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Privatizing stream restoration in the US

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Abstract

In this paper, we use a case study of the stream restoration field to demonstrate how the particular state and market logics of neoliberalism are shifting both the practice of restoration scientists and the relations between public and private sector science. In particular, the embrace of neoliberal environmental management regimes has intensified the demand for environmental scientists to produce applied science that can: (1) be taught as a standardized package; (2) be used by agencies to justify decisions; and (3) form the basis for new markets in ecosystems services. At this point, private sector science produces the most influential knowledge claims, the most widely used applications, and the primary educational system for stream restoration in the US. We argue that the needs of markets and regulatory agencies are heavily implicated in this privatization process, and that the resulting impacts on restoration science and the dynamics of the stream restoration field in the US thus cannot be described without attention to political–economic relations.

Keywords

natural channel design, neoliberalism, political-economy, stream mitigation banking, stream restoration

The idea of the 20th century as a Mertonian golden age of science free from outside influence is clearly mythic (Kleinman, 2003; Mirowski and Sent, 2002; Rasmussen, 2002, 2004; Shapin, 2008), but it is also clear that the relations between public science and private profit have shifted dramatically over the last 30 years with the broad, global

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movement towards neoliberalism (Canaan and Shumar, 2008; Ciafone, 2005; Davies et al., 2006; Fisher, 2009; Mirowski, 2010; Mirowski and Van Horn, 2005). The increasing emphasis on the privatization and commercialization of science has shifted methods, organization, and content across the natural sciences.

In this paper, we use the field of stream restoration as a case study to demonstrate how the particular state and market logics of neoliberalism are shifting both the practice of restoration scientists and the relations between public and private sector science. In particular, the embrace of neoliberal environmental management regimes (Bakker, 2005; McCarthy and Prudham, 2004; Mansfield, 2004; Robertson, 2006) has intensified the demand for environmental scientists to produce applied science that can: (1) be taught as a standardized package; (2) be used by agencies to justify decisions; and (3) form the basis for new markets in ecosystems services.

Drawing on 5 years of fieldwork by one of us,[1] we describe the startling state of affairs in the American stream restoration community. Over the very vocal protests of university- and research agency-based scientists, a consultant with little formal scientific training – Dave Rosgen – has become the most broadly acknowledged scientific expert in the field, providing key new basic knowledge claims, applied techniques, and the primary source of training for the field (Malakoff, 2004). The scientific center of gravity of stream restoration has thus shifted from the public sector (by this we mean both academia and the federal research agencies, such as the US Geological Survey (USGS) and the Agricultural Research Service of the US Department of Agriculture (ARS)) to the private sector.[2] We argue below that the needs of markets and of resource and regulatory agencies are heavily implicated in this shift towards privately produced science, and that the nascent stream mitigation banking industry has deepened it, becoming another driver of privatization for stream restoration science (as well as a source of additional support for Rosgen's work).

Because of the key role of markets and the state[3] in shifting restoration science out of the public sector, we argue that attention to political–economic relations is critical. Further, we argue that these changes in the public/private balance of the stream restoration field are symptomatic of shifts taking place throughout the environmental sciences, and thus are worthy of increased attention from STS researchers.

Stream restoration in the US

Ecological restoration is predicated on the idea that humans can undo past anthropogenic environmental harm. While restoration is quite complex in practice, it has a simple kindergarten logic to it: if you make a mess, clean it up, and put things back the way you found them. The intuitive appeal of this vision of humans as positive environmental actors has made restoration a driving force of the American environmental movement (Jordan, 2000). Despite deep concerns from many preservationists who view restoration projects as at best faking nature and at worst a disingenuous cover for destroying pristine environments (Elliot, 1982, Katz, 1992), over the past 30 years restoration has become a broad grassroots movement, and a key agenda for local, state, and federal agencies. It also has catalyzed the development of a substantial market in consulting services to design, implement, and manage restoration projects.

Stream restoration in particular has become something of a flagship for the movement, because it is implicated in a range of critical issues such as protection of endangered species, flood prevention, drinking water quality, and outdoor recreation, and thus receives tremendous amounts of public attention. Political organizing at the watershed scale has become a key element of grassroots environmental work; for example, there are more than 400 watershed advocacy groups in California, Oregon and Washington alone.

Although there has been a limited amount of stream restoration in the US since the late 19th century (Thompson and Stull, 2002), and watershed and river management have been an active focus of the federal government since the Mississippi floods of 1927, the grassroots stream restoration movement did not take off until the late 1960s and early 1970s.[4] Until that point, the dominant framework for river management was primarily economic, and federal involvement with rivers centered on flood control, hydropower, irrigation, and navigability to improve trade.

In 1968, the Wild and Scenic Rivers Act put forward the first strong non-economic view of rivers at the federal level, followed in short order by the National Environmental Protection Act (NEPA) in 1969, the Federal Water Pollution Control Act in 1972 (re-titled the Clean Water Act (CWA) in 1977), and the Endangered Species Act (ESA) in 1973. Thanks to enforcement of the CWA's permit program for point-source discharges, by the early 1980s most streams in the US had water clean enough to once again support a range of aquatic organisms, and thanks to the ESA some of those organisms had the legal right to be there. Further, because of the NEPA, any impacts to those streams from federal projects had to be disclosed to a public that was increasingly opposed to channelization and other heavily engineered solutions to flooding problems.

Of these laws, the CWA has had a particularly powerful impact on stream restoration. Section 404 makes it far more difficult for developers and public works departments to move or culvert inconveniently located streams without substantial investment in restoring comparable streams.[5] And in recent years, increasing numbers of local water management agencies have turned to restoration to help meet water quality standards under Section 202 of the CWA, particularly in relation to sediment.[6] Thus, by the mid-1990s, the stream restoration market had reached approximately US$1 billion a year, and has continued to grow vigorously (Bernhardt et al., 2005).[7]

The demand for stream restoration science – both basic and applied – is thus quite clear. But what is startling about stream restoration is this: while the field's core tenets and measurement techniques come from research carried out by public sector scientists, today some of the most commonly applied tools and knowledge claims, and virtually all of the basic training, is generated by the private sector.

Is this state of affairs actually unusual? There are any number of fields in which training, professional certification, and applied techniques are largely developed in the private sector, bypassing academia and the federal research agencies: forensic technicians (Cole, 2001), farmers (Henke, 2008), carpenters and beauticians among many others. Clearly, there is no reason why the university must be the obligatory point of passage for a profession or field, but we would argue that in each of these cases the profession started as a practice, not as a science. By contrast, stream restoration began in public sector science, and the basic knowledge claims of the field were developed by academics and federal research agency scientists.[8]

Further, developing the core of the field has given public sector scientists a powerful sense that they *should* be its obligatory point of passage; while few if any public sector researchers would argue that the university should be the primary source of research, training, and certification for beauticians, almost all of the public sector scientists interviewed during the course of this research think the university should serve that role for stream restoration. And indeed, restoration practitioners describe initially looking to universities and federal research agencies to provide techniques and training for the field. But many scientists were slow to embrace the more interventionist focus of stream restoration practice, as is discussed later in this paper, and as a result the seat of scientific legitimacy in stream restoration has gradually shifted towards the private sector. Interestingly, the shift in location has not changed the field's status for participants, who still consider it a science. Rosgen, for example, consistently describes himself as a scientist and a teacher of scientists, not as a consultant.

