HYDROLOGICAL PROCESSES
Hydrol. Process. **15**, 521–523 (2001)

INVITED COMMENTARY

'Truth or Consequences' for the practicing hydrologist: on scientific certainty and ethics

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A number of years ago there was a famous TV game show in the United States called 'Truth or Consequences.' In this show, contestants who told the 'truth' were rewarded with money and those who did not suffered the 'consequences' of receiving nothing. I would hope that for all hydrologists, not being scientifically truthful is anathema, insulting to even consider. But hydrologists in the consulting workplace have to legitimately wrestle now and then with what constitutes scientific 'truth,' balancing what is right for science and the need to satisfy paying clients.

The contrast between how science is done in academia and consulting can be striking. Tenured university faculty who delay research publication because of uncertainty may not get quick grant renewals, but they don't lose their jobs. Practicing hydrologists who hold up reports for clients for the same reasons can lose contracts as well as their jobs. So I ask, how many academic programs teach anything about how hydrology is *really* done in the workplace, namely, how to critically evaluate scant data, sometimes poor data, to arrive at a defendable 'best professional judgement.' Getting to scientific 'truth' costs money and a dilemma always in practice is how much does a client wants to pay for the truth he gets.

Making these kinds of hydrologic decisions, 'best professional judgements,' is particularly important in environmental litigation, common in the United States. An excellent demonstration of how hydrology can be done in practice is the book *A Civil Action* (Harr, 1995) about the Woburn TCE contamination case. Hydrologists reading this book should be appalled by the unsound hydrogeologic conceptualizations suggested by some of the hydrologic consultants, as well as by the distortion of the sound science in the legal arena.

Mistakes and misrepresentation of hydrology and geochemistry are common in practice. I consult as well as teach, and here are some classic 'boners' I have seen in and out of the courtroom (see if your students understand why these are boners): 'Chemicals diffuse through unfractured saturated clay at a rate of feet per day; You can pump a well in clay or competent till at a rate of 20 l/min($\sim$5 gpm) for two days and observe drawdown in monitoring wells 30 m($\sim$100 ft) away; It is plausible that a river can inseep and outseep to groundwater in 100-m long alternating segments along a kilometer reach; The dispersivity of an aquifer is equal to flow-path lengths up to scales of tens of meters.' I have even heard a presentation by consultants on how to purposefully use graphics in hydrologic computer models to enhance scientific positions that are not clearly supported by the data!

What I report above certainly is not the norm in practice—far from it. But I think academic hydrologic training needs to pay more attention to *qualitatively* or semi-quantitatively making sense out of uncertain hydrologic data by back-of-the-envelope style approximations and calculations. To this end, students might be introduced to books such as *Consider a Spherical Cow* (Harte, 1988) or *Thinking Physics* (Epstein, 1990) which teach these kinds of approximations.

I like to visualize the range of hydrologic certainty in practice as a white to black 'rainbow' continuum (Figure 1). The lighter left-hand side of the curve includes the certainty that academics strive to attain before they publish a paper, maybe >90%. Nobody likes to be proven wrong in print! Along this left-hand side of the curve fall flood flow modeling and designing hydraulic structures, science and engineering which generally can be done with reasonable reliability. At the center of the curve is the critical 50% certainty mark.

In the legal arena concerning civil litigation, a certainty greater than 50% is the same as a certainty of 100%, a point worth pondering a bit. Based on the literature and my own 'best professional judgement,' I put hydrogeologic technologies (my own specialty) such as modeling groundwater flow and solute transport in the uncertain gray to black area of the right-hand side of the curve (e.g. Siegel, 1998, 1999; Konikow and Bredehoeft, 1992; Oreskes *et al.*, 1994).

