FUGITIVE DUST:
HOW DUST ESCAPES REGULATION AND REMAINS INSCRUTABLE

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Fugitive Dust: How dust escapes regulation and remains inscrutable

Thesis directed by Associate Professor William R. Travis

Abstract

Dust carries consequences for public health, visibility, trade and transportation, and water insecurity, yet dust largely remains inscrutable. This dissertation focuses on the consequences and politics of how we measure, monitor, and manage environmental systems and the broader "politics of inscrutability" in environmental knowledge. I use a mixed-methods approach including interviews, participant observation, document analysis, a community survey, and spatial analysis to investigate the ways dust is left unknown. My research explores the "politics of inscrutability" in environmental knowledge and its multiple modes of production, specifically focusing on disciplinary, intentional, material and discursive types of inscrutability. My initial chapter explores basic definition questions about my focal object: dust. I found that experts—regulators and scientists—struggle to define dust and that there is an "accepted ambiguity" about the lack of a technical or common definition, which halts the production of dust science. Then, I focus on the role of data collection in inscrutability. I analyze Clean Air Act monitoring system to highlight biases and unquestioned assumptions that lead to large spatial gaps and instruments that are ill equipped to detect extreme events, resulting in incomplete data about dust. Last, I examine how the treatment of "exceptional events" leads to the intentional removal of dust data from the regulatory dataset, altering regulatory action and nonattainment status. My research findings contribute to scholarship on the politics of environmental knowledge, specifically political ecology and STS, as well as make policy-relevant recommendations for dust regulation and monitoring. Ultimately, this work shows how multiple inscrutabilities each with their own conditions and politics keep dust largely unknown: these same processes are at play with many other environmental systems and sectors of environmental knowledge.

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CHAPTER I

INTRODUCTION: THE POLITICS OF INSCRUTABLE NATURES

It was 2010 and I was running late to catch the bus for work. I was hurrying around the Forest Service bunkhouse, dodging roommates and looking for the gear I would need to go up on the mountain. Where was I drying my gloves? Don't forget sunscreen; the elevations here will grill you alive. Brush your teeth. Shhh… only 5 of your 15 roommates are awake. And, hurry.

I frantically was throwing ski gear into my bag along with the educational aids I will use on my tour that day. In go the animal tracks and plant identification booklets and the snacks for clients. In went my IPod and headphones. I layered up and donned my work jacket with a name tag that read "Katie Clifford, Winter Naturalist." OK, three minutes until the bus arrives. I had done it again. I wave goodbye to my groggy roommates, maneuvering furniture as I leave the bunkhouse to race to the street corner to catch my bus to Snowmass Mountain. I swing the door open readying myself to sprint in my oversized Sorels and many layers to catch the bus, and I stop.

I freeze. My internal dialogue and coaching that urged me to move at rapid speed silenced. I was stunned by what I saw outside my door.

RED. Everywhere. A dark, muddy brown red, but a red nonetheless. Everything was tinted, almost as if a sepia tone. Every surface of what I saw was covered in this layer of muddy red. The snowdrifts lining the walkways, the cars in the parking lots, the peaks surrounding town and stretching into the sky—all red. Every surface had a film.

What was this? What happened? I was bewildered. I had worked outside the previous day and it has looked, well, normal. The snow was white, everything in its true color. But overnight something had happened.

Something I had no parallel for. When else do you wake up to your world being totally transformed into something you've never seen before? Everything was where it belonged, but distorted. Everything the same, but different.

Searching, I looked up at the mountains, the ones I worked on every day interpreting nature, ecology, and natural history for visitors to town. I had grown familiar with the mountains with the daily trudging through deep snow followed by a flock of first-time snowshoers. I explained how snow and ice—glaciers to be exact—carved the huge mountain valleys we looked over. My talks were all about the importance of snow, to ecology, cultures and water resources. But what had happened to this snow?

I'd missed the bus. Stunned in my tracks trying to piece together and make sense of this altered reality, I had failed the morning challenge. And, I had a new one. What would I say to the people on my tour about what this was? How would I interpret this foreign element?

On the next bus I sat next to a veteran ski instructor who informed me that this was dust-on-snow. Or "snirt." I launched in with my many questions: Where did it come from? What was causing it? What were the consequences of it? And, what was it? Yet, my unlucky seatmate as well as the countless other people I asked weren't able to answer them.

This ignited a curiosity that has followed me for years. Since my first experience with dust in 2010, I have been hunting down answers to try to gain insight about this process, to help make sense of this transformation I so clearly didn't understand. My search for answers was aided by long term locals and experts alike. I learned that it didn't just change how everything looked, but it also messed up the skiing in a ski town—a near criminal offense. This dust also made the snow melt faster, much faster. Locals reported this and experts had started to quantify how these little particles were causing the peak flows to melt weeks earlier. Many weeks. These initial answers just sparked more questions. Is dust increasing? What type of problem was dust? Who is working on the problem? What type of policy solution is possible? What will happen to water resources with such a dramatic change to the hydrograph? And, a persistent one: where was this coming from?

I had just graduated college and seen how science had the power to answer questions and explain the world. I was a believer and evangelist of science. But, why was science able to answer so few of my questions? The more I dug in trying to answer my many questions about dust, the more evasive it became. Yes, scientific studies were helping us understand elements of dust, but why was no one able to answer what seemed like obvious and easy questions?

Chiefly, where was dust coming from? It looked foreign. The dark red color did not resemble many of the local soils. I repeatedly was told that the dust originated in the deserts out West. But living in Western Colorado meant that did not narrow things down. We were neighbors to the Colorado Plateau, vast desert spanning to the South and West. This dust was dark red, very noticeable, yet its travel was seemingly invisible.

Surely, I could at least get an answer to basic elements of the phenomenon though. Was this "natural"? Was it increasing? Answer: unsure on both accounts. These two questions were largely unanswered in science, yet local communities were eager to fill in these gaps. "Dust was caused by ranchers who overgrazed and we need to stop grazing on public lands." "No, it is the off-road vehicles that don't stay on the designated trails and we need to ban their use." "Naw, it's the oil and gas development that has expanded throughout the Plateau and needs to be curtailed." "It is coming from the Navajo Reservation that has overstocked sheep and need sustainable regulations." "It's a natural cycle—its dust!"

After a year as a naturalist, I packed my bags to move to DC to understand how environmental laws and regulations were created and implemented. I still worked on Western public lands and water, but from a different vantage point and with a less intimate relationship. At the White House Council on Environmental Quality I began to see the dynamic dance between science and policy with many layers of politics. The relationship between science and policy was not the linear, single direction process I had previously thought. Science was not automatically taken up by policy, and in many cases, policy influenced science. My time in Legislative Affairs altered the way I thought about the science-policy nexus. After DC, I returned to the West to work for a wilderness nonprofit so I could engage more closely with the natural resources I worked on, which gave me perspective on the broad and divergent stakeholders engaged in resource management.

Yet, despite moving away from the Rockies and dust, I couldn't drop it. I had not found answers and I couldn't let go. My interest in dust was nagging. More than motivated to understanding dust, I just couldn't stop wondering how and why it was so evasive to science and regulation? Dust was slippery. It was not enrolled in regulatory frameworks nor captured in science. How?

This persistent—and what some might call annoying—obsession with dust has followed me for more than a decade and led to this dissertation. And, after five years of studying, I still have questions and curiosity. Of course, my research morphed and evolved in ways I would not have expected. My focus on dust-on-snow and hydrology were given a backseat to larger questions of uncertainty and how dust remained, in many ways, unknown. My attention moved from red stained snow to airborne storms that carried the dust. I could not just look at the outcomes—dust on snow and hydrology—without looking at the whole system. Further, this inquiry asked me to question previously held understandings of what was "natural" and the political work that category does out in the world.

My dissertation has been somewhat a hunt. I have been a detective in a highly quotidian story of dust but one that has high stakes and is telling of a larger story of regulatory science, environmental monitoring, and the science-policy nexus more broadly. This is both a story of dust and the specifics of dust in the Southwest, but also links to a larger story of how we come to know and manage our environment and its hazards and resources. And, like with many dissertations, it left me with more questions than when I started. Once I began trying to untangle the knot and solve the problem, I learned it was entangled with many other threads and the knot was much larger and complex than I had originally thought.

My dissertation evolved from a focus on dust to a focus on understanding what was unknown and known about dust and ask broader questions about uncertainty, unknowns, ignorance and inscrutability in environmental knowledge. How and why do we not understand or manage some elements of nature? How does dust and other environmental systems evade monitoring and regulation? To answer these questions, it required I examine what is left unknown more critically. My dissertation illuminates what nature is not known, what questions are left unanswered, *and what remains invisible and uncertain. Ultimately, it investigates the politics of inscrutability in regards to environmental knowledge.*

Fugitive Dust in the West

During the winter of 2009, snow in the Colorado Rocky Mountains was painted red by 12 dust storms (Skiles and Painter 2016), in what was later classified as an "extreme" dust year[1]. Mountain communities glowed an eerie red, electronics clogged with particles and stopped working, dust seeped into homes through cracks and crevices, locals coughed as they inhaled dust, newspapers reported that the communities were embattled in a "desert war" and that "skies wept mud," [2] and community members compared the event to a biblical plague. Dust affronted the senses: taste, touch, and especially sight. It was everywhere.

Elevated quantities of dust carry a suite of social and environmental consequences that make these dust storms matter to many. Dust storms strip topsoil at the source, affecting agricultural productivity as well as native desert ecosystem where soils are fragile and difficult to regenerate. During transport, dust creates visibility and respiratory health hazards, causing multiple car pile ups, grounded aviation, and a range of health issues from asthma, to valley fever to cardiovascular distress. Furthermore, when dust is deposited on snow, it can alter the hydrologic regime—by rapidly increasing the speed of snowmelt (Painter *et al.* 2007, 2012)— in an arid region where water is already over-allocated and fiercely contested. Dust, then, represents an issue of agriculture, transport and commerce, health, aesthetics, and water resources.

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[1] This is a qualitative category to measure the intensity of dust events in a season. Due to the very short record of observation (13 years) it is impossible to definitively speak to trends and certain quantitative metrics (Skiles and Painter 2016).

[2] Olivarius-Mcallister, C. (April 12, 2013). "Mud storm cleanup not so easy." *The Durango Herald.*

"Fugitive dust"— the technical term for dust that is produced from dispersed rather than point sources— has a significant history in the American West; it is part of a long-standing earth-systems process that carries red sandstone dust from the Colorado Plateau and deposits it hundreds of miles away in the central Rocky Mountains. While both human land use and climate are important drivers of dust storms, sediment cores indicate that land use practices are a greater contribution than climate driven megadroughts (Neff et al. 2008).

By many accounts this fugitive dust, and events like those described above, are increasing. Local newspapers report increased observations of dust in small, mountain towns. Skiers and boatmen, mothers and fathers, business owners and teachers, and many other local residents describe dust levels that seem to be greater than historic levels. And, scientists from multiple disciplines have tried to examine dust as an issue of soil science, atmospheric science, or snow hydrology. A dearth of data has made it difficult to conclusively say that dust has increased, but numerous studies present information of increase[3], albeit with important qualifiers like distinct timeframes and geographic scopes, use of imperfect proxies, or a focus on certain dust particles and not others.

Government data tell a different story. Remarkably, regulatory air quality monitoring shows no significant increases regionally in recent airborne particulates. Instead, government monitoring indicates that particulate matter is decreasing[4] (Hand *et al.* 2011). Regulatory attainment maps (maps of areas that meet air quality standards) also show significant portions of the Four Corners region as having safe air quality, despite otherwise observed dust storms.

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[3] See studies using a range of methods including sediment cores (Neff et al. 2008), proxies (J Brahney et al. 2013; J. Brahney et al. 2013; Clow et al. 2016; J L Hand et al. 2016), satellite data (Lei et al. 2016), using IMPROVE data to create a "dust climatology" (Tong et al. 2017).

[4] In both long-term trends (1989-2008) and short term (2000-2008) for "fine" particulates (J. L. Hand et al. 2016) (Hand *et al.* 2011).

To complicate things further, there are not just two camps: regulators versus everyone else, nor those who believe in decrease versus increase. Instead, the story of dust is much more convoluted than that. Many people simply do not know dust trends, or many other basic questions about it. Some of the scientists who are renowned for their expertise on dust still find so many dimensions of it imperceptible. Significant gaps in data and knowledge persist. Similarly, many locals in the area also are unsure of trends and impacts of dust. Trends of dust storms, like many extreme events, can be hard to decipher because of their variability. It is not only questions about dusts trends that remain uncertain. Many others persist: *where is it coming from? How much dust is there? What is causing it? What are the consequences of it? For whom? How do we stop it?* Thus, dust is left unknown to many actors who know the system differently: through science, local experience, oral history, and regulatory monitoring.

In the Southwest, fugitive dust is a system with significant unknowns and remains, at least partially, imperceptible to regulators and scientists. The unknowns surrounding fugitive dust are complicated, varied, intentional, accidental, interconnected, and dynamic. It is a case that allows us to trace the different threads of inscrutability back to look at their production and ask questions about how they became that way. Fugitive dust is made inscrutable by many different processes, each that would cloak it in uncertainty or make it invisible. Together, however, multiple drivers of inscrutability solidify fugitive dust as unknown and largely unknowable.

My dissertation explores the politics of inscrutability in environmental knowledge. It argues that inscrutability is produced through many different yet overlapping processes that leave nature beyond knowing. If we open up and examine the production of inscrutability—just as we have opened up the black-box of knowledge production—it can illuminate why, how and by whom elements of nature are left beyond knowing. Each type of inscrutability engages different actors, is a product of difference conditions, and each type carries distinct politics. While the outcomes of inscrutability can generally be viewed similarly—a lack of knowledge—the politics of its production is different. Said differently, inscrutability made intentionally by bad actors has different power relations than inscrutability due to evasive and dynamic materialities of the system, which has different politics than inscrutabilities arising from deeply entrenched disciplinary divides. I use the case of dust in the Southwest to explore the politics of inscrutable natures and highlight how these multiple types work individually and together to keep fugitive dust from being known.

The production of inscrutable natures

A lack of knowledge, be it uncertainty, unknowns, imperceptibility, or ignorance, shapes knowledge systems as much as presences do (Frickel 2014; Galt 2011; Hilgartner 2014; Murphy 2006; Simon 2018). Much attention is given to knowledge that is produced: what is the content? Who was involved in creating it? How does it get used? Yet, its absence can be equally influential to decisions, but often more invisible. Decisions, policies, actions and beliefs are shaped both by what is known and what is unknown. Uncertainty and ignorance are particularly powerful when they conceal risk and harm in the decision-making process or make consequences obscured. A lack of knowledge can be used strategically to serve certain purposes, often hiding certain people, places, systems and relationships (McGoey 2012; Murphy 2006; Oreskes and Conway 2011; Proctor and Schiebinger 2008; Wylie 2018). One of the most infamous examples was how the tobacco industry worked to manufacture doubt and "controversy" about the health hazards of smoking to slow regulation (Proctor and Schiebinger 2008).

Geographers have turned their attention to questions of environmental knowledge production after calls for greater engagement with Science Technology Studies (STS) and knowledge systems specifically (Forsyth 2013; Goldman, Nadasdy, and Turner 2011; Lave 2012a; Lave et al. 2013). More recently, they have turned their attention to its inverse: a lack of knowledge (Kroepsch 2018a;

Sedell 2019; Shattuck 2019; Simon 2018; Wylie 2018). Whether examining unknowns, ignorance, or uncertainty, scholars have turned their attention to unknowns and their consequences, drawing on a wide range of theories and methods.