As we will argue in the remainder of the paper, Rosgen both started and, despite the vehement objections of public sector scientists, consolidated this shift to a private sector restoration science; the emerging practice of stream mitigation banking seems likely to deepen it.

Rosgen: Shifting the center of gravity out of public science

Dave Rosgen is a consultant with little formal scientific training.[9] In the mid-1980s, using classic 1960s work by researchers at USGS and 20 years of his own field data on riparian morphology, he developed a relatively simple system for classifying and reconstructing stream channels (Rosgen, 1994, 1996). Rosgen's approach, which he and his supporters typically refer to as natural channel design (NCD), promises to restore the natural form and function of streams *and* to maintain channel stability.

Geomorphologists have long used typologies and classifications in attempts to shed light on the underlying physical processes that shape channel form (see Kondolf et al. (2003) for an historical review),[10] but Rosgen's classification system differs from past and contemporary typologies in four key ways. First, Rosgen presents his classification as a tool that can '[p]redict a river's behavior from its appearance' (Rosgen, 1994: 170). Claiming that it is possible to diagnose the future evolution of a channel based on evaluation of its current form is a striking departure from the current consensus in geomorphology. It is also critical to the second way in which Rosgen's classification system and overall design approach depart from the geomorphological mainstream: an emphasis on channel stability. Rosgen and his supporters aim to design channels that stay where they are put; the classification system's claimed ability to predict which channel forms are inherently stable is critical for achieving that goal. As Rosgen describes it, 'To restore the "disturbed" river, the natural stable tendencies must be understood to predict the most probable form' (p. 195).

Rosgen's classification system also differs from past channel classifications developed by engineers in its emphasis on working with nature. Rosgen emphasizes channel stability as a means of restoring ecological function, directly contradicting traditional hydraulic engineering practices that valorize certainty of outcome at the expense of ecology. For example, when describing in-stream structures in the original publication on his classification system, he wrote that 'structures may be better designed to not only meet their [ecological] objectives, but [also to] help maintain the stability and function of the river' (Rosgen, 1994: 187). Finally, the classification differs from other typologies because it claims to be universally applicable; according to Rosgen and his supporters, his system should make it possible to classify any channel, anywhere.[11]

These claims of universal applicability, stability, and naturalness are deeply appealing for resource agencies. Since he started his consulting business in 1985, Rosgen's work has been promoted by key federal agencies including the Environmental Protection Agency (EPA), the US Fish and Wildlife Service (USFWS), the National Resources Conservation Society (NRCS), and the US Forest Service (USFS), as well as the natural resource departments of more than a dozen states. Many of these agencies now require Rosgen's restoration approach to be used in projects they fund, manage or regulate.[12]

In many areas of the US, students who have completed PhD degrees in fluvial geomorphology or hydraulic engineering are being turned away from restoration jobs because they are considered unqualified.[13] Professors and full-time consultants with decades of experience cannot bid on projects because they have not studied their own subject as taught by Rosgen.[14] Rosgen's NCD approach is now central to the lucrative stream restoration market, and is increasingly seen as a more legitimate basis for restoration practice than academically-produced science and training. His approach thus has been a key factor in shifting the scientific center of gravity of the field to the private sector, despite the very vocal objections of restoration scientists (which will be discussed in more detail below).

Rosgen's origins[15]

In 1965, Rosgen started work as a hydrologist with the USFS. He was assigned to an area in which he had fished regularly as a child, and was shocked by the changes: thanks in part to extensive clear-cutting, many stream channels that had been narrow, rocky, and hugged by extensive riparian vegetation were now wide, sandy and exposed. Rosgen wanted to understand why some streams could experience severe disturbance without taking substantial damage, while others in the same watershed were profoundly affected. At the time there was no handbook for these kinds of questions, so he began to teach himself by reading, measuring, and talking to everyone he could get to sit still and listen, most notably revered geomorphologist Luna Leopold. During the 20 years Rosgen worked for the USFS, he developed the core of his classification system and design approach, refining them in consultation with Leopold, Lee Silvey, and other USFS hydrologists.

In 1985, Rosgen left the USFS and started a consulting firm, Wildland Hydrology.[16] By 1986 he was teaching short courses at the University of Nevada-Reno, the USFS had been forced to hire him back on a consulting basis for the pivotal Division I water rights case (Gordon, 1995), and he had embarked on his first big restoration projects. This was the period when the stream restoration market was just beginning to take off. There was very little direction available from academia or federal research agencies about how to restore rivers and streams, though, and no one was certain if it was a do-able project. Restoration practitioners were hungry for guidance, and Rosgen stepped in to provide it.[17] His classification system was formally published in 1994, and his first textbook was

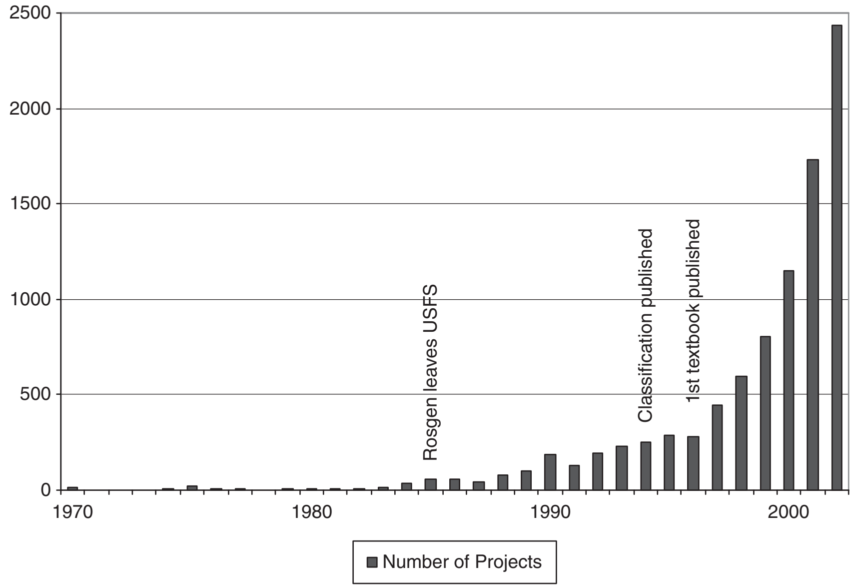

Figure 1. Number of stream restoration projects in the US per year, as reported by the National River Restoration Science Synthesis project (Bernhardt et al. 2005)

released in 1996. This was both response to, and driver of, the exponential increase in restoration projects in the mid-1990s (Fig. 1).

Since then, Rosgen has come to dominate the restoration market. He has completed more than 50 restoration projects, taught more than 10,000 students, and written two self-published textbooks and dozens of papers.[18] His restoration short courses are widely seen as the most legitimate source of training for restoration practitioners in the US. Most recently, the EPA commissioned him to develop a set of methods for assessing channel stability and sediment supply to set allowable levels of sediment pollution *nationwide* (Rosgen, 2007b). This work has the potential to explode Rosgen's reach from just those streams considered for bank stabilization or reconfiguration to every riparian system in the US. Clearly, his influence on the field has not yet begun to peak.

