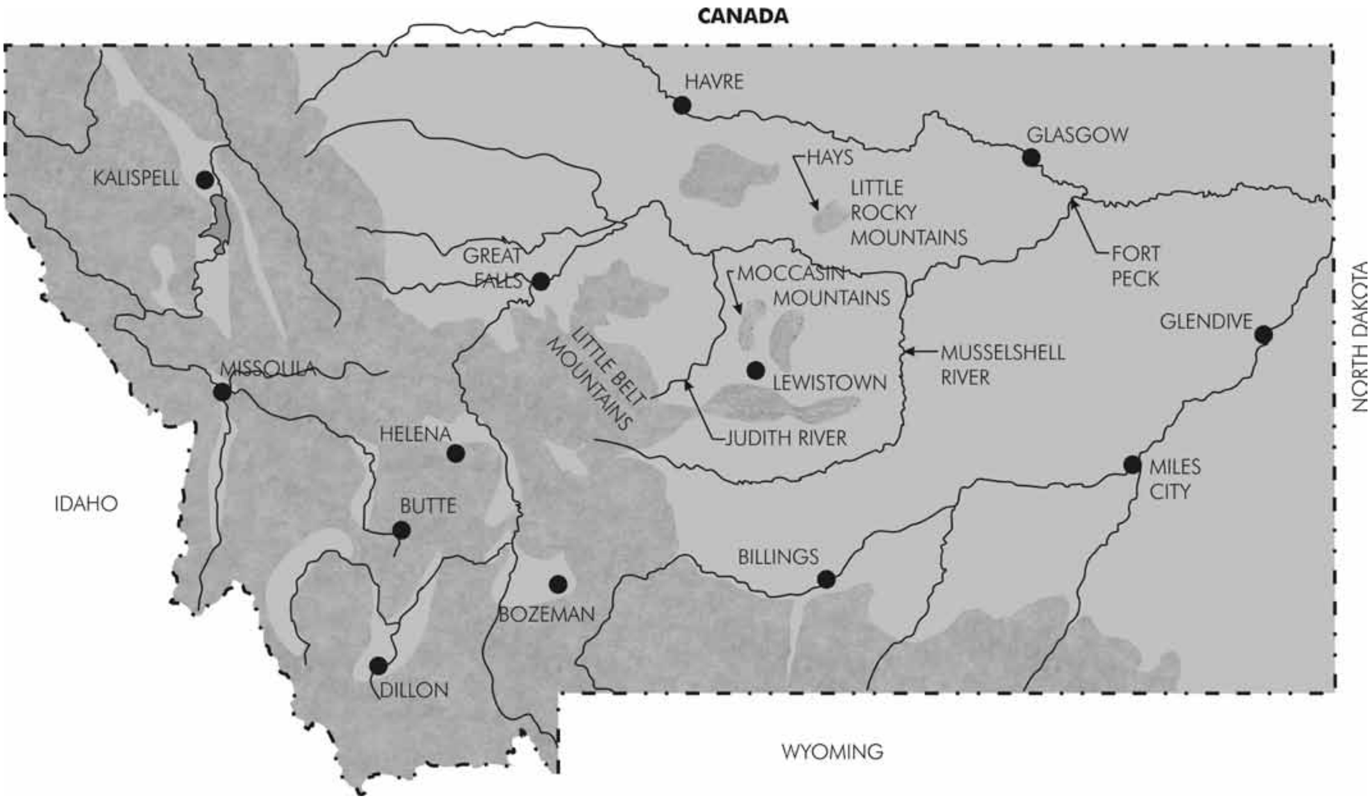

Figure 3.

would normally limit scour, though that is dependent on unit power (Holroyd, 1990). While the scour depth in this small, shallow, gravel-bedded river is computed to be less than the flow depth, that is not always the case, as some spectacular bridge failures from other states and countries have illustrated (Figure 5), sometimes with scour depths of several meters (tens of feet). Evidence from the Judith River in 2011 indicates that considerable deviation from predicted scour depth may also have occurred, as will be shown in Parts II and III of this series.

Table I. Estimated Flow and Scour Depths. Judith River, Montana—2011 Flood.