A lack of knowledge can, and has been, discussed in many different ways, with different terms, all which overlap and diverge. My aim is to apply a broad category of the unknown and I recognize there are many different terms used to describe an absence of knowledge, each with different qualifiers (Croissant 2014; Gross 2007). Uncertainty has many meanings ranging from unknown variability (aleatory uncertainty) to missing data, variables, or general unknowns (Wescoat 2015).[5] Unknowns can be defined quite broadly to encompass many different types of knowledge absences, and often takes on different qualifiers of strategic (McGoey 2012) and known (Simon 2018). Ignorance is usually characterized as a lack of knowledge and often thought of as the outcome of a process, rather than about the process itself. Funtowicz and Ravetz (1990, 87-88) define ignorance as the most extreme of three sorts of uncertainty: inexactness, unreliability and ignorance. In contrast, Wynne (1992) envisions risk, uncertainty and ignorance to all be overlapping rather than on a spectrum under a broader category of unknowns. Proctor and Schiebinger (2008) argued that ignorance should be an object of inquiry and started the new field of agnotology. This focus on ignorance highlighted that the "causes of ignorance are multiple and diverse" (2). Yet, their attention largely focused on the outcomes and consequences of ignorance and much of this field focuses on ignorance that is deliberately produced or information sought to be known (native ignorance). This

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[5] Wescoat (2015) identifies four types including: "1. *Aleatory uncertainty* (i.e., unknown variability in the natural and social phenomena themselves). 2. *Data uncertainty* (i.e., missing data and unknown data quality). 3. *Model uncertainty* (i.e., missing variables and unknown fit between the model and reality). 4. *Epistemic uncertainty* (i.e., unknown approaches to problem framing and ways of thinking about the hazard) (295).

type of analysis of ignorance is productive for thinking through the consequences of unknowns but less helpful of understanding *why and how* dust is rendered inscrutable.

Murphy (2006) provides a more critical lens to examine unknowns: "domains" and "regimes" of imperceptibility. Domains of imperceptibility are made by the limits of knowledge practices. Limits exist in every discipline and are shaped by the types of methods and scientific instruments used and other tangible ways that both scientists and the public make some things knowable (quantifiable, measurable, detectable, seeable) and others not. All disciplines do this work; they study some things and not others. Domains are produced by the larger trajectories of disciplinary traditions and epistemological limits that she calls "regimes of imperceptibility." Regimes refer to the histories of science and the evolution of epistemologies that build upon each other to create pathways of knowledge production. Imperception is not just rendered by one decision, but by a series of epistemological decisions made over time that collectively form regimes that control what is known and what is unknown.

Murphy (2006) argues that chemical exposures were rendered imperceptible both by accidental and inevitable forces (the regimes of imperceptibility that produce epistemological limits, or domains) but also intentionally by the industry-sponsored science. Both leave understandings of chemical exposures partial, uneven, and out of reach. In the case of hydraulic fracturing (fracking), Wylie (2018) similarly traces how industry actors played an important role in keeping the chemicals used, and the health consequences from them, imperceptible to regulators and local people. Regulatory agencies themselves also contributed to the imperceptibility by granting the fracking industry exceptions to key environmental regulations that made it impossible to link emerging illness to chemicals. Sedell (2019) employees and explicitly geographic lens to examine the temporal and spatial elements of imperceptibility in the case of invasive insects. Yet, these cases are not exhaustive for how regimes of imperceptibility are formed.

I will use the term "inscrutability" to encompass the multiple types of unknowns of fugitive dust I examine in this dissertation. Since the aim of this analysis is to explore the different ways dust is not known, I choose a term focused on the ability to know it—its (in)scrutability—and the process of knowing and not knowing, rather than an outcome (i.e. knowledge or ignorance). Of course, inscrutability is deeply intertwined with and related to other categories of unknowns, yet it does not carry the same intellectual baggage as others previously defined and used to focus on narrow elements. Inscrutability allows me to engage with not knowing on my own terms.

What can fugitive dust show us about inscrutability more broadly? It is a case with many different threads that highlight previously identified inscrutabilities, new ones, and overlaps and layering between types. Dust makes these different types and their actions more visible. In addition to *disciplinary* and *intentional* which has been described by Wylie (2018) and Murphy (2006), two other important types of inscrutability are part of the story with dust: *material* and *discursive.*

Types of inscrutability

	Disciplinary inscrutability	**Intentional Inscrutability**	**Material Inscrutability**	**Discursive Inscrutability**
Produced through	The epistemological limits of disciplinary approaches that always value certain metrics at the expense of others or make certain questions answerable and others not. Research always has a series of tradeoffs that make some trajectories doable and others undoable and ultimately shape how knowledge production.	Intentional actions to halt knowledge production or hide elements of knowledge. This is produced willfully and is manufactured to serve certain purposes. It often occurs in cases where a lack of knowledge prevents certain types of actions or responses, particularly regulatory or legal action.	The materialities of the system/object itself make it difficult to know or understand. The way a system behaves and interacts with elements of the material world greatly shape our ability to know it.	Discursive framing that makes some elements harder to know or beyond inquiry. This work often occurs through naming and categorizing objects/systems in ways that excludes certain elements or makes them less visible.
Degree of Intentionality	**Moderate.** The values imbued in different disciplinary	**High.** This is a defining feature of this type. This	**Minimal.** While tools can be tinkered with and improved and	**Moderate.** Discourse can be used to minimize

	approaches that produce imperceptibility (i.e. individual vs population level) are somewhat intentional. However, they are often less overt and often not motivated by obscuring knowledge. Rather, just prioritizing certain knowledge over other types.	imperceptibility is internationally produced and motivated by the benefits of ignorance.	approaches adapted, some material and dynamic properties push against efforts to know them.	or hide concerns, but often many of the problematic categories are not intentional but built on false foundations like the nature/culture divide.
Degree of preventability	**Moderate**. All decisions have tradeoffs and studying one thing is often at the expense of another. In this way, research inevitably produces imperceptibility, but can also work to make the process more representative.	**High**. Since actors intentionally make things hard to know, it is based on conscious decisions. However, greater oversite or transparency might help prevent this.	**Low.** Dynamic systems are hard to understand, especially in unfragmented ways. The level of imperceptibility, however, is usually not inevitable, and different approaches may be more effect with lively materialities.	**Moderate.** All categorizing and naming is political, yet some distinctions are more encompassing, malleable, and can evolve, while others are more fixed and exclusive.
Key Theories	Regimes of imperceptibility (disciplinary) (Murphy 2006) Undone science (Frickel, Gibbon, Howard, Kempner, Ottinger, and Hess 2010) Dominant epistemic form (Kleinman and Suryanarayanan 2013) Doable Science (Clarke and Fujimura 2014) Blindspots & Path Dependency (Sayre 2015; Sayre 2017) Organized Ignorance (Frickel and Vincent 2007) Selective Ignorance	Defensive Ignorance (McGoey 2007) Strategic unknowns (McGoey 2012) Agnotology (Proctor and Schiebinger 2008) Regimes of imperceptibility (by industry actors) (Murphy 2006; Wylie 2018) Production of doubt and debate (Oreskes and Conway 2011) Manufactured Uncertainty (Michaels and Monforton 2005)	Spatial and Scalar drivers (Croissant 2014; Frickel and Kinchy 2015; Sayre 2017) Material characteristics & agency (Liboiron 2016) Timescales (Duvall 2011; Sedell 2019) Aleatory Uncertainty (i.e. uncertainty due to variability in a system) (Merz and Thieken 2005) Inscrutable Spaces (Kroepsch and Clifford 2017)	Desertification (Davis 2016) Classification and Categories (Bowker and Star 2000; Duvall, Butt, and Neely 2018; Sayre 2015) Residual categories (Star and Bowker 2007) Scale Framing (Harrison 2006) Scientific jargon disrupting communicating with lay communities (Leggett and Finlay 2017)

	(Powell et al. 2011)			
Examples	Sick Building Syndrome and toxicology (Murphy 2006) Honey bees and Colony Collapse Disorder (Kleinman and Suryanarayanan 2013) Spatial gaps in testing for environmental toxics in soils and lakes (Frickel and Vincent 2007; Powell et al. 2011)	Tobacco Industry (Proctor and Schiebinger 2008) Revised EPA regulations (Friedman 2019; Lipton 2018) Consequences of Fracking (Wylie 2018) Debate over the science of global warming (Oreskes and Conway 2011)	Groundwater systems (Kroepsch 2018a) Vast rangelands (Sayre 2017) Air pollution (Choy 2012) Pesticide chemistry materiality (Galt 2011)	Categories including "feral" vs "wild" (Rikoon 2006) or "native" vs "alien" (Warren 2007) Examining pesticide drift incidents individually or cumulatively (Harrison 2006, 2011) Wilderness as pristine (Cronon 1996)

Table 1.1: Types of Inscrutability. Note that the dotted lines that separate these types acknowledge that there are not firm boundaries between them and they interact with each other.

I offer this topology because there are important distinctions in how inscrutability is produced, but not to insinuate that the types are siloed or separate. They are not mutually exclusive for how they render something scrutable and inscrutable, but instead they are always interacting. This typology offers some analytical power by highlighting the different processes that produce inscrutability, but engage different actors, different technologies, and are based on different motivations. Fugitive dust is better understood by tracing these different ways, but also shows how these categories are porous and overlap. For example, discourse and the use of categories about dust's naturalness significantly shape what disciplines leave unknown. Of course, this typology like all categories—including the ones I study in this dissertation—highlights certain elements and obscures other. This is not a complete, exhaustive list of ways inscrutability is produced. There are others that new cases can help illuminate and further add to this typology.

Applying the Typology to Fugitive Dust

This section explores how different inscrutabilities are produced about fugitive dust. The lack of answers about fugitive dust cannot be explained by one set of circumstances and conditions, be it disciplinary schisms or bad actors. Instead, it is the layering and knotting of many different threads of inscrutability that creates a whole greater than the sum of its parts. It is through plural inscrutabilities that dust becomes rendered unknown by most and is sometimes rendered invisible despite is significant visibilities.

Fugitive dust's inscrutability is produced through different processes, each with a distinct set of politics, and to understand why dust remains unknown requires investigating the multiple threads of not knowing. Many key questions remained unanswered about fugitive dust: is it increasing? Where is it coming from? What is causing it? What are its consequences? And, what *is* it? None of these questions have conclusive answers, most remaining out of reach on inquiry. In the following sections, I examine fugitive dust by illuminating four inscrutabilities: disciplinary, intentional, material, and discursive.

Disciplinary Inscrutability

Dust falls through the cracks and gaps between disciplines and highlights some of the epistemic limits produced through science. Dust has no standard definition, neither does dust storm. The lack of a definition—in individual fields and more broadly—hinders research and management. It also allows dust to remain somewhat unknown (see Chapter 2). Dust is both everyday and obvious, yet it lacks a technical definition that enables a shared body of research. Without a definition, each study becomes somewhat siloed because it bounds the system differently, creating the proverbial apples and oranges.

Dust is not only difficult to define, but also study. Its dynamism makes it hard to understand just using one disciplinary lens or set of tools, which is a way that disciplinary and material inscrutability enmesh. Dust research is siloed and splintered with different foundations, approaches, and aims. A seemingly simple question about whether dust is increasing highlights this compartmentalization and fracturing. Attempts to understand dust from different disciplinary perspectives each have compelling findings but carry important qualifiers. Regulatory monitoring systems offer insight into trends in small particles in geographies with monitoring (Hand et al. 2016), yet this focusses on a subset of particle and has spatial gaps. Snow hydrologists studying dust's deposition offer insight on a broader range of particle sizes, but are constrained by a short timeframe (since 2003) and spatiotemporal resolution (Skiles and Painter 2015). Others have used proxies as a way to create knowledge without specific data. Dust from different regions often has a distinct chemical signature, and in the Southwest scientists have used Fe and CA^{2+} to reconstruct historic fine dust concentrations (Brahney et al. 2013; Hand et al. 2016; Malm et al. 2004) and dust on snow events over greater spatiotemporal resolutions (Clow, Williams, and Schuster 2016). Still other scientists have used sediment cores to examine longer trends in particulate transport (Neff et al. 2008), yet they have relatively low temporal resolution for recent records. Individually, disciplines leave dust trends somewhat inscrutable and together they enhance perceptibility, but still leave that question of what is going on uncertain.

Dust research is greatly influenced by these trajectories that make certain questions much easier to ask (and answer) than others. Science is an incremental process with each step building upon previous findings and including previous assumptions. Through this process different research trajectories emerge, making some research pathways (or the pursual of certain questions) more doable (Clarke and Fujimura 2014) and some less (Frickel, Gibbon, Howard, Kempner, Ottinger, and Hess 2010). The formation of more doable lines of inquiry is somewhat inevitable, but it also creates a path dependency or current that is hard to break from (Sayre 2015).

Regulatory science plays an important role in what data is available and therefore what questions can be asked. In regulatory science dust is primarily approached from a public health and visibility standpoint, but this misses much of the larger dust system. However, the constraints of these epistemologies—and in this case ones that are largely tied to regulation—focus on narrow parts of dust. For example, regulatory monitors select a subset of particles based on their diameter. The public health focus leads to greater attention to smaller particles that can be inhaled deeper into the lungs and therefore cause more heath risk. This research focus has led to regulatory monitoring systems collecting smaller particles, yet has made it very difficult to study and know larger particles. No data exist about them. Few studies have examined larger particles making it harder to produce incremental findings and ask questions about them, creating a more doable research trajectory focused on small particles.

This narrowing was somewhat driven by confirmation bias. Small particles are more dangerous, but large particles were never shown to be benign. Experts pointed me to a single article that played a significant role in shaping this trajectory. A study in Spokane, Washington found that PM_{10} was not associated with increased mortality (Schwartz et al. 1999). This study found no mortality effects from PM_{10} and was largely taken as evidence that PM_{10} was not dangerous, or even was safe (similar to what Galt (2011) found with pesticide testing). However, this analysis focused on one city and only looked for health impacts that occurred on that day, rather than including lags that might capture people seeking medical attention days later. Also, the study examined mortality, but not a series of other health consequences, which also leaves certain impacts invisible. The discussion about particle size is primarily driven by public health concerns, but for water security, nutrient cycling, and other dimensions of dust, size might not matter, and in some cases, larger particles might be more important to study. Despite the qualifiers, the Spokane study is regularly used as reasoning to focus on monitoring and studying smaller particles.

The outcome is that even researchers who think we might be missing part of the story struggle to show that because of data and science constraints. These other research questions and focuses not only just aren't asked, but in many ways become inscrutable. Researchers struggle to even show that large particles are important when none of the publicly available data includes them. They can monitor dust independently, but this can be expensive and labor intensive and often is at a much coarser temporal and geographic scale. Ultimately it is not just that a narrow set of questions have been asked, but that many other questions are difficult—or undoable—to pursue and this leaves many dimensions of dust hard to know, especially at different scales.