The natural channel design approach

NCD has three main components derived from classic 1950s and 60s work in fluvial geomorphology and Rosgen's own extensive database of morphological field data. The first is a purportedly universally applicable alphanumeric classification system that divides channels into seven categories (A–G, each with multiple numbered sub-divisions) based on a relatively brief evaluation of their physical form (Rosgen, 1994). The second component is a set of structures for implementing restoration designs. These structures perform many of the same functions as more traditional hydraulic engineering structures:

stabilizing the channel to prevent it from moving sideways or downcutting. Unlike those built by the US Army Corps of Engineers (USACE), however, Rosgen's structures are constructed from boulders and logs with roots and branches still attached, and thus have both a much more natural appearance and potentially more habitat value than the typical USACE project. The third component of the NCD approach is a set of design guidelines that specify a 40-step restoration design process. The steps range from assessing the underlying causes of the issues to be corrected, through consideration of passive management alternatives, developing a design for the restored channel, implementation, and monitoring (Rosgen, 2007a). Rosgen's are the only codified standards of restoration practice available in the US.

Rosgen's NCD approach is generally excluded from university curricula and from standard engineering continuing education courses (offered under the auspices of organizations such as American Society of Civil Engineers) because of academic and federal research agency opposition to his work. Thus, to disseminate his classification system and design approach, Rosgen developed a series of four short courses. Rosgen teaches a dozen or more each year, all of which are heavily attended by agency staff and private consultants, despite a fairly steep cost (US$1500–3000 per person depending on the length of course, not including transportation, lodging or meals). After completing the 29 days of courses, attendees are considered to be Rosgen-certified. Attendance at the short courses is spurred by the fact that a growing number of agencies have made Rosgen training a requirement for consultants bidding on restoration projects.

Explanations for Rosgen's success

Rosgen's critics have not taken this state of affairs lying down. Since the mid-1990s, a disjointed coalition of university-trained academics, agency staff, non-governmental organization (NGO) staff, and consultants (including almost all of the most respected academic and agency researchers on stream restoration in the US) have tried to leverage their scientific capital to delegitimize Rosgen, his work, and his students. The ensuing battle, often referred to as 'The Rosgen Wars', has convulsed the stream restoration field for more than a decade (Malakoff, 2004).

Critics' objections are for the most part substantive, focusing on ways in which Rosgen's scientific practice and the content of his classification and NCD approach are seen to depart from the current consensus in geomorphology (see Lave (2009) for an extended discussion of the most important critiques).[19] Two examples should suffice to give a sense of the depth and breadth of the objections raised by the anti-NCD camp. Critics argue that by breaking his approach down into a step-by-step process, Rosgen ignores both the complexity and specificity of stream channels in favor of universalizing simplistic techniques, thus leading to high rates of project failure. Critics also point out that Rosgen's claimed ability to create stable channels is in direct contradiction of the current scientific emphasis on rivers as dynamic systems; today, critics argue, channel movement should be a goal of restoration projects, not a problem to be fixed.

Yet despite the power of these and literally dozens of other commonly voiced objections, critics have been startlingly ineffective at slowing the spread of Rosgen's approach;

far from nipping his success in the bud, they haven't even been able to prune him to a standstill. Scholars have put a great deal of time and ink into demonstrating the erosion of scientific authority in Western culture (for example, Beck, 1992), but that authority is still quite powerful when it comes to delineating the bounds of science itself, as dissident scientists have learned to their cost (Delborne, 2008; Gieryn, 1999). How has Rosgen been so successful in the face of such powerful opposition from the established holders of scientific legitimacy and prestige?

One factor is clearly Rosgen himself. He is deeply knowledgeable, with more than 40 years of field experience studying streams, which is unusual for a consultant in an industry that is itself so young. Rosgen is also a very charismatic man; people light up when they talk about him. He is an honest-to-god Westerner from ranching stock with a lifetime's practice training cutting horses, who sports a rodeo belt buckle he won, western shirts, and a white cowboy hat. He is energetic, opinionated and extremely self-confident, and expresses himself in practiced folksy phrases: idiots have, 'a terminal case of the dumbshits', well-meaning idiots have, 'their heart to cranium ratio out of whack', and following the advice of either is like, 'crapping your chaps and sitting in the saddle'. His appeal is such that, as many observers on both sides of the debate have wryly noted, there is now a large group of people who don't just want to do work like Dave Rosgen, they want to *be* Dave Rosgen.[20]

A second factor is early endorsements that conferred some initial scientific legitimacy. One of Rosgen's first and most enduringly important supporters was Luna Leopold, who, in addition to his academic and research credentials as head of the USGS Water Division, member of the National Academy of Sciences, and holder of the National Medal of Science, is widely regarded as the father of stream restoration in America. Leopold provided Rosgen's primary training in fluvial geomorphology through a sort of extended apprenticeship, as well as giving Rosgen enormous legitimacy by supporting his work, co-teaching his initial short courses, and writing the foreword to his first textbook. Because of Leopold's eminence in the field, he was also able to serve as a buffer between Rosgen and advocates of traditional hydraulic engineering until Rosgen established a constituency for his techniques. A case study on one of Rosgen's early projects in the highly influential 1992 National Research Council (NRC) report *Restoration of Aquatic Ecosystems* describes Leopold serving as arbiter between the USACE and Rosgen on the design of the Blanco River project:

> The project almost failed to materialize when COE [the US Army Corps of Engineers] subjected the unique design to expert review and was told by its reviewers that the new system would not contain flood flows. The project design was then sent for review to Professor Luna Leopold at the University of California, Berkeley, Department of Geology and Geophysics; Leopold praised the project and expressed confidence that it would work. On the basis of his recommendation, COE withdrew its reservations, and the project was allowed to proceed. (National Research Council, 1992: 474)

Without Leopold's support, both supporters and opponents agree that Rosgen's work would likely never have achieved its current prominence.

Then there is the 1992 NRC report *Restoration of Aquatic Ecosystems* itself, which featured Rosgen prominently in the chapter on streams and rivers. A number of interview subjects pointed to that report as a key early indication of Rosgen's legitimacy. But another charismatic consultant was featured in that same chapter – George Palmiter – and he vanished from the national stage soon afterwards, despite the support of a number of prominent restoration scientists in universities and federal research agencies. Thus it seems that charisma and early endorsements are not sufficient to explain Rosgen's rise, and the resulting shift in the center of gravity of stream restoration science. Instead, we will argue in the sections that follow that the most powerful factor producing Rosgen's scientific legitimacy is the way that his knowledge claims, applied techniques, and training system meet the needs of the state and market.

Design guidelines as standards of practice

Rosgen has developed the only set of purportedly universally applicable methods for channel reconstruction projects. As described above, his design approach includes both guidance on the overall form a newly constructed channel should take, and specific restoration techniques to achieve that form. University- and federal agency-based scientists have not put forward a competing methodological framework because their insistence on the complexity of stream systems makes such a universally applicable system seem ludicrous. Motivated by liability for failed projects, the engineering community has started to develop restoration guidelines, but this initiative is only just getting underway and is unlikely to produce solid results for years (see Slate et al., 2007).[21] Thus for the foreseeable future, Rosgen's design approach provides the only systematic standard of practice for stream restoration.

