Annotated Bibliography

Ancey et al 2006

An excellent reworking of Einstein 1950 using Markov birth-death processes. They derive the full probability distribution of the bedload rate from Einstein's assumptions. It is Poisson, which has narrow fluctuations inconsistent with experiments.

Ancey et al 2008

Using a granular avalance "collective entrainment" type process, which is a positive feedback between particle mobility and activity, they modify the 2006 theory to derive a negative binomial distribution of the bedload rate which has realistically large fluctuations.

Ashworth et al 1989

This is an important experimental paper which partitions bedload transport into three stages

Bagnold 1956

This is Bagnold's original work outlining bedload transport as a balance between the power supplied to the fluid flow by gravity and the power dissipated by the friction of moving bedload with the stationary bed. The description is agnostic of aeolian vs fluvial

Bagnold 1966

This is a refined restatement of the original work which highlights the differences between aeolian and fluvial transport.

Bagnold 1973

An excellent and concise paper outlining Bagnold's earlier theories in direct relation to the phenomena of bedload motion. Nice descriptions of washload vs bedload phenomena.

Barry et al 2004

They show simple power law fits outperform mechanical models for predicting bedload transport rates in the field

Berker 1992

This is a big book about granular materials. Lots of cool theory of granular rheology and treating granular flows like dense or rarefied gases with an additional energy cascade that normal gases don't have (since normal gases have elastic collisions but granular gases dissipate energy upon collions between two particles). Highlights that granular gas theories are only well defined for rarefied and highly dense limits, and the intermediate rheology is an utter mystery.

Bialik et al 2015

This is one among a series of cool papers by Bialik which are ensemble simulations of bedload trajectories starting from Newton's laws. They're essentially simplified DEM models (like the LES-DEM type models of Sun 2015 and others)

Bohm et al 2004

A nice study of bedload fluctuations in a narrow channel. Sediment is uniform glass beads and they measure 400% fluctuations in sediment flux out of the channel using an impact sensor. This paper was the impetus for Ancey et al 2006.

Bradley 2017

This is an exceptional tracer study paper. Bradley shows that resting time is heavy tailed, lying on a tempered pareto distribution, and that this explains the anomalous superdiffusion of sediment tracers. The virtual velocity of tracers drops to zero with time. There is an interesting idea suggested about the interaction of flow depth with tracers, too. This idea deserves a model to explore its consequences.

Bridge and Bennett 1992

A classic paper defining a range of critical shear stresses from considerations of Newtonian mechanics, a normal distribution of fluid turbulence, and random granular configurations.

Celik et al 2014

One of the nicest papers summarizing the Diplas et al Virginia Tech group's findings that impulse, or fluid forcing's magnitude and duration, is the real predictor of bedload entrainment, and not just shear stress.

Church 2006

A nice review article about the relationship between channel form and bedload transport. Really a sophisticated recapitulation and refinement of Lane's ideas.

Church et al 1998

A typology-based classification of alluvial bedforms in gravel rivers. This is an early work to join together the ideas of Brayshaw, Ashmore, and others.

Cox and Miller 1965

An excellent and pedagogical book on stochastic processes. Quite readable but packed with information. To understand this entire book is to become a career statistician.

Crickmore and Lean 1962

A nice early paper on radioactive tracers that precedes Hubbell and Sayre. They explore bedload diffusion and particle burial. They make an interesting simplified theory of bedload burial which was later refined and generalized by Hassan and Church 1995

Cudden and Hoey 2003

They measure bedload pulses in the field and relate these to the migration of bedload sheets. There is a nice review discussion of many other similar observations prior to 2003.

Dey et al 2018

A nice engineering article collating all of the theories of bedload entrainment which have followed from Einstein 1950 and Einstein and El Samni 1949. Dey also has another review article from 2008. This is where you learned about Paintal 1969 and Paintal et al 1971.. great papers

Dhont and Ancey 2018

The Ancey et al 2008 theory fails to describe this flume experiment. This is Ancey's foray into flume experimentation. They do a suprisingly complete analysis, and show that the largest bedload fluctuations result from aggradation degradation cycles in pools.