Intentional inscrutability

The EPA is tasked with monitoring and regulating airborne particulate matter, yet it has also played an important role making fugitive dust inscrutable through intentional interventions. The EPA administers and sets the standards of the CAA, but it relies on the states to monitor and manage air quality. In this way, the EPA outsources the day to day regulation of air quality to the states but is charged with oversite to ensure that air quality is regulated. This regulatory set up allows for multiple actors to be involved in dust's regulations, each with different priorities and motivations. Generally, state governments and industry actors often work to avoid violations because of the associated costs. Of course, most government agencies want safe air quality, but they also do not want to incur the increased costs and regulatory requirements of nonattainment. This can often put them in the same boat as industry actors who also do not want increased regulation. The outcome is that state government and industry actors often align on one side, environmental and public health advocates align on the other, and the EPA is left as a mediator.

Fugitive dust is indicative of a larger phenomenon at the EPA right now. Investigative journalists are showing how there are many examples of intentional regulatory ignorance. Under current leadership, the EPA has been changing how it makes calculations about risk, models exposures, and factors in evidence. Recently, the EPA decided to change the way it calculates particulate matter pollution to predict less mortality by making the assumption that no health benefits exist for air cleaner than standards (Friedman 2019). Original calculations showed that an EPA rule saved 1400 deaths a year, but by changing the math—and the variables included—that number significantly decreased. So too did regulatory burden. In another example, the EPA changed how it evaluated health and safety risk of chemicals so that it excludes impacts and only focuses on "direct" exposures with the chemicals, but excludes how it pollutes—and exposes—in the air, groundwater or surface water (Lipton 2018). This means that critical risks are excluded from the assessment and many chemicals that were deemed unsafe previously can be now be deemed safe. Through this manipulation of risk analysis, true risk becomes inscrutable.

Fugitive dust has been rendered inscrutable intentionally in three key ways. Early in my dissertation research, I saw first-hand how the EPA made dust inscrutable through its deletion of the a particular dataset. The EPA and the Mexican government partnered together on a campaign to protect the environment and public health at their shared border. The Centro de Información sobre Contaminación de Aire (CICA) was established to evaluate air quality on the border and they combined U.S. and Mexico monitoring data into a single database. What made this research so compelling to me and the questions I was asking is that it was unique in that it contained data about large particles. The US and Mexico regulate different sized particles. Unlike the U.S. that evolved to monitor and regulate fine particles (see Chapter 3), Mexico still monitored TSP (Total Suspended Particulate), or all sizes of airborne particles, as well as PM_{10}. The CICA dataset combined U.S. and Mexico monitors in close proximity and the U.S. measured PM_{10} and $PM_{2.5}$ and Mexico measure PM_{10} and TSP. This dataset offered a rare opportunity to bring TSP back into the picture and see what might be missed by only monitoring smaller particles (PM_{10} and $PM_{2.5}$). It offered me the chance to make an inscrutable element of dust more visible and known.

However, the dataset was deleted and started my (unsuccessful) odyssey to find it. I had proposed to use this data in my prospectus, but soon after the 2016 election the data was removed from the EPA's website. I discovered this at a conference but was not originally worried because I assumed that once data was "out there" it would be hard to make disappear. I worked with a team of data archivists who had been working to catalog data after the 2016 election. They were unable to find the data in their collections or others, but they helped me submit Freedom of Information Act (FOIA) requests, which I assumed would produce the data. While I waited, I reached out to scholars who had published on the data, but since it was old (from 2003-2007), none had held on to it and I hit yet another dead end. I went to the headquarters of the air quality division of the EPA for interviews and thought that I could ask those regulators, yet the aftermath of the administration was so severe I did not even ask. I was already being obstructed in interviews[6], and decided it wasn't worth asking about something so sensitive. I spoke with regional staff of the EPA who were less impacted by the administration changes at headquarters and they couldn't provide answers. I spoke with the person who currently ran the program and a former director of the CICA project and none of them had the data. Eventually, I ended up talking "offline" with a former EPA staff member who wouldn't give me his full name and had to remain off the record. He thought that he would be able to find it, yet months later I received word that he had not been successful. Neither had my FOIA request. All of my efforts landed me at dead ends. This public dataset had disappeared and so too had the chance to ask and answers the questions I had posed.

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[6] The timing of my fieldwork was not opportune as it coincided with an administration change that told regulators that "leaks" would be prosecuted. But what is the difference between leaks and sharing information? The fear of retaliation lead to many regulators going back on promised interviews or employing obstruction strategies including intimidation, bringing in lawyers to interviews, refusing to talk and only point to text in the federal register, etc. All of these strategies decreased my ability to gain information in interviews.

Why was this data deleted? I never got a full answer. Many people who worked in air quality had not even heard of it. The CICA data was not a highly politicized climate dataset and I seemed to be the only one who noticed it has disappeared. Some of the regulators I spoke with assumed that maybe it had been a technological error made by a website manager. A few I spoke with urged me to consider not the focus of the dataset (air quality), but the geography. The border was the battleground over a wall and a set of immigration policies. Did removing data make it easier to pass environmental reviews? An answer to why the dataset was deleted was unlikely to surface and after months of searching, I made the decision to let go. My decision and the deletion of the data represented intentional inscrutability. Whether the aim was to keep dust imperceptible (not likely the case) or something else about the border (more likely the case), the outcome is the same. It made questions unaskable.

Another way fugitive dust was made intentionally inscrutable was through the EPA granting monitoring waivers to states. As I looked into the uneven monitoring patterns for PM_{10} (see Chapter 4 and Appendix A for a greater discussion on this), I expanded my inquiry to the larger West and discovered even stranger patterns. Monitoring guidelines were driven by population, yet some large Western cities lacked monitors. How? I called state regulators thinking I was looking at partial data or had not fully understood the minimum monitoring requirements, yet I was right. The lack of monitored in major metropolitan areas were due to waivers from the EPA. The EPA granted states waivers to remove monitors and not meet the minimum criteria (specifically the requirement for monitoring in communities of 500,000 people) and this removed any data about the PM_{10} levels in these areas[7]. I asked where I could find the waivers on their website and the regulator shared than most of the "waivers" were really just permission granted in the email and there would

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[7] The state I discussed this with uses proxies to detect PM10 but acknowledge that they were less precise and useful in wet conditions, and this state has a very temperate climate with a very long rainy season.

be no way for me to know those waivers had been given or where. The waivers highlight how key assumptions lead to intentional actions that hide dust. While most of these assumptions are targeted at rural areas (again, see Chapter 4), they also shape urban ones too. Most importantly, this monitoring approach creates a circular logic where areas assumed to not need monitoring go unmonitored and therefore it cannot be known whether or not they needed said monitoring. It makes it both impossible to conclusively prove they need it or do not need it because no data exists.

Even when monitors do detect particles, the regulators can remove the data by deeming events "exceptional." Perhaps one of the most obvious and intentional acts to make dust imperceptible is by designating dust storms that violate air quality standards as exceptional (see Chapters 5 & 6). The Exceptional Events Rule (EER) allows "exceptional" event data to be removed from the regulatory record and not count for nonattainment. Under this rule, fugitive (dispersed) dust is conceived as natural and exceptional, and thus can be removed, regardless of frequency. Maricopa County, Arizona, for example, deemed more than 20 exceptional events in a year. While the County has been in nonattainment for more than 20 years due to its poor air quality, these data exclusions are allowing it to meet standards and become in attainment (see Chapter 6).

The data removed from the regulatory record are not deleted, but just removed from the datasets regulators use to make management decisions. It makes dust storms invisible to regulatory agencies charged with responding (regulating) and people reviewing nonattainment maps, yet for the motivated scientists, the data is still available. Thus, this most intentional act also perhaps is less powerful than the first other two examples where the data is gone—either deleted or not collected. In those cases, data is gone and so are the answers that they might be able to provide about dust and dust exposures.

Material inscrutability

The dynamism of dust itself—its movement over space and time, its scale jumping, and its varied production—play a critical role in its inscrutability. In many ways, fugitive dust *escapes* scientific inquiry and regulation that are unable to keep up with its lively materiality**.** This is not only because of disciplinary lenses, but instead because it is difficult to know an animated object that is part of highly complex and mobile systems. Recognizing these complicated and changing materialities—and relational materialities—means that sometimes "ambiguity is something we must learn to live with" (Lavau 2013, 430).

The scalar and spatial dimensions of fugitive dust allow it to outmaneuver many attempts to understand it (especially taking advantage of large spatial gaps in monitoring, see Chapter 4 and Appendix A). Dust storms travel colossal distances, playing a role in transcontinental migration of particles. Dust from the Sahel makes the Amazon rainforest lush by fertilizing it (Yu et al. 2015). In the case my dissertation examines, fugitive dust is part of a regional scale process that covers large areas and crosses ecological and political boundaries. It travels from arid deserts to the high alpine and falls in (and out of) many jurisdictions with competing priorities and goals (see Chapter 5 for a discussion of cross-jurisdictional exclusions under the CAA). Yet, dust does not just operate at large scales, the regional or global scales, but is constantly shifting and jumping. Dust is multiscalar; it operates from the unseen, microscopic particle all the way to the global, and many in between. It functions at the scale of the body, of regulatory monitoring areas, the city, the state, and the ecological niche. The multiple scales dust operates at makes it hard to know and decide at which scales to study it, and correspondingly, which not to.

Dust's mobility makes this scale jumping possible and allows it to run away from science and regulation in many ways by reconfiguring spatial relations. Studying something that stays in one spot, fixed in place, is usually easier than something constantly moving. "Movement has an essential relation to the imperceptible; it is by nature imperceptible" (Deleuze and Guattari 1988, 280). Monitoring systems have to be much more adaptive to detect mobile natures that flow through large and dynamic spaces (Kroepsch and Clifford 2017) like oceans, the atmosphere, or the subsurface, or that move clandestinely, often at night or during a storm, hidden from remote imagery. Mobility also works to hide histories and obscure past movements, and in the case of dust makes its origins and causes murky. Fugitive dust is produced from dispersed-sources and falls into a class of pollutants that are much harder to study than their point-source counterparts. So many different activities can cause dust that when paired with large spatial networks of sources, it is hard to access relative contributions.

Fugitive dust not only moves across complicated spatial scales, but also temporal scales. Dust storms move quickly, racing across landscapes at rapid speeds. While it moves at the speed of wind, dust is also part of creeping, inching processes of erosion, the slow-moving geomorphic processes that shape landscapes over thousands of years. To pull the knot tighter, the disturbances to cryptobiotic soils that produce dust are not just due to current practices but carry legacies of past land use practices and droughts. Even current measurements are hard to understand—are dust levels a product of current processes or past, invisible ones? Further, dust storms are "extreme events," which denotes events on the edges of the distribution that are less frequent but higher magnitude. Dust, like all extremes, has high variability, and with it, high levels of aleatory uncertainty that complicate monitoring and make it difficult to rely on averages or infrequent measurements (see Chapter 3 for how this complicates monitoring).

Thus, any dust measurements are a snapshot in time and space, somewhat disaggregated from the larger system and only telling of that one place at that particular time. This challenge is akin to what many researchers who study subsurface minerals and groundwater confront. Wellbores become "windows" into the subsurface that allow scientists and engineers to peak down into a hidden and obscured place (Bridge 2009; Kroepsch 2018b), but do not allow the broader system to be known.

The dynamic nature of dust complicates understanding both the type of issue it is and what it is. It does not fit into a single type of issue because different parts of it do different things out in the world. It impacts health when inhaled into the lungs, fertilizes landscapes when it deposits far from its source, blinds people in tan blizzards bringing highways to a standstill, and melts snowy reservoirs in the high alpine. The materiality of dust also makes it incredibly difficult to define (see Chapter 2). It is not only an epistemological but also an ontological question about what *is* dust and about the material constraints of knowing it.

Discursive Inscrutability

Discourse creates inscrutability of dust in many ways—in the titles we give it, in the categories we create around it, and even in the way we explain it. Perhaps the most striking way that discourse works in this case is through the naming of the focal object: fugitive dust. Fugitive dust is the technical term for dust produced from dispersed sources rather than point sources. Fugitive is defined as either someone who has escaped or as something that is quick to disappear or is fleeting. Either meaning describes the type of relationship between dust and the people trying to know it. The name sets the stage for dust being beyond capture by researchers or managers; it removes the responsibility to know or measure it. Fugitive works to foreclose the possibility of detection and defines dust inherently as something that is evasive and fleeting, and thus something that is deeply inscrutable.

Further, the category of "natural" similarly makes dust inscrutable and beyond study, albeit less overtly than its fugitive title. Many experts and community members refer to dust as "natural" and it is even treated as such in regulations. This assignment is problematic for multiple reasons.

First, it hides the very anthropogenic nature of dust and how the proliferating land use is a driver and part of the system, and it relies on a false divide between nature and culture (see Chapter 4). Second, in our society "natural" episodes and systems are treated as beyond intervention, not preventable, and often less important to know and manage. My research showed how these two elements worked together to make the drivers of dust and dust storms themselves hard to know. The category of natural becomes a political tool for regulators and industry representatives who use it to remove dust from regulatory purview (see Chapters 5 & 6).

The natural framing also makes solutions to dust imperceptible. For example, the Exceptional Events Rule removes the burden of states to meet air quality standards if pollution is natural and "unpreventable." In my surveys with local community members, they would both describe dust as high risk and attest to high public health consequences from it, while also saying that nothing needed to be done about it. This perplexing result was driven by dust's assumed naturalness, and correspondingly, uncontrollable character. Yet, scientific findings and analogs like the dust bowl both point to a very human imprint in this system that gets assumed as "natural."

The drivers of dust were also made hard to see by the way they were discussed. When you ask what is causing it, you often hear "disturbed" soils. On one hand, this is true. Most simply, dust is produced from disturbed soils that become airborne. In the Colorado Plateau, disturbances to fragile cryptobiotic soils break up the crust, which is highly durable to high winds when undisturbed, and allow particles to become airborne. On the other hand, this explanation is not particularly illuminating, and it leaves a large piece of the story obscured. Disturbances by *whom*? Disturbances by *what*? A disturbance is an action that inherently needs an actor, human or otherwise. However, many of the times it is used, "disturbances" is just dangling, disassociated with and disturber, actorless. It does not describe who or what is causing dust and, in that way, it allows key questions about the cause to remain inscrutable.

Last, the use of regulatory categories further obscures the true nature of dust and its larger behavior. The EER of the CAA allows for "exceptional events" to be excluded from the regulatory record and not count as violations (see Chapter 5). An exceptional frame denotes something outside of the ordinary, or the typical system, and this changes how the system is viewed. If dust storms are named exceptional—rare—they come to be thought of as rare, even if they are, or perhaps becoming, a more much common element of the environment. This discursive framing changes not just how we see an individual dust storm, but also how we understand the entire dust system (see Chapter 6). Such a change can lead to new frequencies remaining invisible. Just as with natural, when exceptional becomes not only a frame but a legal category it does more than just change discourse, but also impacts the material world. Discourse, in the case of "exceptional events", is a tool used for intentional imperceptibility. Regulators call dust exceptional as a way to make it disappear and not count.

Dissertation Overview

The dissertation is divided into five body chapters that each examine an element of dust's imperceptibility. Each chapter does not align with a single type of imperceptibility. This would be reductionist and not recognize the many ways different types of inscrutability work together and are critically interlinked and mutually constitutive. Instead, each chapter contains multiple threads and highlights the complexity of how they weave together to leave dust inscrutable.