The explicitly spelled-out, step-wise form of Rosgen's design approach has obvious appeal for consultants responsible for designing stream restoration projects, but it is even more critical to the functioning of resource and regulatory agencies. There is a large group of bureaucrats at the local, state, and federal levels who have been confronted since at least the early 1990s with the Sisyphean task of choosing consultants, managing contracts, issuing permits, and writing legislation to produce successful stream restoration projects. These agency staff members are central to the practice of stream restoration in the US, despite the fact that it is a subject about which many, perhaps even most, have little knowledge or experience. They are the ones who must choose between proposals prepared by university-trained consultants and those prepared by Rogen's students. And perhaps even more importantly, because they are bureaucrats they must be able to justify those decisions to their superiors and the public at large using non-arbitrary criteria drawn from the field itself.

How can this decision to accept some consultants' work and not others be justified in the absence of a systematized academic discipline of stream restoration science? Content seems the obvious ground for distinguishing between the approaches, but there is sufficient overlap between the two camps (the core material developed by public sector scientists, referred to above) that it requires a substantial knowledge base to see the differences, much less to understand why they matter. Experience could be another possible justification for accepting one camp of consultants over the other, but there are very experienced practitioners in both.

What remains, then, is the bureaucrat's safe haven of justifiability: the application of accepted standards (Bowker and Star, 1999; Espeland, 1998; Porter, 1995). The only set of standards, spelled out step by step, against which it is possible to check a channel reconfiguration design is Rosgen's. Thus the standards of practice supplied by Rosgen's design guidelines are critical to their utility for the new field. Bill Heatherman, the Stormwater Engineer for the City of Overland Park, Kansas, described his experience in a 2005 email to the River Restoration Committee of the American Society of Civil Engineers:

> One reason why regulatory agencies may be so inclined to require Rosgen courses is because of the lack of credentialing (so far) or even consistent academic coursework sequence that one could use to screen out people who should have some skills at design-scale stream geomorphology and those that clearly don't …. [Without that easily recognizable qualification it] was difficult … to justify why we accepted the work of some consultants in geomorphology, but not everyone who came knocking on the door.

The state has returned the favor by playing an enormous role in promoting Rosgen's claims to scientific expertise. Agency staff at the local, state and federal levels are the anchors of the NCD epistemic community, and federal agencies such as EPA and NRCS have provided critical support for Rosgen's claims to scientific expertise by commissioning him to develop national standards and protocols. Resource and regulatory agencies powerfully support Rosgen's claims to legitimacy and expert status.

Meeting economic needs

For consultants, Rosgen's short course series is even more critical than the design guidelines. Stream restoration has had such a sudden rise to environmental and economic prominence that there is a serious disconnect between the jobs available and the pool of qualified practitioners. While the number of faculty engaged in restoration science has been steadily increasing (see the section on Effects on public science, below) universities have been very slow to develop programs focused on restoration science or practice, and it is not yet possible to get an academic degree in stream restoration in the US.[22] There are some state and polytechnic universities that offer concentrations in stream restoration as part of degrees in environmental or watershed management. There are also two universities (the University of Minnesota and Portland State University) with restoration certificate programs. For the most part, however, motivated students attempt to cobble together a suite of reasonably relevant courses in ecology, geomorphology, hydrology and engineering from the existing course offerings at their university, with highly uneven results.

Many of the factors that influenced universities' failure to build centers or departments of stream restoration will be familiar to any academic, regardless of discipline. Universities are like oil tankers; one should never underestimate their inertia. New programs require resources of administrative and faculty time, space, and funding, all of which are held dear. River restoration, in particular, presents difficulties as it spans disciplines from engineering, to geoscience and the life sciences, and is thus diffused across multiple colleges within any university. Further, the primary proponents of restoration programs have been applied scientists, who are usually lower status than basic researchers and rarely have the clout to start new programs from scratch. Finally, becoming an adequate restoration practitioner requires a major component of learning by doing.

Although this is less true of many state schools, research universities do not tend to encourage apprenticeship as part of degree requirements, nor do their faculty typically have the extensive hands-on project experience to be able to provide such training.

Thus, while Portland State University and the University of Minnesota demonstrate the possibility of developing academic stream restoration programs, it is clearly not an easy project. The group of faculty who produced the research at the core of stream restoration science have been largely unable to provide broad restoration training or, perhaps more importantly, *certification of training,* even as their numbers swell when scientists switch to more applied projects (as discussed in the next section). Without university degrees to provide widely recognized credentials, stream restoration consultants have struggled to establish their legitimacy.

Rosgen has used his series of short courses to fill this gap, creating a system for disseminating knowledge of the NCD approach that is broken down into 5- to 10-day chunks that correspond reasonably well with the normal work week, and that run in a price range that private firms and many agencies can afford within their training budgets. Critically, the short course series offers a broadly recognized qualification: on their resumes, consultants prominently list the level of Rosgen courses they've completed, and many firms state that they have staff who have completed Rosgen training on their websites.[23]

Thus Rosgen's short courses meet the needs of the restoration market by providing consultants with training that fits their mode of operation and a qualification that is nationally recognized. This nimble response to the needs of the market is part of why Rosgen's short courses have been highly successful in building an epistemic and practical community. Consulting firms and regulatory agencies throughout the US are now heavily staffed with people who associate stream restoration with Rosgen and his NCD approach. As Rosgen certification is increasingly adopted as the standard for practicing stream restoration, university-educated restoration designers are being shut out of the field.

Effects on public science

The stream restoration field today presents a striking picture in which, for the majority of participants, university- and agency-based scientists are no longer the most respected sources of knowledge, applied techniques and training. Further, the shift towards private sector science has influenced the content and practices of public sector science itself. This can be demonstrated in several ways.

Data on projects funded by the National Science Foundation (NSF) and on papers published in peer review journals demonstrate the increasing focus on stream restoration among academic river scientists. While there were relatively few peer-reviewed publications on stream restoration through the 1990s, they were followed by a notable increase that began around the year 2000 and continues to the present (Fig. 2). Similarly, the number of NSF grants for research on stream restoration remained relatively low through the late 1990s and then began a marked upwards trend (Fig. 3).[24] Suggestively, these increases in research and publication on stream restoration shadow the increase in number of restoration projects (Fig. 1). Can the increasingly applied focus of researchers in fields such as hydrology, fluvial geomorphology and aquatic ecology be directly linked