Diplas et al 2008

The first impulse based entrainment paper. They convincingly show that impulse, and not shear stress, is the predictor of bedload entrainment using both fluid experiments and electromagnet experiments.

Drake et al 1988

An early and influential video tracking experiment, preceeded by Fenton and Abbott 1977 and by Abbott 1972. Their conclusions are pretty weak. It has lost its relevance owing to technological developments and a large set of more careful and complete experiments.

Dwivedi et al 2010

They measure forces on a spherical sediment grain at entrainment using PIV and an instrumented sphere. They show convincingly that forces on bed sediment undergo massive fluctuations and that we have no reason to expect the average force to be representative of bedload entrainment

Dwivedi et al 2011

This is a followup to the 2010 paper that conecntrates solely on hydrodynamic lift. A related paper is the one by Schmeeckle. The conclusion is that we have basically no understanding of hydrodynamic lift. It does not even correlate well with the fluid velocity. It's definitely not Bernoulli lift, and is probably more related to hyporheic flow than anything.

Einstein 1937

The first bedload diffusion paper. Uses a Dalton's (or galtons?) board concept to derive a Poisson distribution of bedload tracers in space which encapsulates a diffusion in time. This does not account for bedload burial, so it is flawed in a contemporary context. It does not express Nikora 2002's 3 stages of bedload diffusion, and it does not show superdiffusion at long timescales as in Bradley 2017, Martin 2012, Zhang2012, Ganti 2010, etc

Einstein 1950

A crucial paper. Einstein understands particle motion as a consequence of turbulence and he treats bedload motions as random quantities characterized by probability distributions in order to derive a formula for the mean bedload rate. There are many flaws and some outright mistakes. Yalin 1972 carefully points these out. Ancey et al 2006 rectifies many of them.

Einstein 1964

It's very nice to read a broader, more engineering and reach-scale discussion by Einstein, who was primarily an advocate of grain scale perspectives

Engelund and Fredsoe 1976

This is a pretty nasty and hard to read paper, but it's an early paper which restates and more deeply studies Bagnold 1973. It's worth a more careful read, or cryptographic analysis, or whatever.

Ettema and Mutel 2004

A biography of Einstein. This was a nice read. His father really helped him a lot in life. He was lucky to have been the son of a rich, famous, and benevolent man. Our field benefited from this connection. Science does not occur in absence of wealth, which is a strange and under-acknowledged link.

Fan et al 2017

The model in this paper is junk. I have no clue why it became so popular. I do not think the reviewers were well-read in stochastic theory of bedload transport. That said, the introduction (written by Hassan, although this was not acknowledged) is excellent, and has an original perspective on bedload diffusion and the relationship between Nikora's three regimes to the distributions of resting time and travel distance

Fathel et al 2015

A nice video tracking experiment on sand. This shows convincingly that the motion characteristics of bedload are random, and the forms of the distributions of various kinematic characteristics are pinned down. However, they do not agree with other findings such as Ancey et al 2008, Heyman et al 2016, and Lajeunesse et al 2010, so they are provocative. Are there differences in the motions of sand versus the motions of gravels or perfect beads? This question deserves clarification.

Frissell et al 1993

Bill Frissell is a wonderful nature writer and conservationist who also happens to do nice science. I appreciated the "n=1" diagram from his PhD thesis. This paper uses facts to support the assertion that cumulative watershed effects have driven pacific salmon to extinction.

Furbish et al 2012

A classic paper using ensemble concepts to describe bedload diffusion. It is somewhat esoteric and I do not think it was well-phrased. I also think the four papers were not necessary. Most of the information would have fit into one.

Gaeuman et al 2017

An excellent study of gravel augmentation in the trinity river. I did not consider that gravel augmentation is not simply a pulse diffusing to downstream… actually it collects gravel on its upstream side, so it diffuses upstream too. Weird. River restoration is complicated.

Gomez et al 1989

The classic “bedload formulas don’t work” paper. It reads like Wittgenstein’s Tractatus – How-not-to-write 101.

Gonzalez et al 2017

A wonderful LES-DEM paper showing that bedload is more intermittent at low discharges and that fluctuations are relatively more important at low discharges. It supports the argument that Einstein is closer to the physics at low discharges while Bagnold is more relevant at high discharges.