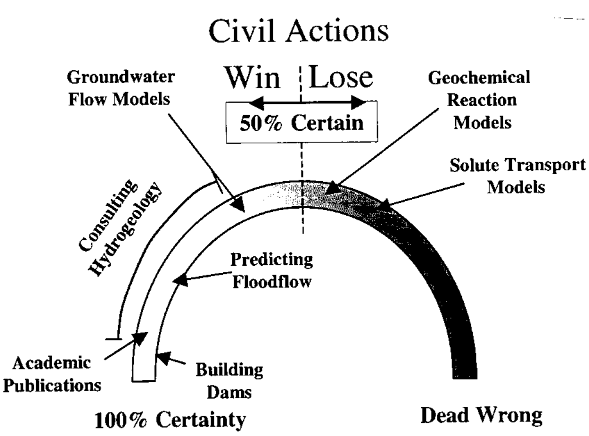

Figure 1. Conceptual 'rainbow' of hydrologic uncertainty. This figure qualitatively presents the level of uncertainty related to various techniques commonly used in hydrology. Depending on the individual problem considered, the certainty of the methods shown can be substantially greater or worse than presented on the figure (e.g. Bair, 1994). In presenting the figure, I certainly do not challenge the clear heuristic value of mathematical models of groundwater flow, solute transport and chemical reactions (e.g. *sensu* Oreskes *et al.*, 1994). However, these methods in the context of applied hydrology do not accurately predict hydrologic and geochemical phenomena well.

Figure 1 also can serve as a hydrologic 'truthfulness scale.' Where would you put yourself on it before you would say that a hydrologic conclusion was 'true enough' to the best of *your* professional judgement? Few clients want their consultants to be wishy-washy. Attorneys want and need statements of certainty. In this context, practicing hydrology also is an exercise in practicing ethics. I know of one hydrologist in a famous university who feels comfortable telling students 'anything goes' in court and that it's up to the lawyers to ferret out truth from falsehood—'It's all a game.' But hydrology in the courtroom is definitely not a game. Errant decisions occur when hydrologists present implausible hypotheses on behalf of their clients, and the material and emotional costs to society can be severe. The difficulty that the courts have to critically evaluate science is well recognized, even by a member of the US Supreme Court, Justice Steven Breyer (Breyer, 1998).

The purpose of law, of course, is not to discover 'truth' but, rather, to adjudicate disputes in a timely fashion. To this end, practicing hydrologists must learn to cut to the essence of complex problems in ways understandable to attorneys, juries, and clients. Although determining the most plausible answer to hydrologic problems can be difficult without complete data, I don't believe for a minute, as does attorney Jerome Facher of *A Civil Action* fame, that 'Truth is found at the bottom of a bottomless pit.' (Personal communication, seminar, Harvard University, 1998). Being a hydrogeologist, I know there is no such thing as a bottomless pit and even in the deepest of sink holes, the bottom ultimately can be found.

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Moreover, can we ever be really certain about all of the consequences of our actions? Our ability to measure and to predict the benefits and harms resulting from a course of action or a moral rule is dubious, to say the least. Perhaps the greatest difficulty with utilitarianism is that it fails to take into account considerations of justice. We can imagine instances where a certain course of action would produce great benefits for society, but they would be clearly unjust.Â The views expressed do not necessarily represent the position of the Markkula Center for Applied Ethics at Santa Clara University. We welcome your comments, suggestions, or alternative points of view. This article appeared originally in Issues in Ethics V2 N1 (Winter 1989). Truth or Consequences was the long-running wild & wacky game show where contestants that were selected from the studio audience could either tell the truth (answer a question) or be forced to pay the consequences (perform a stunt). On the show, people had to answer a trivia question correctly (usually an off-the-wall question that no one would be able to answer correctly, or a bad joke) and had about two seconds to do so before "Beulah the Buzzer" was sounded (in the rare occasion that the contestant â€˜scientific truth.â€™â€ Id, 110. II â€“ The Historic Background to Use of the â€œReasonable Degree of Certaintyâ€ Terminology. The requirement of an expert testifying that a conclusion is held to a â€œdegree of certaintyâ€ emerged in the context of medical testimony, when witnesses in civil cases were asked about the potential future consequences of an injury or illness.Â As well, both the Daubert and Frye tests, when properly implemented, serve to screen out speculative testimony and thus further demonstrate the lack of need for the "reasonable degree of certainty" language. III â€“ Emerging Criticism of the Terminology. Both academic and policy writing have addressed the lack of a requirement for, and the problems arising from use of, the term â€œreasonable degree of [] certainty.â€