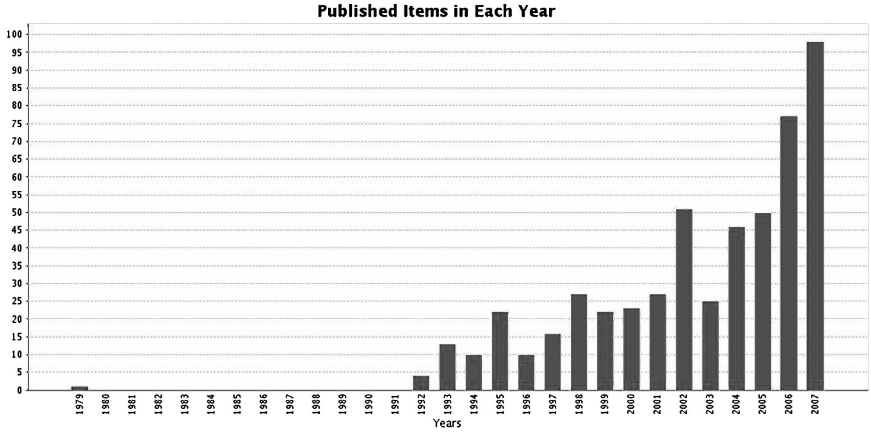

Figure 2. Number of peer-review journal articles on stream restoration published per year (source: ISI Web of Science)

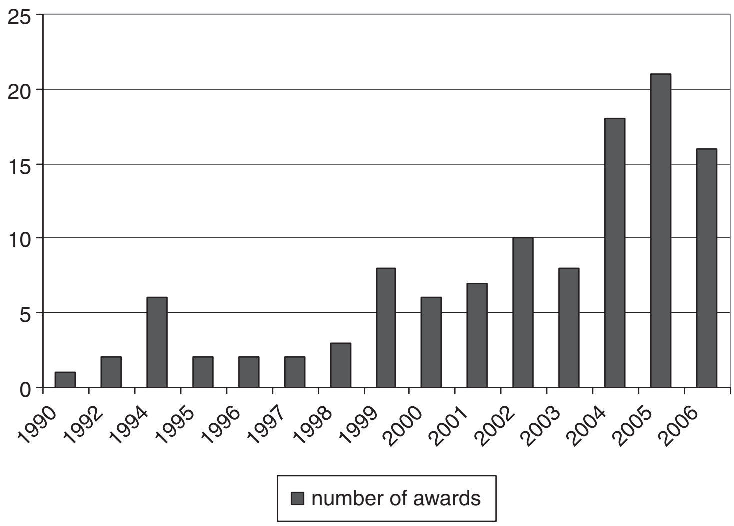

Figure 3. Number of NSF projects on stream restoration funded per year

to expansions in the restoration market, and to Rosgen's success in capturing so much of that market?

Interview data speak to this question; although Lave did not ask the question directly, many research subjects brought it up on their own. Confirming the initial lack of interest in stream restoration by agency and university researchers, consultant James MacBroom said that when he started researching more natural approaches to channel design in the late 1970s and early 1980s,

> [I] found that there really wasn't what we think of as design guides or manuals on how to design a channel for something other than a rigid boundary, prismatic type of geometry. On my own I discovered writings by Luna Leopold, other USGS people, and Gordon Wolman dealing with fluvial geomorphology. But it was never a design manual, it was talking about the subject as a pure geologist or hydrologist.[25]

A number of interview subjects confirmed from personal experience the trajectory of limited academic and agency researcher interest starting in the mid-1990s, with a notable ramping up in 2000–2001. Peter Wilcock, one of the most prominent sediment transport researchers in the US, reported that his level of interest in restoration had changed over time:

> I initially paid attention, back about … eleven or twelve years ago [1994/1995], when I first heard people remarking on this Rosgen phenomena … and complaining at scientific meetings about the dumb things that were being done in the name of stream restoration. … And then, four years ago [2002] … [I started co-teaching, and] that was the first time that I was actively involved in teaching a restoration short course. I certainly came into that as a sediment transport person. Then my level of activity hit the current maxed out level two years ago [2004] when I joined NCED [the National Center for Earth-Surface Dynamics]. They decided that stream restoration would be one of three major areas of emphasis, and asked me to lead that effort.[26]

USDA ARS National Sedimentation Laboratory researcher Andrew Simon, a prominent process scientist and Rosgen critic, described a similar trajectory in his career:

> Up until recently I haven't been involved in stream restoration at all. I've been involved in … the quantitative analysis of unstable systems …. My experience with restoration has come from the other side of trying to work with people who are involved in stream restoration to educate them into what the important processes are … [because] I became uncomfortable with some of the applications I was seeing.[27]

Steve Kite, a geomorphologist at West Virginia University, mentioned Rosgen's indirect impact on the timing of his decision to become involved in stream restoration:

> Can't say as I spent much time thinking about it [stream restoration] until 2001 when I was on sabbatical …. [S]ome colleagues in the Civil and Environmental Engineering department had taken his [Rosgen's] courses. They were trying to put together a stream restoration team, and found out through networking with a fish biologist that I had worked with that there was a fluvial geomorphologist on campus. That's where my active involvement in restoration started.[28]

Gary Parker, a prominent sediment transport researcher at the University of Illinois, described the relation between the rise of Rosgen and the shift towards applied research among agency and university researchers in both direct and approving terms:

> [U]ntil Rosgen started actually doing things, most academics had not the slightest intention of getting involved in an applied project and saying how things ought to be done. They spent most of their time telling people what they couldn't do …. Rosgen has had the effect of moving the

> entire field of river geomorphology more in the direction of thinking about how to solve practical problems.[29]

A final example comes from an informal conversation with Jack Schmidt, a geomorphologist from Utah State University. Schmidt said that he started the restoration short courses at Utah State because the state Department of Natural Resources came to him and said that they were tired of sending all these people out of state to Rosgen classes; since Utah State was a land grant school, would it provide an alternative? Schmidt now runs a two-level short course series at Utah State as a direct response to that government request.[30]

Taken together, these qualitative and quantitative data show an increasing number of agency and academic researchers being pulled into the study of stream restoration and away from more basic research. Further, these data suggest that the practice of public sector science has been increasingly tailored to meet the demands of the growing restoration market and to respond to Rosgen's role within it. Thus we argue that the privatization of the stream restoration field has begun to substantively affect the practice and content of public sector science and scientists. We turn now to the nascent field of stream mitigation banking (SMB), which is providing additional impetus to this shift.

SMB and the privatization of stream restoration science

Mitigation banking is an exemplar of the now dominant neoliberal paradigm of environmental management, which proposes market-based solutions to environmental issues, and a strong state to produce and guarantee those new markets (McCarthy and Prudham, 2004, Mirowski, 2009). In SMB, for-profit bankers work on a speculative basis to restore or enhance an area of stream habitat. This generates a bank of credits that developers can buy to fulfill the conditions of a permit issued under Section 404 of the Clean Water Act. While relatively new, SMB is spreading rapidly in the US, with established banks in states including Florida, Georgia, Missouri, Montana, North Carolina, Pennsylvania, Tennessee, and Virginia. As mitigation banking pulls science into the service of capital (Robertson, 2006), it seems likely to strengthen the shifts in public science research and practice begun by the rise of Dave Rosgen. In many states, it also supports Rosgen's work by extending its use.