Ch 2: Dust to Dust: Accepted Ambiguity and the Politics of Defining

Dust is an environmental element that societies have dealt with and tried to manage and mitigate for centuries, yet despite this long history of engagement the definition of dust remains somewhat elusive. The answer to "what is dust?" rarely yields a clear answer, even from the experts we task with studying it and managing it. This definitional question is a twofold task: it requires defining dust as an object, but it also requires defining the problem—or focus of scientific inquiry—of dust. Dust presents a particularly fascinating case study in part because the multiple ways of knowing and defining dust, or not defining dust, have at least partially allowed it to remain ambiguous and in many ways ignored—despite it being an obvious phenomenon. Its ambiguity begs two core questions: 1) Why do certain elements of the environment resist or escape definition? 2) What are the politics of this type of uncertainty or leaving knowable things unknown? This chapter broadly interrogates these questions to better understand the politics of knowledge and explore why and when we accept uncertainty.

This analysis draws on semi-structured interviews with experts—scientists and regulators—who were asked to define dust. Dust's lack of a shared definition is largely known and acknowledged, yet not framed as a problem. I argue that this represents an "accepted ambiguity," a type of uncertainty with a distinct set of politics and that we need to politicize uncertainty to ask why it persists, for whom, and with what ends. Ultimately dust highlights the politics of defining nature, but keys into the deep—but often overlooked—politics of ambiguity.

Ch 3: Dust and The Clean Air Act: Gaps, Challenges and Opportunities For Air Quality Monitoring

The CAA is one of the most comprehensive and effective environmental regulations and has made significant improvements to air quality, yet its monitors continue to miss dust storms. Dust storms have serious consequences for Southwestern communities and the environment more broadly. Without measured dust levels, the CAA cannot respond; any regulatory action—particularly nonattainment designation—requires a measured violation. The result is that communities do not have access to information about their exposure and no regulatory action can be taken to decrease exposures. This first part of this paper diagnoses three elements of monitoring that make CAA miss dust storms, specifically monitors that focus on 1) small particles, 2) averages, and 3) urban geographies. The second part makes the argument that while the CAA has evolved to largely leave dust undetected and unregulated, that it can also hold promise. More specifically, productive changes to monitoring systems are possible and feasible within the current CAA legislation that do not require significant political changes. Five such changes are offered to improve dust monitoring and regulation.

Ch 4: (Un)Regulated Rural Spaces: The underlying logics that shape regulatory monitoring

The regulatory monitoring system for particulate matter (and dust) is deeply, yet furtively, built upon a problematic assumption of the distinction between nature/culture and urban/rural. More specifically, the assumption that urban environments are shaped by human processes and rural environments are considered natural or un-impacted by society. These assumptions about place are stealth ‘unknown knowns’ that underpin the very notion of pollution and correspondingly impact all attempts to understand it. If critical scholars define pollution broadly as “matter out of place,” then this raises questions about our expectations for these places and the different pollutants within them. Expectations are tied to these two problematic divides. This paper examines the stealth ‘unknown knowns’ that shape how we understand pollution and environmental monitoring, specifically in regard to dust, and highlights the impacts of two fundamental assumptions. The first underlying logic is that pollution is man-made and a product of population density, and correspondingly that pollution cannot be produced through ‘natural’ processes. The second underlying logic is that rural spaces are empty. Together, they lead to an assumption that rural places are unpolluted and a corresponding consequence that rural places do not need monitoring. The EPA requires air quality monitors locations based on population density, leaving most rural areas unmonitored. However, if underlying logics are explicitly examined and challenged, they can lead to new understandings and actions about pollution and the places it occurs in. Highlighting these 'unknown knowns' can help challenge the problematic divisions that produce uncertainty at best, and false assurances of safety at worst.

Ch 5: The Exceptional Events Rule: Policy perspectives on exclusion justifications

In 2016 the EPA revised the Exceptional Events Rule of the Clean Air Act (CAA) making important changes to what types of events could be justified as exceptional. The rule allows "exceptional" air quality events to be excluded from the dataset used to determine air quality violations, and more specifically attainment and nonattainment, revisions to it. In effect, these exclusions allow air quality levels to remain *above* standards, yet simultaneously show safe air quality. This policy analysis focuses on the 2016 revisions, examining the exclusion criteria in the rule. It asks two questions. First, what are the unintended consequences of this rule, particularly in how it defines exceptional events? Second, does this rule support the primary goal of the CAA to improve air quality and protect human health? The paper analyzes four exclusion criteria, focuses in on a specific type of exclusion (High Wind Dust events), and draws on a case study of Lamar, Colorado. It returns to the original questions to argue, first, that the rule allows common events to be excluded from the dataset, and second, works against the ultimate goal of the CAA because it undermines public health.

Ch 6: Natural Exceptions or Exceptional Natures?: Regulatory science and the production of rarity

While the national air quality monitoring system established by the Clean Air Act is widely lauded, the EER) undermines these monitors by authorizing the exclusion of "natural events" from the regulatory dataset. Some of these events are clearly rare (e.g. volcanic eruptions), but others, such as dust storms, are normal, common events. Excluded data on the latter compromises air pollution maps, leaves communities uncertain as to their exposures, and most importantly impedes regulatory action in communities with poor air quality. The framing and regulatory language of the EER raises many questions about scientific assumptions around the 'natural,' especially when written into law. By analyzing manipulated datasets and their consequences and drawing on theories of STS, risk, and hazards, this paper raises questions about how regulatory science can produce ignorance and conceal emerging hazards.

The act of producing "natural exceptions" has another important unintended consequence: it inadvertently creates "exceptional natures." That is, natures that despite their common occurrence are deemed rare. By repeatedly removing data, the EER changes understandings of normal or expected events. These exceptional natures are created both through our explicit framing of them, and by our manipulation of the data so they appear as outliers (if they appear at all). When taken up in regulations, exceptional natures are reified and become further reinforced as exceptional. Ironically, while regulations produced exceptional natures, they are simultaneously undermined by them. They lead to regular and repeated surprises, unnoticed hazards and signs of environmental change, and undetected exposures. Exceptional natures have implications for risk assessment, regulation, and management, as well as public health.

Concluding thoughts

This dissertation is as much about trying to understand the issue of dust as it is trying to understand dust's inscrutability**.** My research helps theorize and provide new understanding of unknowns, examining the many different ways that inscrutability in environmental knowledge is produced, and the consequences of the resulting regulatory ignorance.

My analysis has important contributions for the understanding of environmental science and management as well as the broader politics of knowing (and not knowing). Both knowledge and unknowns are unable to escape the conditions of their production: the motivations, actors, and processes that mold the character of these uncertainties and are imbued with different types of politics. Greater scrutiny of inscrutability highlights the key differences of its politics and its outcomes. Importantly, this analysis serves any attempts to make unknowns known, reduce uncertainty, or render the inscrutable perceptible.

CHAPTER 2

FROM DUST TO DUST:
ACCEPTED AMBIGUITY AND THE POLITICS OF DEFINING

Introduction

Dust is everywhere. We constantly sweep it from our houses or under our rugs. When we drive down unpaved roads, dust spins off our tires leaving a brown cloud in our wake. We know dust because it affronts all the senses: it pelts our skin and cakes our lips. When inhaled, it assaults the throat and penetrates the lungs. It is not new; instead it is seared into our nation's collective memory with the Dust Bowl representing one of the worst environmental catastrophes in our history (Worster 2004a). Dust is a nuisance, a hazard, and a danger. It is ubiquitous and obvious, almost relieving the need to define something as quotidian as dust. You just know it. And yet, despite its omnipresence, it has managed to evade definition. The term "dust" is used to describe an unclean house as well as transcontinental particulate transport.

Even the dictionary struggles to concisely define "dust." The venerable Oxford English Dictionary offers four definitions with more than 20 iterations, all of them somewhat ambiguous. As a noun, dust is "earth or other solid matter in a minute and fine state of subdivision, so that the particles are small and light enough to be easily raised and carried in a cloud by the wind; any substance comminuted or pulverized" ("Dust" n.d.). Dust is also a verb, and here its definition is even more incoherent as different definitions are contradictory. Dust as a verb means either to remove small particles from a surface or the exact opposite: the cover a surface. After reading these definitions, it is not hard to see the challenge of using "dust" in a technical way. One would think that technical experts have better definitions, yet they do not.

When experts who have worked with, studied, and managed dust were asked to give a definition of their focal object it became clear that the ubiquitous object was in fact quite slippery. Even experts who have published peer-reviewed literature on "dust," or who have helped to design monitoring networks to collect "dust," falter when asked to explain what it is. The more experts were pushed to provide a concrete definition, the more it became clear that a common definition did not exist. This was not a case in which dust was just defined differently by expertise. Rather, many experts left dust undefined, even ones who regularly use the term in professional and technical ways. For experts—just like the rest of us—dust is both obvious and unintelligible. Most of the definitions are dependent and contextual; they are ambiguous and never really articulate just what counts as dust. For such a studied and regulated element, the very question of "what is dust?" remains surprisingly unresolved.

So, what *is* dust? The simplest explanation is that dust is made up of particles that travel from one place to another; but that hardly suffices as a clear definition[8]. Scientists approach and study dust with different methods; this yields divergent understandings of the particles that are collectively known as dust. Some experts count a particle and others discount the same particle. This confusion not only stems from how dust is studied or known, but also debates over what dust is. Understanding multiple epistemologies and ontologies illuminates the role of uncertainty in the science-policy nexus—a place where discursive and material politics are conjoined, and the politics of knowledge quickly link to consequences for people and environment. We are thus compelled to reexamine the seemingly obvious question of "what is dust" to disentangle the politics of definitions.

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[8] The lack of definition is even further complicated by the fact that there are many different subcategories of dust that also remain somewhat undefined. For example, "fugitive dust" refers to dust that is not produced from a point source, but rather dispersed sources. Beyond the discursive politics of employing fugitive, it also does not explain what dust is.

Defining dust is a twofold task: it requires defining dust as an object, but also requires defining the problem—or focus of scientific inquiry—of dust. Leaving dust undefined largely leaves *the problem of dust* undefined. The uncertainty around what constitutes dust prevents it from becoming understood as a problem that requires scientific assessment: How can you manage or mitigate an environmental process without a technical definition? Decisions and definitions about either affect both, and ultimately shape scientific knowledge, solutions, and management responses. Narrow definitions lead to narrow problem framings and narrow scientific engagement, which correspondingly leads to narrow solutions, solutions that might miss key elements of the problem and ultimately fail to respond to it. However, broad definitions can carry their own challenges, specifically being so encompassing that they lack precision or are unfit for technical use.

Of course, priorities and politics are always at play in definitional work. Dust, though, presents a particularly fascinating case study in part because the multiple ways of knowing and defining dust, or not defining dust, have at least partially allowed it to remain ambiguous and in many ways ignored—despite it being an obvious phenomenon. Its ambiguity begs two core questions: 1) Why do certain elements of the environment resist or escape definition? 2) What are the politics of this type of uncertainty, of leaving knowable things unknown?

This paper broadly interrogates these questions to better understand the politics of knowledge and explore why and when uncertainty is accepted. After discussing the theoretical framing and methods of this analysis, I present empirical findings that highlight lack of definitions of dust, fragmented definitions, and the challenge that leaving dust undefined creates for scientific and regulatory experts. Finally, I draw on the concept of Accepted Ambiguity to explain how dust is both the object of study and management yet simultaneously undefined. This analysis provides an explanation for why dust is left largely undefined, or defined in fragmented ways, and the consequences that it has on both science and regulatory responses to dust. Probing multiple epistemologies and ontologies is particularly relevant for the things that are seemingly omnipresent and obvious because they both are constantly overlooked and taken-for-granted as well as creep into many parts of everyday life. In the West, dust is something that everyone knows and deals with on a daily basis yet also remains largely unknown, making knowledge about it both counterintuitive and telling.

Theoretical Framing

Multiplicity

Examining multiple definitions, and lack of definitions, requires focusing on the production of knowledge, with a particular focus on multiplicity and ignorance. In this paper, I use multiplicity in the context of knowledge production to encompass both multiple epistemologies and ontologies. The assertion that objects, issues, or phenomena can be understood or defined differently—or even exist differently simultaneously—is not a novel assertion. A rich set of literature in political ecology and science and technology studies examines these questions and theorizes how and why multiplicity exists.

Some take an epistemological approach, which can offer keen insight into *why* different ways of knowing nature arise (Escobar, 1999; Goldman, Nadasdy, & Turner, 2011; Robbins, 2007). In many cases, examining multiple epistemologies has been a tool to challenge dominant narratives that explain an environmental outcome based on scientific assumptions and partial knowledges (Blaikie and Brookfield 2015; Forsyth 2013; Simon 2016; Watts 2013). This approach has been used to question concepts and understandings about deforestation (Robbins 1998), wildfire (Simon 2016), and conservation (Goldman 2007). While many cases explore epistemic difference that fall across expert and lay or indigenous divides (Goldman 2007; Nadasdy 2003; Robbins 2006), others have focused on the differences *within* expert communities, whether between scientists or between scientific and policy experts. Lave (2012) showed how conflicts over scientific knowledge and its application for stream restoration are contested within expert communities. Snedden, Magilligan and Fox (2017) examine the "epistemological bind" between dam removal management and policy that outpaces the related science. Central to most of these approaches is a focus on the divergencies between epistemologies, or ways of knowing, and how epistemic communities contest each other's definitions and knowledge claims[9]. Dust scientists approach dust differently relying on unique tools and data – remotely sensed imagery, passive air collectors, continuous monitors, snow samples etc—and each follows a divergent understanding of dust.

The definition of dust is not only shaped by how we come to know it, but also "what it is," which moves beyond epistemological to ontological differences, and the possible existence of multiple ontologies. This shifts the focus from looking at one reality approached in different ways, or what has been called "perspectivalism" (Mol 2002), to instead the possibility of multiple realities. Viewing ontology as "enacted practice" leads to the possibility of multiple ontologies emerging simultaneously and enacted differently through space and time (Mol 2002), which can often create ontological conflicts (Blaser 2013). Goldman, Daly and Lovell (2016) move away from multiple epistemologies to take an ontological approach recognizing "that different enactments are valid, and that they do not exist in isolation but rather overlap, sometimes interfere and contradict each other" (p.32). This helped explain a contradiction of Maasai experience of drought with scientific records of drought. Similarly, Lavau (2013) offers the analytic of ontological cleaving, where multiple ontologies are both pulled apart and together, a double act, to understand water's multiplicity.

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[9] In some cases, different understandings of an object do not halt collective action or cooperation. Scholars call these "boundary objects," where a common concept or object that is understood differently by various actors, but maintains cohesive enough to translate between different groups (Star and Griesemer 1989). Boundary objects have been identified in wildlife corridors (Goldman 2009), museum exhibits (Star and Griesemer 1989), ecosystem services (Kull, Arnauld de Sartre, and Castro-Larrañaga 2015), and the concept of resilience (Brand and Jax 2007).

Building on her work, Yates, Harris, and Wilson (2017) focus on the political process that leads to ontological frictions, particularly why disjunctures and conjunctures to persist. Examining a plurality of ontologies has been applied to many different contexts and relationships including glaciers (Cruikshank 2007), hunter-animal relations (Nadasdy 2007), fish (Todd 2014), environmental change (Forsyth and Levidow 2015; Nightingale 2016), water (Lavau 2013; Yates et al. 2017), and the body (Mol 2002). Dust exists differently to the different experts in part because they engage with different materialities of dust.