Gregory et al 2006

A nice global scale discussion of the geography of human disturbance on river channels. We move more dirt than the rivers or hillslopes themselves.

Habersack 2001

An early RFID tracer paper in a braided channel in New Zealand. Reviewed by Marwan– he did not like it. I don’t really like it either. He’s forcing his data onto the concepts of Einstein. Voepel et al 2013 apparently took his data from his plot to argue a different conclusion regarding the resting time distribution than did Habersack, and this is unbelievable. This task seems impossible, which makes me question the scientific integrity of Voepel.

Hassan et al 2017

An excellent paper on tracer dispersion which presents clear evidence that mesoscale morphological elements control the grain scale motions of bedload grains, and makes the concept and relevance of morphology-transport feedbacks difficult to refute.

Hassan et al 1991

Marwan's classic paper on the statistics of bedload motion from tracer studies in Ireland and Palestine.

Hassan et al 2008

A complete review of micro, meso, and macro scale gravel bedforms. A wonderful classification diagram, some discussion of their formation and destruction, and an integration of the role of wood and these bedforms into considerations of channel stability and change.

Hauer et al 2016

An excellent paper which every river scientist should read: a holistic picture of watershed hydrology, ecology, landscape evolution, and human disturbance with excellent textbook-style diagrams.

Heyman et al 2013

The inter-arrival time of bedload particles displays two distinct humps, one associated with individual motions, and another with collective motions such as gravel-type avalanches. You should generalize this paper onto Hassan's light table data. Do meso-scale bedforms impart a particular signature to the inter-arrival time distribution?

Heyman et al 2014

A followup paper from Ancey et al 2014 analyzing spatial correlations in bedload transport. Obtuse- need to read again.

Heyman et al 2016

An excellent and cutting edge video tracking experiment in which they discern the probability distributions of bedload kinematics over a range of flow conditions, and try to relate the entrainment and deposition probabilities required by birth-death Einstein-type models (Ancey 2008) to standard quantities like the shear velocity or bed roughness. They seek "closure" to the stochastic bedoad theory, using the term similar to its use in fluid dynamics with regard to the RANS equations.

Hoey et al 1992

A nice field study showing very large bedload fluctuations which they relate to aggradation degradation cycles in pools and to the formation and breakup of bars.

Hooke et al 2000

Humans move a lot more dirt than gravity does.

Houssais et al 2015

Standard Jerolmack bullshit that makes sweeping conclusions from limited data obtained from idealized and highly simplified experiments. These guys just can't forget self-organized criticality. Nature ain't necessarily easy.

Houssais et al 2016

Does not do what it claims it does, but nonetheless interesting because they analyze the friction laws between grains which would be required to express the observed phenomena of bedload transport.

Hubbell and Sayre 1964

Classic paper of radiative tracers in the North Loup River of Nebraska. They clearly indicate bedload diffusion, and they apply Einstein 1937 to describe it. They claimed this model as their own, but 3 years later, Sayre translated Einstein… I think there is a lack of integrity here.

Iseya and Ikeda 1987

Need to read this one again, but basically they show bedload sheets due to alternating bedload patches, where fine and coarse fractions leapfrog over one another, so there are alternating fluctuations in the fractional rates

Iverson et al 2013

This paper discusses validation of geomorphic transport laws. They suggest that because geomorphic transport models are usually semi-empirical, stochastic models are actually more legitimate, because the higher statistical moments present additional benchmarks against which models can be judged

Jackson et al 1982

Classic paper which Frey and Church cite. It describes three regimes of bedload motion which basically correspond to no transport, partial mobility, and full mobility. Your idea is that Einstein pertains to the lower end of partial mobility while Bagnold pertains to the upper end of full mobility, when bedforms are washed away. Frey et al 2014 has better discussion of the particular Shields numbers which would characterize each of Jackson's regimes.