Managing streams the neoliberal way

Since the mid-1980s, environmental economists have urged policymakers to deal with environmental degradation by treating the natural world as a set of public goods that must be assigned economic value, preferably through the creation of actual markets, in order to be conserved (Costanza et al., 1997; Joeres and David, 1983; Kneese, 1984). This is part of the larger neoliberal trend towards market-based solutions to a broad range of issues, which brings together the classical liberal economic faith in the ability of properly functioning markets to improve social welfare with a new political commitment to expand market relations into traditionally public arenas such as health care and education (Harvey, 2005; Peck and Tickell, 2002). The neoliberal shift in environmental policy has produced new markets in ecosystems services that trade in commodities such as carbon credits and constructed wetlands. The state's role is not to directly compel compensation for permitted environmental impacts, but to set up and guarantee a market within which compensation becomes a commodity, with a price tag negotiated by buyers and sellers.

SMB embodies this neoliberal trend: instead of commercial developers being forced to restore streams regardless of cost, SMB allows them to shop for mitigation credits at a negotiated price. Further, as we will explain below, the organization of the market is heavily influenced by the mitigation bankers who produce the credits.

Regulatory context

Section 404 of the Clean Water Act requires any public or private developer whose project will impact a river, stream, or wetland to apply for a federal permit. The 404 program is administered by the USACE (see comprehensive review by Hough and Robertson, 2009), which can require developers to mitigate unavoidable impacts by restoring other streams or wetlands elsewhere.

Mitigation banks were initially developed for wetlands. In the early 1990s, private developers frustrated with the slow pace and uncertainty of Section 404 permitting and the high cost of creating new on-site wetlands proposed the creation of large consolidated areas of constructed wetlands (wetland mitigation banks) as advance compensation. Working together, developers and local USACE and EPA staff developed the regulatory rules necessary to define, create and maintain a market in a new commodity: wetlands credits (Robertson, 2006). This wetlands mitigation banking framework allows private companies to restore wetlands which can be sold as credits to developers who do not wish to perform compensatory mitigation work themselves.[31]

SMB, which began in 2000, follows the wetlands mitigation banking structure (Hough and Roberston, 2009). While there are now federal rules specifying the requirements for establishing a stream mitigation credit market in a given region or district, they are based on a market structure originally developed collaboratively by local USACE Districts, EPA branches, state environmental agencies, developers, and private firms that hoped to establish mitigation banks; all of those groups continue to play a role in developing state mitigation banking protocols within the bounds set by the new federal rules. Regulatory and market needs dominate the SMB structure, but public sector science plays a role as well, as we explain below.

The role of science in mitigation banking: Establishing equivalency

Mitigation banking depends on establishing some kind of ecological equivalence between impact and mitigation: the stream to be destroyed and the stream to be restored. Assuring equivalence, however, is a task of *measurement*,[32] and this has drawn scientists into the task of establishing metrics that can be used to anchor ecosystem service markets. These metrics attempt to express stream ecology and geomorphology in simple schemes that can be used to convert riparian ecosystems into 'credits'. By converting streams into generalized objects that can be sorted, certified, and sold as commodities, the classification systems and metrics at the core of mitigation banking create a pared-down equivalency between highly complex systems.

Developing agreed upon, replicable standards of measurement is thus critical to any state's mitigation banking system. The stakes are high, and so are the tensions among the principal players negotiating mitigation banking regulatory frameworks: developers and bankers, state and federal agencies, and university- and agency-based scientists. For bankers and developers, the key need is a clearly defined, consistent, easily tradable commodity. For state and federal regulators, the key is to fulfill their legislative mandate to compensate for stream loss. And for public sector restoration scientists, the goal is scientifically credible definitions of ecosystems.

In North Carolina, a state with one of the earliest and most extensive SMB systems, the banking framework has been structured around Rosgen's classification system (North Carolina Department of Environment and Natural Resources, 2001; US Army Corps of Engineers, 2003). Despite the objections of public sector scientists, and the fact that Rosgen himself argues that it was not designed for such use, his classification system is the central metric establishing the equivalence of destroyed and restored streams in North Carolina (and most other states with SMB industries as well). Channel form was thus treated as a proxy for ecology and water quality, based on the assumption that if bankers got the form of the channel right the rest would follow.[33] In the world of mitigation banking, this is referred to as a *bundled* measure because it lumps all ecosystem functions together in one credit rather than separating them out.

The use of Rosgen's classification system in the context of mitigation banking is not as strange as it might appear. North Carolina has been a national hot spot of restoration since the early 1990s, and in North Carolina restoration means Rosgen. Everyone involved in restoration there is familiar with Rosgen's classification system, and with the NCD approach to restoration. Based on research Lave conducted in North Carolina at the end of 2007, NCD is the primary approach in which the staff has been trained in five of the six state and federal agencies that fund restoration,[34] and three require it. Among the five state and federal permitting agencies, four use an NCD approach[35] and the fifth (the USFWS) has one regional field office that uses an NCD approach (Asheville) and one with a more mixed approach (Raleigh). Every single one of the 20 survey subjects had heard of Dave Rosgen, and all but two of them employed his approach in their restoration work. As David Phlegar, the Water Quality Supervisor for the city of Greensboro, North Carolina put it, 'Rosgen's work and NCD are pretty much the standard here. If you talk about stream restoration that's the rule.'[36]

The new SMB framework is thus structured around a metric that is already broadly known and utilized in North Carolina. Further, the Rosgen classification system provides a relatively simple bundled metric for converting the messy reality of streams into easily tradable commodities. Credits are determined solely based on linear feet of particular Rosgen channel type. For example, if a developer sought a permit to destroy 400 feet (122 m) of E4 channel, s/he would be required by permit to purchase credits for 400 to 1200 linear feet (122 to 366 m) of E4 channel,[37] with little regard to the relationship between the scale of the destroyed and restored channels, or their particular ecological functions.[38]

The bundled metric based on the Rosgen classification system works well for bankers in North Carolina because it is relatively simple to measure and produces credits that are easy to market. It also works well for state and federal regulatory agency staff because it already has broad legitimacy in the state, and because correspondence with desired channel form is easy to assess. Public sector scientists, however, have opposed this use of Rosgen's classification system because they do not believe that channel form is an adequate proxy for the entire range of ecological characteristics specific to the channel to be destroyed. In addition, use of Rosgen's classification system, which many university- and agency-based scientists opposed long before it became the basis of North Carolina's SMB framework, is viewed as a further discount of their scientific expertise.

In response, some university- and agency-based scientists have begun to discuss the possibility of switching to *unbundled* metrics for SMB. Unbundled metrics would separate out individual ecosystem services, such as denitrification or turtle habitat, rather than using one bundled measurement as a proxy. Unbundled measures are seen as problematic by many in universities and federal research agencies because ecosystem functions are deeply interdependent: how can water quality be separated from endangered species survival? But unbundled measures become more appealing as long-term monitoring data suggest that projects constructed under the current Rosgen-based bundled system thus far are failing to restore ecological function.[39] At least with unbundled measures, public sector scientists could be sure that *some* ecological functions were being addressed. Further, development of unbundled measures would require research, which would presumably help to reassert the centrality of public sector scientists.