The project of defining dust is entangled in both multiple epistemologies and ontologies, which are not separate or opposing but mutually productive (Goldman, Turner, and Daly 2018). Scientists study dust in different ways based on their relationship to its materialities. Similarly, regulators create dust as a management concern based on different relations to different materialities of dust. Whether we approach dust through epistemologies, ontologies, or both, what is ignored is an important element of its definition. A case like dust requires attention to what is not known or understood and how that leads to a lack of response.

Uncertainty and Ignorance

Ignorance is produced systematically through definitional work. Definitions can be instrumental in the production of knowledge, but impede it when they are too narrow (Frickel 2014), limited by earlier definitions (Kleinman and Suryanarayanan 2013), or when uncertainty exists around what something is (Murphy 2006). Murphy (2006) chronicles how one of the reasons Sick Building Syndrome (SBS) remained relatively imperceptible and invisible was due to the challenge of defining it. It became known as a syndrome—a web or multiplicity of symptoms—that could manifest differently in those affected and was defined primarily by its *absence* of causal explanation. In fact, when a symptom was understood, and its cause explained, it was removed from SBS so that only the unexplained and uncertain symptoms remained. SBS became a category for what was unknown, therefore complicating its ability to be known. In this case, uncertainty as to what SBS was at least partially prevented an understanding of the problem and slowed regulatory action to respond.

The case of dust is punctuated by a lack of a shared definition which stunts or halts scientific inquiry and allows dust, in many ways, to remain invisible. Most of the analyses of multiplicity focus on something that is *known* and knowledge (Nadasdy 2003; Robbins 2006) or ontological conflicts (Blaser 2013) but engage less with how multiplicity leaves things *unknown* and *not defined or understood.* In this way, understanding the contradictions of dust's definitions also requires linking multiplicity to studies of ignorance, unknowns, and uncertainty. STS scholars have long argued that the production of knowledge and ignorance are twin processes, making what is left unknown just as political as what is known (Harding 1992; Kleinman and Suryanarayanan 2013; McGoey 2012). Many empirical challenges complicate studying ignorance, or an absence of knowledge (Croissant 2014; Frickel 2014; Rappert and Bauchspies 2014), but ignorance can be approached as an "ethnographic object" (Mair, Kelly, and High 2012). Scholars have brought many different lenses and approaches to making uncertainty and ignorance a research focus (Croissant 2014). This body of scholarship provided insight into the "social production of ignorance" (Kleinman and Suryanarayanan 2013), factual ignorance (McGoey 2007), organized ignorance (Frickel and Vincent 2007), unknown knowns (Simon 2018), and undone science (Frickel, Gibbon, Howard, Kempner, Ottinger, and Hess 2010).

Institutions, and regulatory agencies in particular, play a large role in creating and perpetuating systems that produce ignorance (Frickel and Vincent 2007; Kleinman and Suryanarayanan 2013; McGoey 2007). Kleinman and Suryanarayanan (2013) explore how the Environmental Protection Agency (EPA) has produced multiple types of ignorance about the toxicity of insecticides on bees that causes Colony Collapse Disorder. In this case, ignorance is produced by a dominant, historical epistemology: certain research questions go unasked, or are considered unanswerable, because narrow definitions of expertise exclude critical knowledge. Frickel and Vincent (2007) show how the types of tests conducted by the EPA and the choices of where to sample during the aftermath of Hurricane Katrina, produced ignorance about certain spaces and elements of pollution. McGoey explores both intentional and unintentional forms of ignorance produced in regulatory systems. Strategic unknowns (McGoey 2012) refers to how ignorance can be harnessed as a resource by those in power whereas defensible ignorance (McGoey 2007) is not produced intentionally, but rather through complications of interpreting conflicting evidence. Other studies have highlighted the role of disciplinary norms, foci, and constraints in producing ignorance (Proctor 1994; Wynne and Mayer 1993).

Bringing together approaches to multiplicity and ignorance can help shed light on why and how some elements of the environment—or some illnesses—fail to be defined and how that shapes knowledge production and action. In the case of SBS (Murphy 2006), the multiplicity of ways the symptoms manifested prevented a clear definition from emerging, which contributed to significant uncertainty about the impacts of the illness, what it was, and what should be done about it. Dust is similarly paralyzed by definitional questions based on a multiplicity of different epistemologies and ontologies of dust, but also on the uncertainty and unknowns about what it *is* and how we understand it. Ultimately this uncertainty produces ignorance about key elements of dust (quantities, trends, causes, and implications). This type of uncertainty, and ignorance, undermines the problem dust poses and responses to that problem because the precursor—the definitional work—remains undone. Understanding these linkages helps shed light on why, and with what politics, certain topics remain unknown.

Methods

This paper draws on analysis from semi-structured interviews and document analysis. Twenty-six semi-structured interviews were conducted with environmental regulators (n=8) and scientists (n=18) who work on or study particulate matter, and dust, in the American Southwest and hold expertise on the topic (see Table 2.1). Strict boundaries do not exist between regulators and scientists; many regulators have been trained in different scientific disciplines and scientists do not conduct their research in isolation from regulation and policy. However, for the purpose of this analysis, regulators—who may also be scientists—have the main objective of examining dust through the lenses of management as something that needs to be mitigated, which is distinct engagements from scientists. Regulators included personnel from a variety of federal, state, and local governmental agencies who manage air quality at different management levels.

In contrast, scientists are defined as experts who do not work for regulatory agencies with management objectives, and who study basic processes and phenomena of dust rather than those linked to regulation. The scientists that were interviewed all studied dust and particulate matter in some capacity but had a range of disciplinary and methodological training. Scientists worked for academic institutions, governmental research labs, and nonprofits. They included snow hydrologists, biogeochemists, ecologists, soil scientists, atmospheric scientists, and epidemiologists. Interviews ranged from 45 minutes to 3 hours.

Total experts	***26***
Regulators	*8*
Scientists	*18*
Snow	*4*
Soils	*7*
Atmospheric	*3*
Other	*4*

Table 2.1: Interview Participants by Expertise

Interviewees were asked to define "dust" and were probed with a series of follow up questions about their definitions. They were also asked to respond to definitions offered by other experts. Interviews were transcribed verbatim and coded using *a priori* and emergent coding structures to explore different definitions for dust. Additionally, coded interview data were analyzed quantitatively to provide descriptive statistics about how the 26 experts defined dust.

Dust (Un)Defined

Despite the many peer reviewed articles and management plans that focus on "dust," it still remains largely undefined. Rather than a case of competing definitions from different disciplinary scopes, dust was regularly left undefined by the very experts who used the term professionally. Even when pushed to offer a definition, some experts gave unspecific and ambiguous answers and stopped before offering a definition, leaving the very question of "what is dust?" largely unresolved.

Even experts who used the term dust themselves struggled to concisely define their focal object. Many remarked how hard it was to answer a seemingly obvious and straightforward question about an everyday object. Some admitted they had not reflected on it before. A regulator laughed when I asked and said "I guess, I've never really thought about this."

Others had thought about it before but still struggled with offering a definition. One prominent scientist whose peer-reviewed publications regularly use the term "dust" remarked how challenging it was to come up with a definition. She explained that "dust is kind of a loosely defined term, for sure" and how she encountered different definitions regularly in her work. Another scientist who is regularly described as one of the experts explained,

> I don't think I have a specific definition for dust. I think a lot of people do this. They have different lines of evidence… I think they kind of use many different lines of evidence to point to probably what it is.

This is a scientist who says that dust is important and an issue, yet clearly explains how on a personal level, and in the field more broadly, that definitions are malleable and in part are defined by the evidence accessible. In this way, dust is like many other cases in environmental science where the system is messy, make understandings of the system partial, and evade definition (Davis 2016; Sayre 2017). In these cases, scientists have to live with a certainty level of uncertainty. Another scientist echoed this sentiment that dust can have multiple meanings and there are different approaches to measuring it.

> You appreciate that it's a complicated issue. Just even in terms of my own general use of that term, I would be talking about something different if I was talking about dust in my house than I am if I am talking about dust outside. So it kind of gets down to how you are measuring it.

These quotes highlight a theme discussed by many of the scientists. Dust has key data gaps and one of the implications is that the available data, or evidence, ends up defining what dust is. Available data is often partial and leads to limited understandings that can hide important elements of dust and important consequences of dust, like health impacts from larger particles or from heavy metals transported on particles.

A longtime regulator was concerned by the undefined nature of dust and felt that the implications were significant enough it might undermine the use of the term at all.

> As an aerosol guy, as a particle guy, I don't like the word dust. Because it's not specific… You talk to the aerosol people, the aerosol scientists, they don't like to use generic terms like dust and mist because it's not specific. It doesn't tell you enough about what it is you are talking about. It's not well defined. Scientists in general like to use well defined terms.

Yet, dust is regularly used in research spheres and in scientific ways even though it lacks a clear definition. He regularly encountered a lack of specificity around the nature of dust and felt that this devalued even using it as a term or thinking about it as an entity. He was not just concerned that it was defined differently by different camps of scientists, but rather that there lacked any dominant definition. However, removing dust from the scientific lexicon might remove an important focus on these types of particles, as a focus on particulate matter contains a much broader set of particles from a variety of sources, caused by a variety of drivers, and with different implications. Does dust get lost in particulate matter?

Many factors led to dust remaining undefined, but one of the most important was that defining dust was multiple projects (i.e. both the definition of the object and the problem). Indeed, scientists and regulators alike acknowledged the twofold nature of their answers, discussing the material characteristics that define a particle, but also grappling with understanding dust more broadly. Importantly, many recognized that defining dust also meant defining what dust meant to society and regulation, which influenced how experts studied it and with what goals. This secondary aim of determining what type issue dust was— or if it was an issue that required scientific investigation at all—was similarly left unsettled. One soil scientist elaborated on the challenge of studying and defining dust explaining that "dust is not just one thing. Dust is an issue. Dust is a concern." This shows a recognition that defining dust is not just describing an object of scientific inquiry, but also determining what it means and for whom. The implications for defining dust narrowly is that problems associated with dust are similarly defined narrowly, which hides the broader consequences.

Diverging Definitions

While many experts struggled to offer a definition, others tackled the challenge of defining dust, yet many of these definitions were disparate, dependent, and contextual, which further complicated articulating what counts as dust. Experts offered dissimilar definitions of dust that did not just diverge along disciplinary or professional lines but were far less consistent and more complex than one might assume. These divergent definitions of dust are both produced by disciplinary approaches and methods that lead experts to examine and know dust differently, but they also are ultimately about dust having distinctly different properties and relations to different communities.

When experts who worked with, studied, and managed dust were asked to give a definition of their focal object it became clear that the ubiquitous object was in fact quite slippery. Different factors were cited as critical to what made a particle count as dust, with the most important factors being its transport, composition and size (Table 2.3). There was no agreement on definition, even within a field (Table 2.3), so discrepancies were not fully explained just by different training or disciplinary lenses.

Transport/ Suspension	Mineral Composition	Particle Size	All particulates
22 (84%)	17 (65%)	7 (27%)	8 (30%)

Table 2.2: Different Definition Characteristics Table. Definition characteristics from experts across fields and positions. This is not a tally of only the primary characteristic, but a tally of all characteristics that were mentioned. Thus, the quantities do not sum to 100%.

	Particle Size	*Mineral*	*Transport*
Regulators (n=8)	63%	50%	88%
Scientists (n=18)	11%	72%	83%

Table 2.3: Definition Characteristic by Expertise. Characteristics broken down by regulators and scientists. This is not a tally of only the primary characteristic, but a tally of all characteristics that were mentioned. Thus, the quantities do not sum to 100%.

This section explores these definitions drawing attention to both the key physical characteristics used to define dust and the problematic—and often implicit—elements intertwined in these descriptors. Analysis indicated that most definitions were built around three main criteria: transport, composition, and particle size.

Transport

Most interviewees (84%) agreed that at the most basic level dust represents particles that travel through the air and deposit somewhere else. This was true across different scientific fields with regulators. One ecologist shared that "dust is particulate matter. It's particulate matter that hasn't stayed in its source of origin, that through wind was transported somewhere." This definition required a particle, or many, that had a source and a deposition. It is a definition that is inherently dynamic, involving movement, and always airborne transport from wind rather than other forms of particulate transport (e.g. hydrologic). A similar perspective was echoed by many experts, including a soil scientist who said dust is "any particle that can be moved by the wind." However, most definitions linked to transport built upon this elementary, and rather uncontroversial, definition of dust to add different qualifiers, qualifiers that quickly change the definition, meaning and what counts as dust. For example, many definitions included a minimum distance traveled or even how the particle traveled (i.e. completely airborne travel).

Even with broad agreement that particle transport was an important factor, experts disagreed about the distance that particles needed to travel to be defined as dust with some arguing that dust is a local issue and that particles do not travel far and others arguing that dust is "something that could at least be suspended in the air for regional transport, more than just bouncing along the ground." Others, however, made a point to include saltating particles, particles that bounce along the surface but are never suspended for significant time. They pointed out that the saltation process actually drives dust emissions because it can disturb soil crust and that these particles are both suspended and transported, even though on a much smaller scale than other dust processes. This debate over what constituted transport was largely concealed in discussions of definitions, but when experts elaborated it was clear that defining dust as a particle that moved in the air was much more complicated. How far did it need to move? For how long? How far up did it need to be suspended in the air? These distinctions drew boundaries that made seemingly similar definitions quite different. This meant that while two scientists could be using the same or very similar definitions, they might come up with different measurements because one would discount particles because they did not move far enough while others would count those same particles.

Composition

The second most common defining feature of dust was its composition, the very matter of dust. The majority of experts interviewed (65%) expanded on the foundational element of a transported particle and considered dust to be soils or have mineral composition. Dust was not just any airborne particle, but instead many argued that it was "suspended soil in the air." A soil scientist articulated that point; "I think dust is best considered as that fraction of airborne sediment that actually remains suspended and gets captured and can be carried far down wind."

This definition emphasizes the composition, and by doing so excludes other forms of particulate matter, such as organic material (i.e. pollen or duff) and black carbon[10]. This was not agreed upon across experts, however. Some experts identified any transported particle as dust which included a broader range of particles than soils. One scientist explained that while she defined dust as having mineral composition, that she knew "that a number of people sort of just use dust as catchall term for all aerosols." This difference can have very important implications in different geographies. If all aerosols are considered dust, dust may no longer be an issue of arid regions and instead expanded to

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[10] Airborne dust is primarily measured through particulate matter monitors, that capture any type of particulate matter including wildfire ash, black carbon, vehicle emissions, pollen, and other particles often considered different than dust. Therefore, if we want to must measure airborne dust, our current particulate matter monitors may not suffice.

issues in urban, wetter climates which raises the question of how useful a broad definition of dust would be.

Experts' definitions based on composition were fraught with implicit distinctions that complicate a precise understanding of dust. Many linked the composition of dust particles to either the causes of dust erosion or the source of particles. Defining dust and its composition by its source and cause, pulls in a new set of politics and may lead to discussions about dust being about much more than just particulate matter.

An important factor that arose when linking dust definitions with their sources and causes was the naturalness of dust. For many, dust was "natural" and excluded any anthropogenic particles. This was in part tied to the social construction of arid lands that were naturalized as dusty and unvegetated (Davis 2016). The dust bowl also worked to naturalize parts of the West as dusty, despite strong political economic drivers (Worster 2004a). Others, however, asserted that dust particles came from disturbed arid lands, but did not comment on *what type* of disturbance by *whom*. Still others bound dust to specific rural land use on the Colorado Plateau like grazing, recreation, or oil and gas development (Copeland et al. 2017). (See Chapter 3 for a larger discussion on the discursive politics of naturalness).