Estimated Flow Depth, Approach Reach	Estimated Flow Depth at Bridge	Estimated Scour Depth	$(y_{app}/y_{brg})^{5/3}$
1 ft. (0.3 m)	1 ft. (0.3 m)	0 ft. (0 m)	1.00
3 ft. (0.9 m)	3 ft. (0.9 m)	1.4 ft. (0.4 m)	1.00
6 ft. (1.8 m)	9½ ft. (2.9 m)	2.7 ft. (0.8 m)	2.15
12 ft. (3.6 m)	14 ft. (4.2 m)	1.6 ft. (0.5 m)	1.29

An anonymous reviewer of an early draft of this paper brought to my attention work done in Colorado. He stated:

> McCoy, commenting on the work of Anderson et al. (2015) involving a single storm in the Colorado Front Range that eroded what was calculated as "hundreds to thousands of years [*sic*] worth of accumulated hillslope material." This observation leads him to question: "How do surface processes shape the landscape in which we live? Is it the every-day flow of rivers that gently, yet persistently, erodes and transports sediment from highlands to ocean basins, dissecting the land surface into networks of ridges and valleys? Or is it cataclysmic events of incredible magnitude that, despite their infrequency, conspire to shape

Figure 4. Judith River at low flow.

> Earth's surface?" And then referring to the importance of this distinction of rate, he commented, "accurate portrayal of the magnitude and spatial-temporal patterns of sediment fluxes is critical for understanding how landscapes evolve." (McCoy 2015, p. 463)

Expanding Our Knowledge

There are many hydraulic equations for stream competence that have been derived largely from actual observations (Klevberg and Oard, 1998), partly due to the complexity and variety of processes, and to a lesser extent, various choices in conventions. Each time a flood occurs, it is an opportunity to test our theories and learn new things.

Very large floods, larger than any observed in available historical records but with inferred peak flows in excess of 10^6 m^3/s, are called "megafloods" (or "superfloods"). These have been inferred from geologic evidence and include the Bonneville Flood and Missoula Flood. The most powerful flood ever recorded, of course, is the Deluge in Genesis 6–8. Greater extent and greater energy clearly would produce much more geologic work.

A great many examples can be found for geologic analogues. The examples chosen for this series were selected primarily because I had the opportunity to work on these projects as part of my regular job, but Montana is also particularly well suited to display some of the main points of this paper. Other stimuli for researching and getting some Central Montana flood and geologic information in print included, "The geology and geography of floods," by O'Connor et al. (2002) and my previous work on the paleohydrology of deposits on higher planation surfaces (Klevberg and Oard, 1998).

Equivocal Terminology

The popularity of the term "Flood Geology" among creationists may be unfortunate. Many concepts not related to floods are sometimes lumped under this term. *Flood geology* as more commonly used (O'Connor et al., 2002) refers to the geologic processes active in floods as we observe them. (*Flood basalt* is basalt produced in a flood of erupted lava, not water, but that is normally clear from context.) That a global flood could produce a great many phenomena not observed in local or regional floods will be explored further in Part IV of this series. I will use the term only in reference to flood processes and deposits, regardless of whether the scale is local, regional, or global.

Conclusions

Much knowledge has accrued from observation of floods and the geologic work they do. These include the following.

- In general, most geologic work by rivers occurs during infrequent floods, with little geologic work between. This is contrary to the traditional uniformitarian idea that small changes over long periods of time have produced most or all of the geologic features seen today.
- Floods are considered the primary type of natural disaster in the world. Geologic change caused by floods represents a large portion of the geologic work that takes place in the modern environment.
- Stream power is proportional to flow depth, bed slope, and velocity. Velocity is related to depth and bed slope; thus, the stream power equation is nonlinear. This explains to a large degree why floods have such a disproportionate effect on geologic change.
- Stream power must exceed the bed shear stress threshold before significant erosion commences. Below the critical bed shear stress, removal and transport of earth materials is insignificant.
- The rate of erosion is proportional to the surplus of stream power above ω_c.