Jenkins and Hanes 1998

This paper along with PK Haff's 1983 paper are excellent describes of granular flows using the theory developed in Chapmann et al 1970's treatment of densely interacting gases. This work contrasts directly with Bagnold. They are essentially the same except Bagnold's theory uses a quasi-static granular rheology, characterizing granular friction by a constant factor, assuming that grains collide so frequently that they are basically always colliding, while Jenkins and Hanes use a rarefied gas rheology involving a coefficient of restitution for every collision between two grains, with these collisions considered to be rare. All in all an excellent paper which you should understand better. Extending this paper in any way is new and important science.

Kasprak et al 2014

Another paper similar to Hassan and Bradley 2017 which highlights the transport-morphology feedback going the opposite direction from papers like Church et al

2006. Morphology informs bedload transport, just as far as bedload transport informs morphology.

Kuhnle et al 1988

Laboratory observations of bedload fluctuations. Authors started to get comfortable with the idea that bedload was not deterministic around the early 90s as a result of this paper and others such as Hoey et al 1992.

Lajeunesse et al 2010

A nice video tracking experiment with limited conclusions. Their findings on bedload kinematics are consistent with Ancey et al 2008, Bohm et al 2004, and Heyman et al 2016, but they disagree with Furbish et al 2012, Roseberry et al 2012, and Fathel et al 2015. Basically they agree with gravel experiments but disagree with sand experiments, suggesting there are differences between gravel and sand transport. (Of course there are.)

Laronne and Caron 1976

An early paper fostering the perpsective that bedload transport and morphology are carefully interlinked. This paper along with others' work like Shumm 1977 lays the groundwork for subsequent authors like Whiting and Montgomery to found frameworks for channel classification based upon the interrelationship between supply, storage, and transport

Lee et al 2002

A bagnold esque model which attempts to rectify the motions of indivdual particles with the collective power balance theory of bagnold. It fails, vastly overpredicting bedload rates, which Lee attributed to a poor incorporation of collisions between moving grains, calling for a renewed effort to understand interactions and collisions among moving bedload (see Frey et al 2014)

Lisle and Madej 1992

A nice discussion of spatial inhomogeniety in bed surface texture caused by supply pulses into channels

Luque and Van Beek 1976

Another super terse restatement of Bagnold 1973. You can revisit one day with a magnifying glass and a team of cryptographers

Ma et al 2014

A very rich theoretical progression from Ancey et al 2008, using a path integral approach to define the bedload flux from the Ancey model in a slightly different way, counting the number of particles that cross a line. They get a bedload distribution that depends on the sampling interval and displays three different stages across the sampling interval. This tri-partite behavior of the bedload flux is problematic and deserves more careful attention. Do flume experiments actually measure a stable bedload rate? Or is it fundamentally modified by the sampling interval?

Martin et al 2012

A nice flume expierment which shows anomalous diffusion is due to particle burial, and not to heavy-tailed travel distances. This conclusion is mirrored by Hassan et al 2013

Martin et al 2014

A simple quasi-2d flume experiment in which they measure the time series of bed elevations and relate this to the resting time of bedload grains as they undergo burial. They model the bed elevation changes with a mean reverting random walk, and their results contrast with Voepel et al 2013. They conclude that the probability distribution of resting times, originally considered by Einstein 1937 to be exponential, is actually a power law distribution which decays at large resting times approximately as 1/T. This means that the virtual velocity of bedload tracers should fall to zero with time, as a consequence of bedload burial, and that tracers should superdiffuse at large times in accord with Nikora 2002 and Zhang 2012.

Martin and Church 2000

A terrible paper which says a lot of nothing apart from pointing out clearly that Bagnold fails at low bedload rates.

Maxey and Riley 1983

A nice physics paper which uses the Navier Stokes equation to derive the force imparted by an open channel flow on a small sphere suspended within it. Long story short, we expect many terms apart from the typical drag and lift, and these terms are definitely not expected to be negligible.

Meyer-Peter and Moeller 1937

bedload transport goes like excess shear stress to the 3/2 power. The original paper is impossible to read, but the takeaway is clear

Miller and Byrne 1966

They show that water worked beds have a different angle of repose than totally unconsolidated beds. Apparently, water drives beds to become more stable, so that their angle of repose is higher. This is reasonable. They get to this conclusion using a removable bed and tilting it until it gives. There is nice info here about the expected angle of repose of water-worked beds. The associated friction coefficients of these real beds are not consistent with the assumptions required to fit Bagnold to bedload transport at relatively low rates.