When asked to define dust, one regulator quickly transitioned from what dust is to what causes it.

> For me dust is the soil in the air and it can be generated by a truck driving down a dirt road, or by wind moving over a disturbed surface, an un-stabilized surface. So, I see both. I see air quality data impacted by dust generated by industrial activity. But I also see high PM data that is due to dust that's largely generated by the wind blowing over disturbances.

This segue from what dust is, into the causes of dust, shows how closely dust's nature is tied to its causes. This quote also highlights how some experts considered dust not only outside of human action, but also to be a product of it.

Many attributed dust to disturbed soils, which fell between the two poles of natural processes and distinct human drivers. One regulator explained, "I think any time really that there is dry disturbed earth and it becomes airborne, that is what I would say. That is the definition of dust." This was similar to many definitions that discussed disturbed soils, but often failed to articulate a clear actor. This definition hints at a human cause, even if its undefined. Even soils disturbed by animals are likely to be hooved livestock brought in by people. This actorless qualifier remains uncertain making it challenging to systematically identity dust, but it also may better speak to the messy, spatially dispersed nature of dust that is driven by a suite of causes rather than just one.

Another scientist defined dust in opposition to anthropogenic aerosols while simultaneously attributing dust to human land use actions.

> I would describe dust as having a mineral component. So, the mineral based aerosol's that come from arid, disturbed landscapes. They have a geologic origin. I would differentiate it from man-made or biproducts of man-made aerosols like black carbon.

This quote also explains dust as coming from a disturbance, but this one makes a point to distinguish dust from anthropogenic products. Dust is an object where naturalness gets difficult to distinguish; in the Anthropocene, disentangling the natural from the social is particularly challenging work. Furthermore, most of the disturbances referred to are *human* driven; dust emissions are correlated closer to human activities than drought (Neff et al. 2008) and human activities are proliferating on the Colorado Plateau (Copeland et al. 2017).

Particle Size

Only a small portion of experts (7) explicitly linked dust to the size of the particle being transported. These experts used both undefined qualifiers (i.e. big and small particles) and specific particle sizes that were used in regulator and regulatory monitors (i.e. PM10 and PM2.5). Of the seven experts that reported size explicitly, six were regulators, which may reflect the way their agency monitors airborne particles including dust.

One regulatory expert explained that her attention to particle thresholds was because she approached the issue of dust through a broader lens of pollution. "When I think of, when… I see the dust… I think of it as pollution and I think of it as, what's the PM2.5 and PM10? Because that's my lens." By thinking of dust as pollution, she focuses on the thresholds used to measure pollutants and regulate them. Since these thresholds were established as public health measures, her focus on dust as pollution is imbued with public health concerns, distinctions and assumptions. Another regulator acknowledged similar influences by explaining that "professionally, I would call PM10 dust." Distinctions between if particles size was considered central to definitions were more closely linked to disciplinary practices than the other factors (transport and composition).

However, even with clearer disciplinary influences, no cohesive understandings of dust was evinced by experts from different backgrounds. Some regulators did not think size was critical, or employed different thresholds that were not linked to regulatory frameworks.

Only a fraction of definitions included specific particle sizes, but many more included qualifiers related to particle size that did important work in differentiating which particles counted as dust. Many definitions did not include any mention of size but were crafted around it at their foundation. One ecologist had a seemingly uncomplicated and inclusive definition of dust as "soils *that can be* lifted and carried, lofted and carried." This definition is not really about transport—focusing on how far, what mechanisms drive the movement, or how high dust is suspended—instead this speaks to size. The qualifier "can be lofted" is about the qualities of the particle that allow it to become airborne and the key factor that was almost universally agreed upon in determining this was mass. Wind speed is an important variable in dust transport with stronger winds carrying larger particles, but outside of intense wind events, particle size is considered the variable that most determines if soil moves or stays. One expert explained the relationship of particle size to transport, "probably size is the most important single first thing one needs to think about in dust. Now, size is important because large grains don't go into the atmosphere very far." While this quote highlights the importance of size, it did not offer specific sizes making it challenging to identify *how* size impacted their definition. "Large grains" are undefined and he does not clarify if he excludes particles that do not move far.

The distinction of which particles are able to become airborne is still an unsettled element of physics of dust transport, and if asked, experts would report a wide range of particle sizes that could be lofted. These very contextual answers highlight the material complexities of studying environmental science in the field. This threshold—the size of airborne particles—is not easily quantified, making the qualifiers "can be lofted" and "go into the atmosphere very far" unsettled and ultimately ambiguous definitions that cannot be used precisely or preemptively to define dust. Many experts can agree with this definition of dust being soils that can be lofted, but actually be talking about very different particles based on different scientific assumptions about particle transport.

Challenges of Multiple Dusts

The general lack of consensus on what counts as dust creates challenges in its management and research that undermine these experts' work. Different definitions, and in many cases lack of definition, lead to the second, intertwined problem: lack of collective production and circulation of knowledge among scholars and different academic fields; this also complicates interactions between scientific research and management or policy. When dust gets defined in certain ways that are partial and contingent, research findings also carry these qualifiers, and multiple definitions translate into multiple findings about different entities, about different dusts, that have trouble speaking to each other.

As soon as dust gets defined one way—a way that excludes certain particles while counting others—we see it become incongruous with other dusts. Findings about dust defined by particle size are challenging to integrate with findings about dust defined by mineral composition. They are different dusts. These challenges became clear when a scientist responded to a question asking if particle size was part of his definition of dust. "Yeah, it factors in in the sense that other people have factored it in and I think that those cutoffs are not always useful. There is $PM_{2.5}$, there's PM_{10}, and then there is other categories that people use." This quote shows how one definition of dust can have impacts on another. Because many of the scientists use public datasets and because they are trying to build off previous research by confirming or challenging previous assertions, differing definitions can complicate research or even require scientists to accept definitions with which they disagree. This scientist disagreed with the particle size thresholds used by some researchers. He continues that:

> By limiting the size that we measure, we're potentially missing a bunch of mass and information, basically. So, I think, certainty, there are very fine limits, to some extent. Saltating particles don't go very far. I think that's still dust.

This highlights the implications of defining dust in a limited way. This scientist asserts that these size thresholds employed by others are leading to definitions of dust that are missing particles. He argues that even saltating particles, ones that are much larger, suspended intermittently and bouncing along the surface, count as dust for him, but are often not counted by other scientists understandings of dust. For him, any particle that becomes airborne counts, so size thresholds are not useful, and instead limit an understanding of dust. He argues that anything suspended should count as dust, but it is challenging to operationalize such a dynamic definition because saltating particles are on the edge of suspension. They are suspended temporarily and alternate between being airborne and grounded, and because of this are often left uncounted and excluded from already partial understandings of dust. Saltating particles highlight the challenge of defining an element of study and management in a meaningful way that is specific enough to be useful but does not discount the complexity of the system.

Accepted Ambiguity

This debate over whether saltating particles count because they are only intermittently suspended perfectly distills the broader ontological as well as epistemological entanglements of 'what is dust.' It is easy to look at some of these responses as a classic epistemological challenge: scientists with different disciplinary training, using a range of methods come to understand a common thing differently. Yet, multiple epistemologies only partially explain this case; conflicting findings rendered from different approaches and tools fail to fully explain dust's lack of definition. Experts within a field disagreed and differences were not confined to how to measure dust but also to its very nature. If the same particle counts for some experts while being simultaneously discounted by others, then this definitional dispute clearly carries over to the ontological sphere as well. Expert's own responses repeatedly showed how the two spheres are entwined and mutually constitutive.

To define dust as an object, then, means addressing both registers of incongruity: different ways of studying and measuring dust and the differing natures of dust itself. Similarly, while the definitional work is both epistemological and ontological (Goldman et al. 2018), it is also both in the sphere of science and in the sphere of policy, constantly tacking forth between two worlds, in two senses.

Experts acknowledged that persistent uncertainties remained, in both ways, yet there was not a significant effort to rectify these differences and establish a common definition of dust, nor were there subgroups advocating for different definitions as might be expected. In essence, these findings reveal an "accepted ambiguity": the fact that dust is undefined and defined differently was largely not viewed as a problem, or at least not a problem that needed to be fixed. While such an accepted ambiguity might seem innocuous, in practice the lack of a common definition leaves the challenges arising from a lack of consensus unaddressed. This is to say, by not framing dust's lack of definition as a problem—one that halts the production of scientific findings—scientists and regulators maintain and perhaps even perpetuate a level of epistemological and ontological fuzziness. Thus, it is important to ask why certain topics are considered uncertain (Forsyth 2013).

It is important to note that acceptance does not infer support or comfort. This acceptance is in many ways reluctant; it is an uncomfortable acceptance, tolerated rather than embraced. Experts expressed discomfort and their acceptance was awkward and begrudging, but it was still an acceptance rather than framed as a problem that required a remedy. On a whole, experts were not advocating their definition be taken up by others, nor prioritizing finding a common definition for expert use.

Accepted ambiguity differs from other forms of uncertainty in important ways. It is different than a contested ambiguity, when uncertainty is not accepted and different groups advocate for changes to reduce uncertainty. For example, Ottinger (2010) shows residents of cancer alley rejected regulatory monitoring that hid spikes in airborne pollutants and generated uncertainty as to hourly trends and instead developed their own methods to resolve those issues. Accepted ambiguity is different than cases where the uncertainty is not well understood or known. For example, Kroepsch

(2018) explores how groundwater modeling and the competing models—and epistemologies—both produce uncertainty and are used to identify subsurface unknowns, which are relatively poorly understood and carry significant uncertainty. Accepted ambiguity is different than some other areas of scientific inquiry that are not just uncertain, but undoable or unknowable. Questions of uncertainty around earthquake prediction and constraints about mapping a fault line for the siting of nuclear reactors (Hund 1986) is an example of significant uncertainty that will remain unknowable. Acceptance of a problem—knowledge related or not—speaks to it either being unimportant or trivial, inevitable, or impossible to fix. Yet, uncertainty of dust and dust trends is not undoable, it is not unknown, nor is it contested. Why does it remain so?

Accepted ambiguity, and in this case lack of a clear definition, inherently speaks to the value of dust, and the value of dust science. More explicitly, it speaks to a lack of value for understanding dust trends and their implications. Consequences stretch across the science-policy nexus, from impacts to scientific expertise and scientific findings to the legal and regulatory responses made possible by those scientific findings. Specifically, ambiguity affects understanding fundamentals of dust transport, analysis of the health consequences of dust exposures, assignments of cause, blame, and liability, and ultimately, it shapes how dust can—or cannot—be regulated and managed.

Persistent ambiguity about the nature of dust disrupts the production of scientific knowledge and undermines even basic findings. The current modes of inquiry lead to many snapshots and partial understandings of the of dust transport, but limit a broader knowledge. Foundational questions like "how much dust is transported in the West?" and "are dust levels increasing?" remain partially answered, simultaneously answered differently, or unanswered all together. Without first order questions being answered about baselines and trends, the second order questions – like "how much is dust increasing?" or "what is causing increased dust transport?"—are rendered unaskable, inadvertently stalling knowledge of how dust impacts other systems.

In this way, the acceptance of dust's ambiguity also requires an acceptance of ambiguity regarding the *impacts* of dust, which in this case includes exposures of significant populations in the American West. The main populations at risk of dust exposures are in rural Western communities, many low income, and acceptance of dust trends as unknown requires an acceptance of leaving rural exposures as unknown. Despite a broad range of scholarship showing the significant health impacts of particulate matter (Anderson, Thundiyil, and Stolbach 2012), dust's ambiguity hinders most studies of its specific health impacts, rendering them uncertain, illegible, and outside of regulatory purview. For example, Crooks et al. (2016) examined the health impacts of dust exposures but relied on very partial data of dust storms from weather station operators that either marked dust storms as present or absent, but offered little information about the nature or intensity of the storm. Even so, they found evidence of cardiovascular effects from dust. In contrast, clear dust trends and quantities, which depend on an accepted definition, would allow epidemiologists to correlate differential dust levels with health impacts to better determine harm, and intensity of such harm.

Another consequence of uncertainty regarding dust transport is that it makes the causes, drivers, and sources illegible, stunting any mitigation efforts or attempts to understand liability. Beyond health impacts, dust has wide-ranging impacts to soil health, agriculture, water security, visibility, and ecosystems. Yet, an ability to assign blame, understand cause, or determine source areas requires more certainty in dust science.

For example, in the Southwest, research indicates that the largest driver of dust has been disturbances from human land use (Neff et al. 2008), but there is little information as to the relative contributions of different actions from various sources. This means that many contributing land use practices—grazing, oil and gas development, recreation, increasing use of dirt roads, etc.—are shielded by a general ambiguity that disconnects causes from consequences. With greater, and more accurate, knowledge some of these changing land uses would undoubtedly be linked to dust production and the numerous consequences of dust. Thus, this ambiguity relegates dust as an environmental problem that is unknowable and unfixable, and therefore halts responses. This is especially the case for regulatory actions which are "science-based" and therefore become science-stalled. In other words, the onus on directing policy based on science, while commendable, makes it difficult to respond nimbly, proactively and with precaution to emerging issues that still have uncertainty or lack scientific certainty.

A limited understanding of dust ultimately undermines legal and regulatory action that could mitigate impacts. As is the case with most environmental and health policies, dust regulations require understanding its threats to human health and environment as well as understanding its baselines and changing levels. Regulatory thresholds that characterize dust levels as either 'safe' or 'unsafe' are built upon epidemiological findings. In order to protect public health, agencies need to understand the health risks of dust and the current exposure levels that populations face, both largely uncertain at this point. Ironically, it is regulation—and how it shapes particulate matter monitoring systems—that is partially at fault for this scientific paralysis. Current regulation requires that dust be proven dangerous and a concern in order for it to be monitored or managed; yet studies to document the threat of dust need government monitoring data for assessment. Thus, regulation both is hindered by and simultaneously hinders dust science.

When dust's accepted ambiguity is compared to other environmental systems, its politics become more pronounced. Similar uncertainty about trends and definitions in natural resources (ones that produce profit) or other hazards (ones that have clearly understood threat) would be considered a problem. For example, significant investments are made to understand subsurface resources like groundwater and minerals, despite significant challenges of studying such inscrutable spaces, because the value given to these resources. Similarly, flooding, and other natural hazards, are well-researched and widely accepted as important because they result in high financial and social costs; these findings have allowed for the establishment of 100-year floodplains, which has significantly mitigated flood risk.

In contrast, persistent known—and accepted—uncertainties drive the invisibility of dust. A lack of a definition for dust places limits on what can be known, erasing elements of dust systems and producing ignorance about dust quantities and trends. Without a clear definition, dust fails to gain traction as a problem or a research agenda, and dust findings remain somewhat isolated rather than cohesive bodies of knowledge. These piecemeal studies, each defining dust differently, never evolve into a dominant narrative about dust, nor build a collective body of knowledge, paralyzing science-based regulations.

Conclusion

This paper started with the elementary question of "what is dust?" but has shown how answering it is a complex task. This is in part because answering this question is a two-fold task, requiring attention both to the object of study and to the type of issue dust represents. It is also is both epistemological (how dust is known, measured and seen) and ontological (what dust actually is). The definition of *dust itself* cannot be untethered from the definition of the *problem of dust;* they intimately connected and mutually constitutive, or in this case mutually de-constitutive as a lack of definition in one prevents a definition in the other. Bringing a critical lens to this question, and the variety of responses it elicited, highlights the knowledge politics at play, but it also helps us better understand how these nuances influence the production of environmental science and regulation.