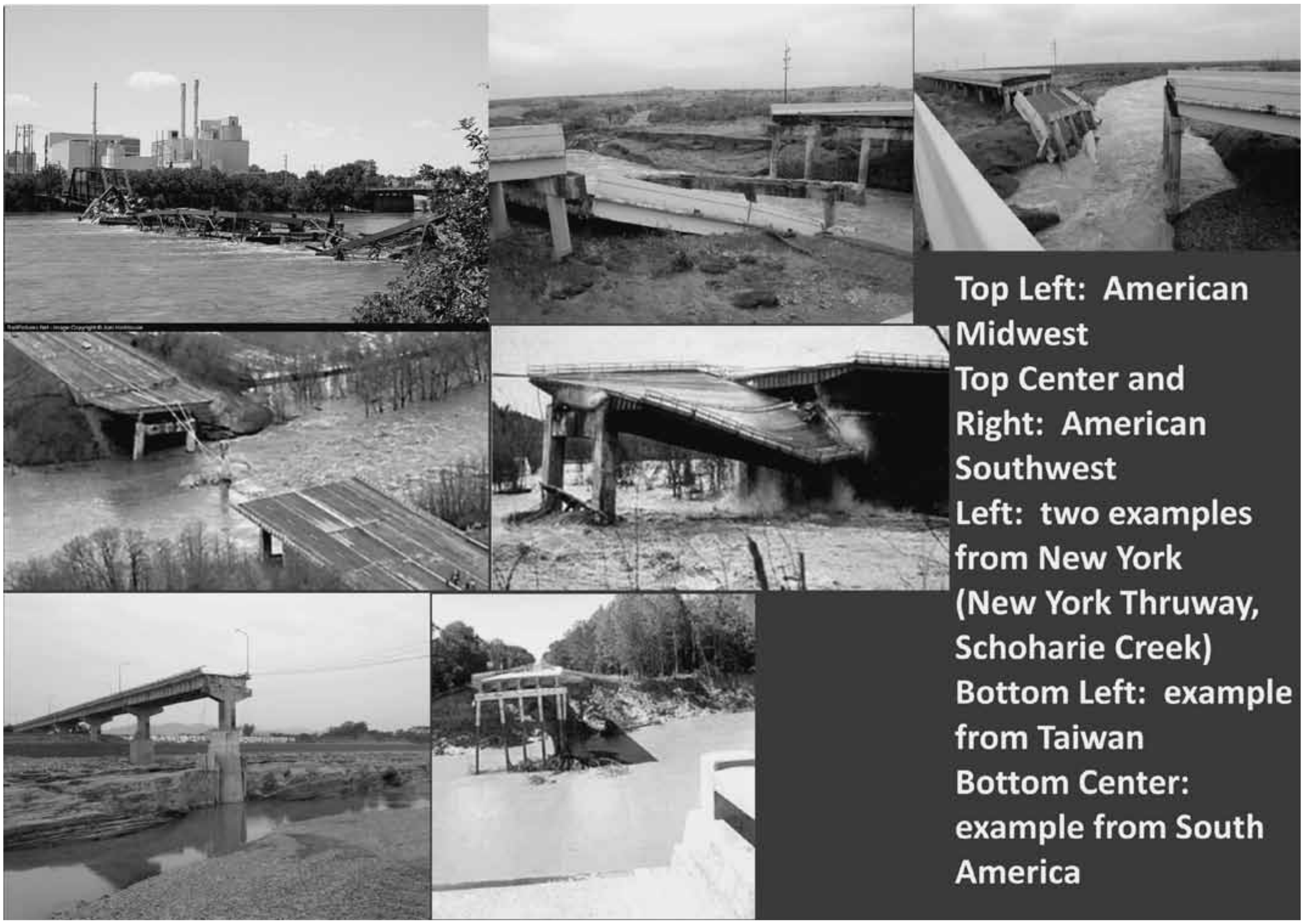

Figure 5.

This relationship is also nonlinear.

- Head loss, which is the sum of resistive and dissipative factors, is partly proportional to the square of difference in velocity between upstream and downstream reaches (i.e. change in current speed down the channel). Thus, a change in the current speed produces a nonlinear effect in flow resistance.
- Alluvial channels tend to reconfigure to achieve the minimal energy loss state. This requires geologic work to reduce dissipative losses from channel constrictions and obstructions.
- The assumption of steady flow is usually appropriate when the peak flow is of interest. The assumption of uniform flow can be more problematic, especially at larger scales.
- Estimation of scour depth is complex. Typical methods are normally conservative but observed scour depths sometimes exceed predictions. Scour depths of several meters have been observed at bridge piers, sometimes with disastrous results.

Science must be constrained by real world data. Through first-hand experiences, important principles of geology in particular and science in general can be demonstrated that should prove useful to others.

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