This return to centrality, however, would come at the cost of placing restoration science more firmly in the service of capital interests in stream restoration: to develop unbundled metrics for SMB, scientists at universities and research agencies would have to focus their efforts on an agenda determined by the needs of the SMB market. Thus, while it might shift the center of gravity of restoration science back towards the public sector, unbundling seems unlikely to restore the researchers' intellectual autonomy. Instead of basic research to resolve the many outstanding fundamental questions about riparian systems, scientists at universities and research agencies would need to deepen their new focus on topics of interest to the restoration industry and regulatory agencies.

Clearly, science in the service of capital is not precluded from simultaneously serving the interests of environmentalism; the increasingly dominant ecosystem services paradigm exemplifies efforts by ecologists to combine economic and environmental agendas. However, in the case of SMB the technical difficulties with developing unbundled measures may make this impossible. As Robertson (2006) has demonstrated in relation to unbundled measures in wetlands mitigation banking, there is good reason to believe that public sector science may not be able to provide adequate, replicable, credible measures for a wide range of narrowly specified ecosystem functions. Presumably the influence of university- and agency-based scientists would wane further if they were simply unable to provide the metrics the evolving SMB market required.

Conclusion

While it is clear that public and private science have been interconnected for decades, the extent to which the demands of markets and the state have been able to influence the trajectory of the stream restoration field is striking. Agency staffs' and consultants' need for standards of practice and an educational system to provide both training and a broadly accepted credential were clearly critical factors in Rogen's success. Just as clearly, the epistemic community created by Rosgen's short courses has been instrumental in promoting his work. About 85 percent of the more than 10,000 students he has taught over the past 20 years were agency staff (~60%) and consultants (~25%). Restoration consulting firms and local, state, and federal agencies throughout the US are thus staffed with people who associate stream restoration with Rosgen, and insist that it's Rosgen's way or the highway. Despite his relative lack of the traditional sources of scientific credentials – training, peer-review publications, and university employment – Rosgen and his work are increasingly seen as more scientifically legitimate than public sector scientists. Two telling examples discussed above are the North Carolina SMB industry turning to Rosgen rather than public scientists for their initial framework, and the EPA's choice of Rosgen rather than academically recognized researchers to create national guidelines for assessing sediment loads in riparian systems.

The influence of market and state demands goes beyond pulling the locus of scientific legitimacy into the private sector, however. In response to these demands, and to Rosgen's rise, there has been a substantive shift in the content and practice of university- and agency-based researchers. While there are still scientists at work training PhD students and filling the many gaps in basic knowledge of the ecology, chemistry, and physics of riparian systems, there has been a notable shift in focus for many other scientists studying riparian systems. This latter group is now attempting to fend off Rosgen and meet the needs of markets and the state through more applied research and the development of educational systems and short course series that mimic the form of Rosgen's while providing alternative content. The growing field of SMB has the potential to reinforce the shift away from a stream restoration science whose goals, standards of training, and legitimate content are defined by public sector scientists.

While stream restoration is clearly unusual in the extent to which the balance of power between public and private science has shifted,[40] we believe that the overall picture of growing state and market influence on the content and conduct of science is an increasingly common one, symptomatic of neoliberal influences on the university and environmental policy. There are a number of fields that deal with issues in which governments and developing or established markets have powerful interests, and that, like stream restoration, are changing to address those interests. We are thinking here of examples such as the impacts on meteorology from the growing weather derivatives market and the rise of private sector meteorology modeling (Johnson, 2010; Randalls, 2010), on hydrology from calls for regulatory agencies to develop more accurate flood maps (Porter, 2007), and on fisheries biology from the dependence of most commercial fisheries on maximum sustainable yield numbers (Bavington, 2002). As markets and states demand solutions that suit their needs (for ease of measurement, universal application, certainty, repeatability, and so on), these environmental sciences are being forced to shift focus or lose influence to private consultants.[41]

Further, the increasingly commercialized structure of the neoliberal university reduces the resources of public science to defend itself against private incursion. The growing emphasis on the marketplace of ideas and on evaluating research on its economic merits give increasing credibility to outsiders offering applied science solutions. This suggests that stream restoration is not a fluke, but a portent of things to come. And if that is the case, political-economic analysis will come to have increasing utility for STS researchers.

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Notes

1. Lave's research consisted of semi-structured interviews investigating the history, usage in practice, and critiques of Rosgen's approach with more than 60 academics, practitioners, and agency and non-governmental organization (NGO) staff centrally involved in stream restoration science; participant observation at restoration short courses and conferences to see how stream restoration work is taught; a mail survey of short course participants to delve more deeply into the motivations of short course students and their understanding and utilization of the material presented; a detailed case study of stream restoration practice among local, state, and federal agencies in North Carolina, a hot spot of restoration activity; and post-project appraisals of several restoration projects in California that have been mobilized in the controversy over Rosgen's work to explore how the struggle between public and private sector science plays out in practice.
2. While the privatization of science literature often refers to the movement of scientific research to for-profit companies or contract research organizations, in this case the work of a single consultant has been pivotal to privatization.
3. The state clearly plays a contradictory role in the privatization of stream restoration science. On the one hand, scientists at federal *research* agencies such as USGS and the ARS have been among the most vocal critics of Rosgen's work. On the other hand, staff at *resource and regulatory* agencies have been a critical constituency for Rosgen's restoration approach. This picture is further complicated by the fact that each local and state agency, and each regional office of federal agencies such as the Environmental Protection Agency (EPA) and US Army Corps of Engineers, has some autonomy in relation to stream restoration projects. Within the confines of regulatory requirements, staff at these resource and regulatory agencies can propose projects, write requests for proposals, and select consultants. Agency staff members charged with regulatory oversight, particularly at the federal level, can demand changes in projects and even set the conditions for requiring restoration projects in the first place. Thus, even in resource and regulatory agencies in which the top level managers are overwhelmingly supportive of Rosgen's approach (such as the EPA, US Fish and Wildlife Service, or the Natural Resources Conservation Service), project-level staff have some discretion about whether or not to employ it. This is why the depth of the support Rosgen has developed among low-level agency staff is just as crucial as the support he has garnered from their bosses (see the section below on 'Rosgen: shifting the center of gravity out of public science').
4. While concerns about fish habitat drove early restoration work, the primary catalyst of the stream restoration movement was opposition to flood control projects. Riley refers to the

decades between the 1936 Flood Control Act and the early 1970s as the 'Golden Age of Channelization': during that period the US Army Corps of Engineers and the National Resource Conservation Service channelized 20,724 miles (33,350 km) of rivers and streams and constructed 5897 miles (9490 km) of levees (Riley, 1998: 220), profoundly affecting riparian landscapes in the US.