Examining the multiple definitions and their relationship with ambiguity also helps explain why scientific fundamentals of dust remain unanswered and correspondingly the lack of regulatory action. It is ambiguity that halts dust from gaining traction, traction that would spur new scientific understandings and enable more effective regulations. Accepted ambiguity removes a need for action because the issue disappears or because there is a dearth of information about it. In this way dust becomes a moving target. In contrast, when something is well defined, the problem is clearly framed, and a body of knowledge is developed, it can be easier to hold actors—the government, individuals, scientists—accountable for action or inaction. For example, in cases of environmental justice, activists often hold governments responsible for mitigating risk from carcinogens, toxic dumping, and other known harms (Bullard 2000). In other cases, activists with clearly identified a problem demand new research on previously undone topics (Frickel, Gibbon, Howard, Kempner, Ottinger, and Hess 2010). A shared definition does not guarantee responses at the science-policy nexus, but can enable them.

The accepted ambiguity about what constitutes dust carries a specific set of politics and raises questions that can be asked of other environmental uncertainties: why do we accept ambiguity for some parts of nature and not others? Instead of just framing this type of unknown as uncertainty—a neutral framing—it is important to understand the type of uncertainty and *why* something remains uncertain. Asking these questions can provide a better understanding of how knowledge and ignorance work together and why some "problems" fail to gain traction. Ultimately dust highlights the politics of defining nature, but keys into the deep—but often overlooked—politics of ambiguity.

CHAPTER 3

DUST AND THE CLEAN AIR ACT:
GAPS, CHALLENGES AND OPPORTUNITIES FOR AIR QUALITY MONITORING

Introduction

The Clean Air Act (CAA) has been heralded as one of the most important and effective environmental laws in the United States and is credited with significant improvements to air quality. The CAA sets standards—the National Ambient Air Quality Standards (NAAQS)—for six airborne pollutants that are dangerous to human health including particulate matter. The goal of the standards is to monitor and regulate air quality issues nationally. The CAA regulations, and their significant investment in monitoring and mitigating airborne pollutants, have been credited with saving millions of lives (Tucker 2011). Reduction in particulate matter levels has been one of the most important drivers of public health accomplishments. Yet, despite the numerous advancements and successes of the CAA, its monitoring system largely leaves dust storms (and their risk) undetected.

This paper focuses on how CAA monitors largely miss dust storms and the consequences for science and management. It draws on particulate matter data and analysis because most collected data do not distinguish between dust and particulate matter. The CAA dictates the regulation and monitoring of particulate matter nationwide. Key to regulating air quality is monitoring pollution levels to see if they meet standards. Monitoring data allows the EPA, which administers the CAA, to respond to areas with air quality violations by designating them as nonattainment, a designation that carries significant regulatory imposition. Thus, this case is like many other issues of regulatory science as the monitoring system both shapes what is known about particulate matter, and dust, but also how it is regulated.

Particulate matter is a broad category that includes dust. The Environmental Protection Agency (EPA) defines it as "very small pieces of solid or liquid matter such as particles of soot, dust, fumes, mists or aerosols"[11]. This means that dust, for instance, is always particulate matter, but particulate matter is not always dust[12]. Importantly, the composition of particulate matter differs by geography. For example, in arid regions dust is often a main contributor to particulate matter levels, while highly urbanized regions have a greater relative contribution from combustible sources (i.e. motor vehicles or industry). Both are collected and categorized as particulate matter, but ideal measurement protocols for these two sources differ in important ways; monitors designed to measure urban, combustion-produced particulates may be less equipped to measure dust.

Particulate matter is one of the most harmful airborne pollutants because of its risk to people and the environment. Both short- and long-term exposures to particulate matter increase mortality and morbidity (Anderson et al. 2012; Dockery et al. 1993; Pope et al. 1995). Furthermore, particulate matter generally, and dust specifically, has important effects on water resources and security (Deems et al. 2013), visibility in protected areas (Sisler and Malm 2000), transportation safety (Ashley et al. 2015; Morganroth 2017), and respiratory infections such as valley fever (Tong et al. 2017). Climate models predict increased aridity particularly in the Southwest (Cook, Ault, and Smerdon 2015; Prein et al. 2016; Schubert et al. 2004; Seager et al. 2007), which will produce more dust (along with changing land use patterns) and increase risk associated with dust.

While this system was not designed to monitor dust *specifically*, an important caveat, the CAA already is required to monitor and regulate particulate matter—matter that by definition includes dust. The question, then, is if the lack of dust monitoring represents a problem of infeasibility or

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[11] https://19january2017snapshot.epa.gov/climatechange/glossary-climate-change-terms_.html#P

[12] No standard definition is used by regulators and scientists for dust (see Chapter 2) or dust storms (National Academies of Sciences Committee for Review of the DOD's Enhanced Particulate Matter Surveillance Program Report 2010).

inaction: do we not monitor because we cannot or because we have not yet? Given that the fundamental objective in establishing the CAA monitoring system was to provide information about air quality trends and decrease dangerous levels of particulate matter, then it makes sense to ask if and how blind spots in the monitoring system may be limiting EPA's ability to do both when it comes to dust.

This paper makes two arguments about dust and the CAA. First, I show that the CAA monitoring system is missing dust due to three blind spots: focuses on small particles, average levels, and urban areas. Second, I propose that this absence of monitoring and regulation can feasibly be addressed under the CAA. To be clear, this paper does not suggest that the CAA is ineffective, nor that dust is a greater risk than other monitored pollutants; neither are true. Rather, it makes the case that the CAA can address dust feasibility and without significant change.

Impacts of Dust

Dust specifically, and particulate matter more generally, carries a suite of health and environmental impacts for communities and ecosystems, particularly those in the American Southwest. One of the results of not measuring dust is that it becomes harder to understand its consequences and risks.

Most of the related public health research focuses on particulate matter—the broader category that dust falls into—because it is difficult to get dust data and because the EPA regulates particulate matter, not dust. However, these findings are also true of dust, just not exclusive to it. Extensive research shows that particulate matter has severe and detrimental impacts on human health and wellbeing (Anderson et al. 2012; Fuzzi et al. 2015). Long and short-term exposures have numerous health impacts affecting cardiovascular and respiratory health, leading to morbidity and mortality across contexts and at multiple scales (Anderson et al. 2012; Brook et al. 2010; Dockery et al. 1993; WHO Regional Office for Europe OECD 2015; World Health Organisation 2013). The World Health Organization estimates that particulate matter contributes to 800,000 premature deaths worldwide every year (2002).

Some scholars have found ways to focus on the health impacts of dust specifically even though obtaining data about dust is much more difficult than particulate matter. Crooks et al (2016) worked to detect health impacts of dust, despite significant limitations affecting data quality. They used a compilation of partial datasets including the NAAQS particulate matter monitoring system, observational data of dust storms from a NOAA/NWS database[13], and visibility data, none of which fully capture dust. Even with very conservative estimates of dust levels, dust was correlated with cardiovascular mortality. Tong et al (2017) show that dust is spatially and temporally correlated with valley fever occurrences, which is an infectious disease carried by dust. The results suggest that valley fever, and other infectious diseases associated with dust could increase with climate change. In addition to cardiovascular mortality and valley fever, dust storms also pose severe risk for travel with dust storms being the third largest cause in weather related fatalities in Arizona, after extreme heat and flooding (Lader, Raman, and Davis 2016; Shoemaker and Davis 2008).

Dust's impacts stretch far beyond public health concerns. Visibility impacts the scenic quality and viewsheds of national treasures (Sisler and Malm 2000) and transportation. Dust storms in Arizona caused 25-car pile ups resulting in deaths (Morganroth 2017) impacts travel and trade more broadly by grounding planes. Before dust is an airborne particle, it is soil and the loss of topsoil has consequences for agriculture and native vegetation in source areas. And, its impact on snowpack has made dust a driver of water insecurity in the arid West. During an "extreme" dust

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[13] The NOAA/NWS dust storm observations come from many different sources including media reports, emergency management officials, the insurance industry, law enforcement, skywarn spotters, damage surveys and the general public (https://www.ncdc.noaa.gov/stormevents/faq.jsp). The NWS itself acknowledges the uncertainty of this piecemeal database that lacks a systematic reporting method, but this still remains the most complete national, dust storm record.

year, dust deposited on snowpack can accelerate the melt and runoff by up to 6 weeks earlier (Deems et al. 2013), which dwarfs the near-term impacts from climate change. Such drastic changes to runoff timing promise to upset already tenuous legal agreements over water rights, complicate dam and water management, and upend a system with many competing stakeholders. These are all reasons that the stakes are high for missing dust and leaving it beyond regulatory authority.

The Clean Air Act and Dust

Established in 1970, the CAA represented a major shift in how the federal government engaged with air pollution. This law not only greatly increased air quality monitoring and our knowledge about air pollution, but it also gave the federal government the authority to set and enforce limits. A key element of the CAA was the National Ambient Air Quality Standards (NAAQS), which required the EPA to create national standards for six criterion pollutants[14], particulate matter being one. The national standards for particulate matter dictate thresholds that divide particles into safe and unsafe, or in regulatory terms attainment and nonattainment.

Nonattainment designations are one of the most important parts of the CAA and its success. Attainment means that an area has met air quality standards and nonattainment means that an area has failed to meet standards. The EPA can designate a community as nonattainment if monitors detect pollution levels exceeding a standard for any of the six criteria pollutants. When an area is in nonattainment for an airborne pollutant, regulatory action leads to a reduction in that pollutant, but analysis suggests it also leads to overall reductions in other forms of pollution such as water and ground pollution (Greenstone 2003), magnifying the impacts of the CAA. However, nonattainment

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[14] The six criteria pollutants: carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, lead, and particulate matter.

designations carry a suite of costs and challenges for state and local governments, creating large incentives to meet standards.

When an area is designated as nonattainment, the state government must create a State Implementation Plan (SIP) on how to improve air quality and gain attainment designation. More specifically, they must detail how they will ensure their state will meet, maintain and enforce standards by: developing detailed emissions inventory, evaluating new emission controls, modeling impacts of improvements, and offering contingency measures if the area does not make progress on attainment. The costs of producing SIPs are substantial, with the state of Texas estimating that its nonattainment areas cost the state $2 million *each* (EPA HQ OAR 2018-0365). The costs and consequences only increase if the state plans are unsuccessful; in those cases, sanctions are implemented—including a sanction on federal highway funds—and the federal government steps in to create its own plan (a Federal Implementation Plan, FIP) that supersedes state governance. Thus, air quality monitoring and regulation is not only about clean air, but also economics and state sovereignty, making air regulations contentious.

While the CAA has been touted as saving millions of lives by improving air quality (Tucker 2011), like many other areas of policy, it has unintended consequences, disparities and inequalities that work against its goal of air quality protections. Insight into unintended consequences is important for comprehensive evaluation of the CAA and for generating solutions. Environmental justice scholars have documented the uneven impacts and unequal protections among communities, particularly along lines of class and race (Bullard 2000; Konisky 2009; Gwen. Ottinger 2013; Ottinger 2010). Others have examined how the CAA legislation meant to improve air quality has unintended consequences, including disincentives to updating of older plants (List, Millimet, and McHone 2004) and incentives for mountain top removal mining practices in Appalachia (Hendryx and Holland 2016). The lack of monitoring of dust is another way that the CAA works against its one goals, but a case that can be rectified.

Dust is much more than just an air quality issue as its reach stretches to soils and water, but air quality is the most regulatable element of dust. The CAA offers the best regulatory lever to address dust because of its focus and its scale. Dust is dynamic and so too are its impacts, but air quality is the only sphere that already has well established regulations. For example, dust impacts snowmelt, but we have no regulations regarding snow quality or changes in hydrographic peaks. Additionally, dust storms require regional or national regulations to match the scale that they operate. While land use policies could be used to mitigate dust, those are all formed at the local level and make it difficult to address a complex regional issue. The CAA is particularly useful in this case because it was designed to focus on airborne pollution that often can move great distances—across political and geographic boundaries—and it operates on many levels, including county, state and federal. Another benefit of the CAA is that it has installed national monitoring systems for particulate matter.

Dust presents a threat to air quality and falls under the prevue of the CAA. If we accept that dust is a threat to health, then dust falls under the primary standard of the CAA focused on public health risk. Emerging research indicates dust poses risk as other types of particulate matter as well as specific risks like valley fever. Even if some are hesitant to accept this until more research is conducted, dust falls securely under the category of public welfare, the CAA's secondary standard. It is hard to argue that public welfare is not impacted by car accidents, interrupted trade, decreased water security, impaired visibility, and soil loss. In recent years, environmental advocates have argued that the welfare clause allows the CAA to regulate a broader range of airborne pollutants and evolve to meet current threats. The main focus of these arguments has been focused on CO_2 and climate change (i.e. *Massachusetts v. EPA*), but dust similarly affects public welfare and merits the same consideration.

Methods

I employed mixed methods research design to explore fugitive dust drawing on semi-structure interviews, participant observation of science in the making, and analysis of regulatory documents. Over four years of research, I conducted more than 80 semi-structured interviews (Rubin and Rubin 2011). I interviewed scientists, regulators, journalists, staff of nonprofits and businesses, and local community members. Categories of regulators and scientists are not clearly separate, but for the sake of analysis I separate them into regulators, who might be producing knowledge but play a role in regulating and managing the environment, and scientists, who are producing knowledge not tied to a direct regulatory action and tending to examine more basic and fundamental questions. Scientist interviews included researchers from a range of disciplines (engineering, epidemiology, soil, hydrology, etc.) and at a range of institutions (universities, government agencies, field stations etc.). Regulator interviews included a similarly broad sample including federal and regional staff of the Environmental Protection Agency (EPA), regulators from state environmental quality agencies, employees of county and municipal offices, and staff from other public land management agencies. My interviews with staff of nonprofits and businesses and local community members ranged significantly. Most of the staff worked for companies of nonprofits in the outdoor recreation or environmental fields and were directly impacted by dust, albeit in different ways.

I relied mostly on snowball sampling for the expert interviews (regulators, scientists and sometimes non-profit and business staff) (Biernacki and Waldorf 1981). This allowed me entry into a number of expert communities, who had both formal and informal expertise. My sampling for local community members was more random as connections were made during the nine months I spent living in various communities impacted by dust.

To understand the different intricacies of measurement protocols, I followed a number of scientists into the field as a participant observer (Spradley 2016). My goal was observing science in the making (Latour 1987) so that I could understand key decisions and tradeoffs made in each study, such as which geographies they studied, which particles they counted, at what timeframes and with which instruments. In the field, I both collected data alongside the scientists (as well as analyzed it in the lab with them), but I also took notes about their different epistemologies and measurement practices. In this phase I worked with soil scientists, ecologists, biogeochemists, snow hydrologists, and atmospheric scientists, giving me a glimpse into many ways of measuring dust.

Analysis of legal documents allowed me to understand the intricacies of monitoring protocols as well as the political framework they operated in. Examining the NAAQS and CAA laws in depth along with policy briefs and legal reviews, provided insight into how the monitoring system operates and why. It also allowed me to explore opportunities for changes and flexibility within the CAA.