Mouilleron et al 2009

A cool paper which shows a linear velocity distribution within the moving layer of a bed undergoing a sheet flow, when a huge shear stress is applied to the surface using a viscous liquid, much thicker than water

Nakagawa and Tsujimoto 1976, 1980

Crucial. These guys were genius, and the best stochastic theorists of the 1970s and 80s. It's a recapitulation and refinement of Einsteins original 1937 and 1950 theories, and a generalization of this theory to include changes in bed elevation.

Nelson et al 1995

They show that turbulence is primarily responsible for the entrainment of sand, and that bedload tends to organize preferentially along the low speed streaks visible within a fully rough flow which were first identified by KLein et al 1967

Nelson et al 2010

A longwinded PHD thesis which uses image analysis techniques to discern the development and breakup of patches on the bed surface. This is a paper which quantifies the longitudinal sorting earlier noted by Iseya and Ikeda 1987

Nelson et al 2014

Just a publication based upon Nelson's thesis

Newson et al 2000

A nice discussion of channel morphology influences on within-channel habitat.

Nikora et al 2002

They argue that bedload diffusion should depend upon observation timescale due to the relative importance of entrainment and deposition procesess across the various timescales. This is difficult to describe in short form, but it relates to the sub/normal/super diffusion framework stemming from Einstein 1905 (Einstein's father) and Fick's ideas of sand diffusing through pipes.

Nino and Garcia 1998

A tireless description of the phenomena of sand transported by a turbulent flow against a smooth metal sheet. Sand grains preferentially organize along low-speed streaks which are the heel pieces of the horseshoe vortices reviewed carefully by Adrian 2007. When turbulent bursting occurs, these grains are transferred back into the high speed fluid which can boost their motions. This paper goes on and on.

Paintal et al 1971

An excellent simplified theory of the probability that bedload entrains, based upon randomness in the supporting configuration of surface grains, and the assumption that fluid shear stresses are random and lie on a normal distribution. It was later generalized more or less to take accuont of Diplas' impulse concept by Tregnaghi 2012

Radice et al 2006

A poor but influential video tracking experiment. It led into Lajeunesse 2010, which I also consider to be poor but influential. The Ancey et al experiments are much better.

Recking et al 2016

Another generic bedload-informs-morphology paper in the vein of Dr. Church's 2006 paper.

Rennie et al 2018

There are strong geological controls on the geometry of the Fraser river canyons.

Roseberry et al 2012

Video tracking of sand is used to discern the probability distributions of various kinematic quantities. The same data set was used for a more careful analysis in Fathel et al 2015

Schmeeckle et al 2014

An LES-DEM simulation of bedload transport which neglects two-way coupling and finds that, at high transport rates, MPM fits the numerical data. This approach is relatively simpler than other LES-DEM models which have two-way coupling, but it is highly influential because of its authors.

Schmeeckle et al 2007

Forces on bedload grains are highly variable, up to 700% fluctuations. These are quantified with an instrumented sphere submersed within a turbulent flow. Drag laws kind-of work, Lift laws definitely do not work. They conclude we essentially do not understand lift at all.

Schumm 1977

A nice classic textbook which understands channel morphology as the coordination of sediment supply, storage, and transport, and advocates a holistic consideration of river channels.

Seminara et al 2002

They use some sketchy arguments to invalidate Bagnold's fundamental hypothesis, and then they replace the "invalidated" hypothesis by Einstein-type concepts and arbitrary other hypotheses in a later paper (Parker et al 2003). I don't like Gary Parker's work much.

Silbert et al 2001

They study granular flows down an inclined plane and find the limits of Bagnold's quasi-static approximation for the friction of the granular flow.

Singh et al 2009

A nice study that does a lot of stuff I don't care about, however, they did measure the bed elevation probability distribution using the same apparatus of the Wong and Parker 2007 experiments. They find with unconsolidated sediment the distribution is not really a normal distribution at all.