5. Section 404 of the Clean Water Act regulates the discharge of dredged or fill materials into 'waters of the United States', which include riparian systems. To do so legally requires a permit from the USACE. Any proposed dredging or filling of an existing stream must be shown to be the least environmentally damaging practicable alternative for achieving the overall project purpose. Should significant environmental degradation still result, permit applicants must compensate for their impacts by restoring comparable streams on- or off-site, or by purchasing credits from stream mitigation banks that restore streams on a speculative basis, creating a strong incentive to develop stream restoration technologies. This will be discussed in more detail below in the section on SMB.
6. Author interview with Greg Koonce, principal Interfluve Inc., 14 September 2007.
7. According to a recent report by the Environmental Law Institute (2006), the federal government alone spent more than $2.9 billion on compensatory mitigation projects required by CWA permits in 2006, although the report does not make clear how much of this was spent on streams. Most likely, the majority of the funds were for wetlands restoration, but even if only one fourth of the $2.9 billion federal dollars were spent on streams, this would suggest a large rise in overall spending on restoration in the US, since many restoration projects are financed by private developers.
8. Craig Venter's breakaway from the public human genome project is somewhat analogous in generating considerable resentment among academic and government researchers. Those researchers still hold considerable legitimacy in the field of genetic science, though, so the analogy is not exact.
9. Rosgen earned a BS in forestry from California State University at Humboldt in 1965. In a surprising move given his longstanding critique of academia, he completed a PhD at the University of East Anglia in 2003, though without any coursework, which is not unusual in English PhD programs. Despite the fact that completion of the degree required Rosgen to pass muster with two outside examiners, the legitimacy of his PhD is questioned by Rosgen's critics, as it was completed under the supervision of Dr Richard Hey, who is effectively Rosgen's employee.
10. Channel classifications are geomorphology's equivalent of systematics in biology.
11. In part, these claims to universal applicability are set up by a lack of geographical specificity on Rosgen's part. He has never listed the locations, or even the hydro-physiographic provinces, of the rivers and streams on which the classification is based, writing only that it was derived from data on, '450 rivers throughout the US, Canada, and New Zealand' (Rosgen 1994: 169).
12. See endnotes 3 and 5 for more information on the regulatory process.
13. For example, Dr Steven Kite, a fluvial geomorphologist at West Virginia University, said that one of his first exposures to Rosgen's work was when, 'I had a graduate student who got an MS with a project that was in fluvial geomorphology, and applied for a job and was told he wasn't a geomorphologist because he wasn't Rosgen trained.'
14. Every Rosgen opponent Lave interviewed addressed this issue, as typified by Scott Gillilan, a consultant with 19 years of experience, who has stopped working for resource agencies

because there are so many that will, 'write into the RFP that you're going to do it this [Rosgen's] way. I've stopped trying to fight that battle and I don't respond to those RFPs anymore. I got burned out trying to educate them, and for the last five years, I've mostly been working for private clients.'

15. The material in this section is drawn from conversations with Rosgen in August 2003 at the NCED/NRC conference in Minneapolis; his Level I short course in Santa Cruz, CA in January 2005; his Level II short course in Fayetteville, AK, in November 2006; and a formal interview on 22 April 2007.
16. While working on the Arapaho-Roosevelt National Forest, Rosgen refused to do a project he considered unethical, and in response the Regional Forester issued him a directed reassignment (an involuntary transfer) to a forest to which he knew Rosgen would refuse to go. Technically, Rosgen resigned; effectively he was fired.
17. The absence of standards pre-Rosgen is notable because in the US, responsibility for developing standards of practice for river work and hydraulic engineering belongs to the research arm of the USACE. The Corps' Hydrologic Engineering Center typically requires years or even decades to develop its guidance documents. Without guidance from public science (in this case the Corps and academia), consultants and agency personnel were more open to the possibility of following standards set by a consultant.
18. All of Rosgen's papers have been published in conference proceedings except for the early paper in *Catena* (1994) that introduced his classification system, and a paper with Peggy Johnson on which he is listed as fourth author (Johnson et al., 2001).
19. For a selection of journal papers critical of Rosgen's work, see Gillilan (1996), Juracek and Fitzpatrick (2003), Kondolf (1995, 1998), Kondolf et al. (2001), Miller and Ritter (1996), Roper et al. (2008), Sear (1994), Shields et al. (1999), Simon et al. (2007), and Smith and Prestegaard (2005). For conference presentations, see for example Ashmore (1999), Doyle et al. (1999), Shields and Copeland (2006), and Simon (2006). For national guidelines efforts where authors have argued against the broad application of Rosgen's work, see Federal Interagency Stream Restoration Working Group (1998), Shields et al. (2003), and Slate et al. (2007).
20. One of the most striking of these stories comes from an agency staff person, who told of watching with mounting disbelief as employees of a consulting firm that used the NCD approach stopped to put on white cowboy hats like Rosgen's before photographing each of the cross-sections they surveyed.
21. The engineering community has long had well-developed guidelines for creating stable channels, but not channels that address the ecological mission of restoration. It is also worth noting that a few federal agency-based scientists who are also licensed engineers are participating in the guideline development process, but under the auspices of the American Society of Civil Engineers, not their agencies.
22. Civil and environmental engineering programs typically offer coursework in water resources, but most often from a flood control, rather than restoration, perspective.
23. At meetings, it is increasingly common for people to introduce themselves by name, place of work, and number of levels of Rosgen courses completed.
24. NSF lists no grants for stream or river restoration before 1990. For Fig. 2, Lave searched using the phrases 'stream restoration' and 'river restoration'.
25. Author interview, Dr James MacBroom, Milone & MacBroom, 24 July 2006.
26. Author interview, Dr Peter Wilcock, Johns Hopkins University, 24 July 2006.

27. Author interview, Dr Andrew Simon, USDA–ARS National Sedimentation Laboratory, 13 December 2006.
28. Author interview, Dr Steven Kite, West Virginia University, 26 July 2006.
29. Author interview, Dr Gary Parker, University of Illinois, 26 June 2006.
30. Personal communication with Dr Jack Schmidt, Utah State University, 22 October 2004.
31. See Lave et al. (2008) for a more detailed discussion.
32. The STS literature on metrology has clear relevance to the discussion that follows. We are thinking specifically of Porter's (1992, 1995) work on use of accounting and statistical tools, Curtis (1998), and O'Connell (1993). Donald MacKenzie's work on carbon markets (for example, MacKenzie, 2009) is particularly relevant as it deals with the construction of metrics for neoliberal environmental management.
33. Informally, this is referred to as 'the field of dreams hypothesis' (Palmer et al. 1997; Sudduth et al., 2010; Violin et al., 2010) or the 'build it and they will come' approach, with the 'they' in this case being not a disgraced baseball team, but fish, bugs, and ecological processes more generally.
34. NRCS, EPA, and the North Carolina Soil and Water Conservation agricultural cost share programs, Ecosystem Enhancement Program, and Clean Water Management Trust Fund.
35. USACE, EPA, and the North Carolina State Wildlife Division and Division of Water Quality.
36. Author interview, David Phlegar, City of Greensboro, NC, USA, 19 November 2007.
37. Mitigation ratios are determined by the quality of the stream system being destroyed.
38. Some attempt is made to limit trading to similar stream orders, and there is also limited attention to coldwater vs. warmwater systems.
39. Recent studies show that while stream mitigation projects reached targeted geomorphic success criteria, none reached minimum success criteria based on benthic macroinvertebrate communities (Violin et al., 2010), or nutrient retention (Sudduth et al., 2010).
40. The only other comparable example we know of is the field of range science, where consultant and teacher Allan Savory plays a role that is structurally quite similar to Rosgen's.
41. Scientists push back against these forces in a wide variety of ways; it is not yet clear which, if any of the techniques used will prove successful in limiting the influence of political–economic forces on the content and practice of scientific fields.

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