Slaymaker et al 2009

An excellent youtube video of a lecture Dr. Slaymaker delivered at green college. I liked this and found it educational. His conclusion is that we're putting too much effort into studying non-anthropogenic forcing of natural systems, and we should really be concentrating on understanding anthropogenic forcing, because humans are the primary geomorphic agent. He challenges the listener to prove him wrong, asserting this is “the essence of the university” in the style of a Cambridge scholar.

Sun et al 2014

Nice discussion of partial mobility with various conclusions drawn from flume experiments. I don’t fully understand his model yet and need to read this again.

Sun and Donahue 2000

An excellent paper using the assumptions of Einstein 1937 in a two-state continuous time Markov process theory in order to derive the probability distribution of the bedload rate, and on a mixture, no less. This precedes Ancey et al 2006, but it is poorly written and published in a less respectable journal, so it received limited attention. Apparently, Sun published this work much earlier in Chinese, in Sun et al 1989 and Sun et al 1991. However, this is unknown to Western research apart from citations in professor Tsai’s work from Univ. of Buffalo. She is now back in Taiwan, as well.

Tregnaghi et al 2012

A generalization of Paintal et al 1971 to include the impulse concept of Diplas et al 2008 and Celik et al 2014. It’s a nice paper, but I should read it again.

Valyrakis et al 2010

This is my favorite impulse-based entrainment experimental paper. Valyrakis is the best writer among the Virginia Tech guys. There is convincing data here that we should really characterize bedload entrainment by a distribution of critical impulses, and not by a distribution of critical shear stresses as advocated by Bridge and Bennett 1992, and definitely not by a single critical shear stress as advocated by Shields, Wilcock, Montgomery, and many others.

Van Rijn et al 1984

An attempt to incorporate the trajectories of individual particles into the collective power balance framework founded by Bagnold 1954. This theory was later shown to overpredict bedload transport, and this failure was attributed to a lack of inclusion of inter-granular collisions between moving bedload grains (Lee et al 2002, Frey et al 2014)

Venditti et al 2017

A nice paper in the vein of Church et al 1998 and Hassan et al 2008 which studies the various stabilizing morphological elements which can be discerned within gravel bed channels.

Voepel et al 2013

Studies the burial time of bedload sediment using a concept of a random walk model with hard reflecting barriers. Apparently picked the Habersack data off of Habersack's graphs, which is really an impossible task. All subsequent experiments disagree with the exponentially tempered distribution which Voepel's theory predicts, including your own stochastic theory of tracer burial.

Whiting et al 1988

Classic experimental observations of bedoad sheets. You should give Whiting a more careful read. He is excellent.

Wiberg et al 1989

Wiberg's famous model incorporating individual bedload trajectories with a bagnold-type concept of power disspation which limits the number of particles in motion.

Wohl et al 2017

A state of research article on wood dynamics in gravel bed rivers. Lots of citations here to the key papers on large wood within channels and the role it plays in sediment storage and in providing aquatic habitat.

Wolman and Miller 1960

frequency + magnitude

Wu and Yang 2004

run of the mill entrainment paper in the vein of Einstein 1950, Paintal 1971. Reviewed alongsize many others in Dey et al 2008 and Dey et al 2018.

Yalin 1972

An exceptional book which provides a cutting criticism of Einstein's ideas, and also refines them extensively. His description of Einstein's work surpasses Einstein's own description.

Yang and Sayre 1971

Excellent work along with Nakagawa and Tsujimoto 1980 which extend Einstein 1937 to describe bedload diffusion in context of bedload burial, so that the resting time is not exponential.

Yano 1969

Insanely good tracer experiment and validation of Einstein's theoretical ideas on the randomness inherent in sediment motion. What became of Yano? Can you find more of his work?

Zhang et al 2012

Eh, ok. Applies hard math to describe anomalous diffusion of bedload in extension of Einstein 1937, but it's not really physically justified or descriped with deference to the observed phenomena. All in all, a poor paper. It does have a very cool plot demonstrating Nikora 2002's three regimes of diffusion using data amalgamated from various experiments across the decades, with each experiment sampling one of the three regimes only owing to their intrinsic limitations. This plot explains why anomalous diffusion took researchers so long to identify.