I combined interview data, field notes, and document analysis to compare and contrast different monitoring practices and how they shaped dust measurement. Bringing together multiple different epistemologies and their different instruments helped me make visible the elements of monitoring systems that left dust undetected and lead to the three elements highlighted in this paper. Further, this triangulation also helped identify feasible changes to the monitoring system that can be made within the current CAA.

CAA Particulate Matter Monitoring

Regulatory standards and thresholds dictate dust monitoring, and thus, the current measurement and monitoring procedures of government institutions require examination for this study. The CAA and its influence on monitoring networks have allowed fugitive dust to remain undetected, at least partially. The problem of dust monitoring is complex, interconnected and multifaceted; it is an issue of dominant research trajectories, of the dynamic material qualities of dust, intentional dismissal of data, and how monitoring networks function. This analysis focuses on the last issue—how monitoring networks function—to highlight three key elements of the regulatory monitoring system that allow dust to remain undetected: particle size, focus on averages, and spatial gaps. This is not an exhaustive analysis of the CAA's impact on dust monitoring and regulation, but instead a focus on three significant issues of the design of monitoring networks. Further, these three elements are not operating in isolation but deeply connected. However, for this paper I examine them individually, which is not to indicate that they are disconnected, but rather to offer clearer analysis.

1) Monitoring small particles

Over the years, the standards for measuring and regulating particulate matter have shifted dramatically, with a focus on smaller and smaller particles[15] (Figure 1). New understandings about which particles carried the greatest harm drove the evolution toward monitoring smaller particles. Regulators regularly explained the narrowing particle size as an improvement that responded to new information and discoveries. A health scientist described this evolution:

> The way that air quality regulations for particulates have worked is that they started out regulating total particles and then they realized, oh its full of smaller stuff. So they regulated

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[15] When the CAA was established, it measured and regulated particles of all sizes, or total suspended particulates (TSP), as part of NAAQS. In 1987, TSP standards were replaced with PM10 standards, particles that have a diameter of ten micrometers or less. For comparison, a strand of hair has the diameter of 50-70 micrometers, making a PM10 particle one fifth or seventh its size. In 1997, the EPA made significant changes again creating two indicators for "coarse" and "fine" particulates, at PM10 and PM2.5 respectively. For comparison, the diameter of a single strand of hair ranges from 50 to 70 micrometers, making even the "coarse" particles, quite fine. With revisions of standards there were corresponding revision in the instruments and monitoring procedures.

> PM_{10}. Then they realized, oh no it's the really small stuff, so they started regulating $PM_{2.5}$…they kept tightening the fine particle regulations.

The scientist keys into how this evolution is logical because small particles were discovered as more dangerous to public health than their larger counterparts. This focus on small particles as more dangerous has led to the $PM_{2.5}$ standards being updated with each revision but the 24-hour standards for PM_{10} have not been revised or tightened since they were established in 1987. The only PM_{10} change is that the annual standards were removed completely in 2006. While some scientists described this as an improvement, it causes monitors to miss important data.

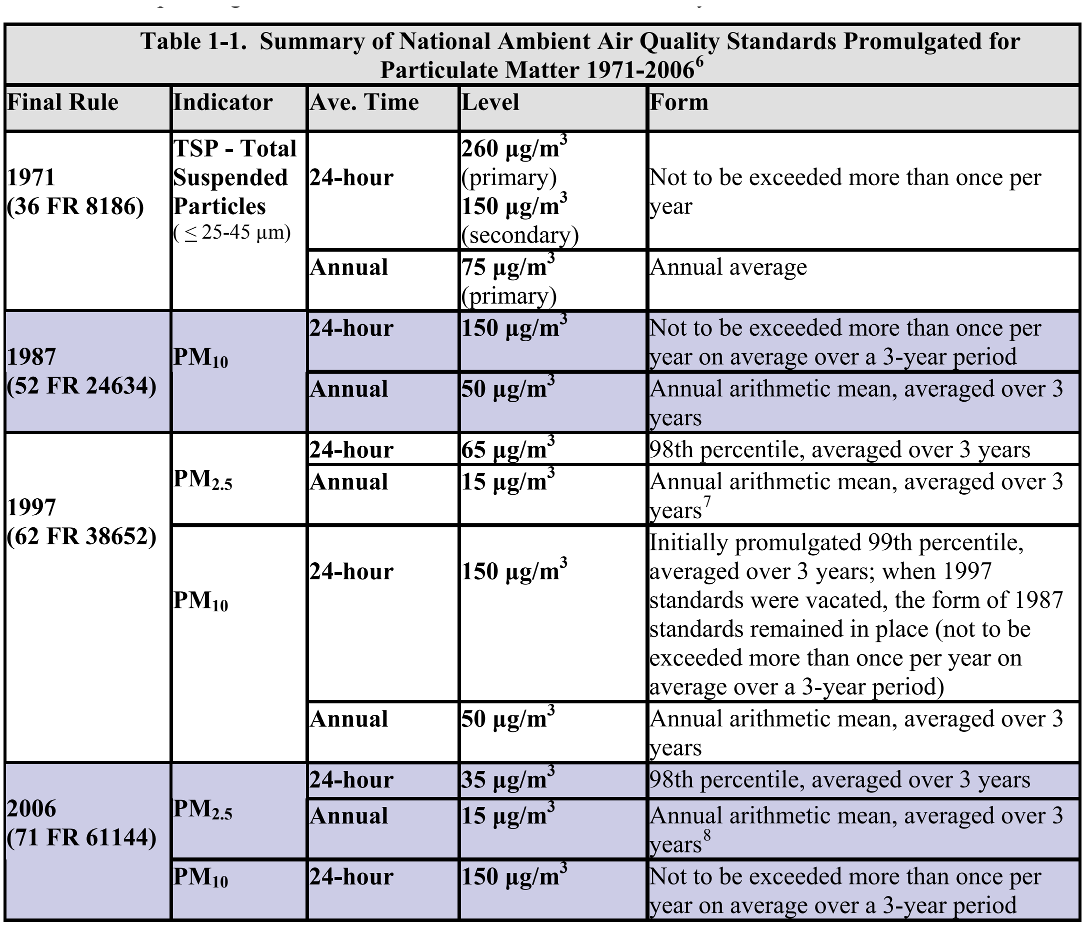

Table 1-1. Summary of National Ambient Air Quality Standards Promulgated for Particulate Matter 1971-2006[6]

Final Rule	Indicator	Ave. Time	Level	Form
1971 (36 FR 8186)	**TSP - Total Suspended Particles** (≤ 25-45 µm)	**24-hour**	**260 $\mu g/m^3$** (primary) **150 $\mu g/m^3$** (secondary)	Not to be exceeded more than once per year
		Annual	**75 $\mu g/m^3$** (primary)	Annual average
1987 (52 FR 24634)	**PM$_{10}$**	**24-hour**	**150 $\mu g/m^3$**	Not to be exceeded more than once per year on average over a 3-year period
		Annual	**50 $\mu g/m^3$**	Annual arithmetic mean, averaged over 3 years
1997 (62 FR 38652)	**PM$_{2.5}$**	**24-hour**	**65 $\mu g/m^3$**	98th percentile, averaged over 3 years
		Annual	**15 $\mu g/m^3$**	Annual arithmetic mean, averaged over 3 years[7]
	PM$_{10}$	**24-hour**	**150 $\mu g/m^3$**	Initially promulgated 99th percentile, averaged over 3 years; when 1997 standards were vacated, the form of 1987 standards remained in place (not to be exceeded more than once per year on average over a 3-year period)
		Annual	**50 $\mu g/m^3$**	Annual arithmetic mean, averaged over 3 years
2006 (71 FR 61144)	**PM$_{2.5}$**	**24-hour**	**35 $\mu g/m^3$**	98th percentile, averaged over 3 years
		Annual	**15 $\mu g/m^3$**	Annual arithmetic mean, averaged over 3 years[8]
	PM$_{10}$	**24-hour**	**150 $\mu g/m^3$**	Not to be exceeded more than once per year on average over a 3-year period

Figure 3.3: A table of the evolution of particulate matter standards under the CAA. Accessed at the EPA's website (https://www3.epa.gov/ttn/naaqs/standards/pm/s_pm_history.html). Importantly, the indicator (the second column) shows the evolution over time.

While narrowing standards inherently excluded some particles, most regulators were not particularly worried about moving away from TSP to smaller particles. In fact, many even suggested that nanoparticles, ones that are less than PM$_1$, was the direction regulations were moving. They considered TSP a poor measurement, especially for public health concerns. An EPA staff member argued that he thought "that PM$_{10}$ and PM$_{2.5}$ are certainly appropriate standards for monitoring public health impacts. So, I don't think there is anything lost moving from TSP, from that perspective." This statement is telling because it not only elevates PM$_{10}$ and PM$_{2.5}$, but it moves further to say that nothing is lost by this narrow focus. He is careful to continually relate the standards back to public health, driving the connection between the monitoring instruments and the job they were designed for. When asked about the standards, other regulators were unsure the logic for why the standards focused on smaller particles. One state regulator tasked to implementing CAA monitoring requirements was unsure, “I don’t know why that’s the regulation, why that’s the rule. I don’t know. I can’t answer why EPA has that rule for PM_{10}.” This in part highlights the obscured and somewhat black-box nature of these standards, even for the regulators charged with enforcing standards. Without knowledge of why certain particle sizes are important and the focus of standards, it is also hard to evaluate the decision and scientific findings that lead to the exclusion of large particles.

The focus on monitoring smaller particles was driven by concerns over public health and assumptions about particle physics, yet when explored explicitly these drivers become somewhat more complicated. A series of assumptions that stand on tenuous ground emerge when the evolution of science underlying monitoring systems is traced. The widely accepted thinking is that smaller particles are the greatest health risk because they can be inhaled deeply into the lungs (Anderson et al 2012). Significant evidence supports this assessment, yet very little is known about the risks associated with larger particles and dust more broadly (Crooks et al 2016). Over time the findings that showed small particles were dangerous led to the exclusion of large particles from studies. Eventually the lack of information about large particles was often taken as evidence that they were benign. However, the trajectory to move away from large particles was not because large particles were safe, but rather a lack of data to show harm.

Conclusions about the health risk of large particles remained obscured due to multiple forces. Large particles were removed from research studies, in part because no public data included them (Harrison & Yin 2000), making studying large particles infeasible. Large particles also have less acute impacts than smaller ones and this makes them much harder to quantify; analyses are complicated with issues like with time lags or impacts that do not require hospitalization (Kishi 2012). The field of epidemiology uses correlation and observational data, both which carry limitations and biases that can lead to incorrect conclusions (Young and Karr 2011) Further, large particles were also deemed less important to study in part due to confirmation bias that repeated throughout studies[16].

The focus on smaller particles also can be attributed to commonly accepted fundamentals about the relationship between transport distance and particle size. The repeated wisdom was that smaller particles traveled further because they were more easily entrained and transported and larger, heavier particles deposit sooner because of high settling velocity (Prospero 1999). An earth scientist explained that, "so, in general, small particles travel further than large particles. And that relationship is non-linear. So small particles travel much further than bigger particles." This logic holds true and is tied to basic physics principles, yet the problem arises when the discussion moves from large particles traveling shorter distances than small particles to the idea that larger particles do not travel far. Regulators repeatedly justified not monitoring for larger particles—both TSP and even PM_{10} — because they claimed they were too big to travel far and were thus a highly localized issue. Yet, the scientists working to understand the fundamentals of dust transport often disagreed with that framing. One scientist who studied a broader set of particles described the problem with the current thinking.

> There's this kind of framework of thinking as you travel farther, your grain size gets increasingly tiny. And that, once you get beyond, like 10 miles or something, you're only going to have these PM_{10} and smaller particles, but that's just not what people have found. You can get these larger particles moving long distances.

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[16] One health study in Spokane (Schwartz et al. 1999) that did not find health impacts of PM_{10} is one of the drivers often cited to justify the focus on smaller particles and can show the power of designated pathways in incremental scientific studies. Since that study, no new analyses have focused on population-level impacts of dust storms in the United States until 2016 (Crooks et al. 2016).

She pointed to many instances that showed that particles larger than PM_{10} were being transported regionally, hundreds of miles. This evidence is in direct contradiction to primary logic used by regulators that the mass of large particles prevents them from significant travel. It opens up the geographies and spatial possibilities for large particles. However, the thinking about large particles remained stuck and did not respond to new evidence. Scientists repeatedly lamented that regulator paradigms were not shifting with new findings that large particles did travel (see Lawrence et al. 2010). Many other scientists who studied particulate matter in the arid West felt similarly and were frustrated that regional qualities—like high winds and arid conditions— that could lead to greater quantities of dust and larger particles transported were not being taken into account in the design of CAA monitoring systems. This contributed to dust being undermonitored.

A focus on smaller particles, while important for public health, shapes how we understand dust. Importantly, the narrow focus on the particles deemed dangerous—drawing on somewhat unproven assumptions of health and particle transport—excludes many dust particles, making the monitoring system useful for a narrow job. A state regulator from an arid Western state acknowledges that TSP would be a better indicator of all particles and dust storms in particular.

> TSP would pick up dust storms probably better, but TSP not a pollutant of concern so, what the EPA has come out with their studies on the public health hazards of particulate matter is that it's the smaller PM that's more concerning to public health

It is not that TSP is not useful or telling, but instead that it becomes obsolete because it does not match the health focus, or at least the current state of thinking about health risk. This response also shows how much the standards around what is a "pollutant of concern" influences scientific instrument design.

However, even if debates about the blind spots in health science—particularly around large particles—are set aside, environmental change may alter the risk around particulates. The health scientist discussed how the increased aridity that is projected for much of the Southwest might alter dust systems in ways that disrupt these conclusions and this calculus. He explained that for his community, or "for people coming at it from a climate perspective though... I think these large particles, it's not crazy to think they would come back into play. If someone were to measure them!" This last sentence was accompanied by laughter but highlights the frustration from scientists that dust is not even measured; his ability to ask basic questions about dust and its risks were stymied by a lack of data.

The consequence that many dust researchers confronted was that they lacked data to ask and answer even basic questions about dust, particularly data on all sizes of particles. Data was available, but it was somewhat fragmented and did not capture all of dust. A scientist explained that some particles are counted "to some extent, they may have, within their datasets, a record of dust because dust can include those smaller particles. It often does. But it can be bigger as well." Yet, this is only a partial record of dust because it misses large particles. When asked about measuring particulate matter at $PM_{2.5}$ and PM_{10}, another scientist responded that "it misses the whole story! Well, it captures the human health story, but misses the ecosystem story. It misses the human economic and visibility and traffic accident story." The narrowed monitoring produces narrow datasets, or in other words, significant portions of dust left undetected. The result is only partial data on dust, which makes it difficult to find evidence that large particles are worthy of study, further reinforcing the focus on only small particles.

2) A focus on averages over extremes

The CAA monitoring network focuses on ambient, or average, air quality explicitly and this has important implications on the type of data collected. Because the air quality was historically understood as an urban problem from pollution sources like traffic emissions and industrial activities that were emitted at somewhat regular levels, monitors also were developed to look at average air quality. This notion of harm is directly opposite to a natural hazards approach which places the largest risk on the extremes, or low probability, high consequence events. The ambient focus does not look for the extremes and in many cases avoids them.

The goal of collecting an average sample of air quality influences both where the instrument is located and how it functions. CAA monitoring often intentionally avoids high pollution areas—or hot spots—that might give elevated readings. The logic is that these elevated readings would not be representative of larger areas making them less valuable. Of course, the communities living near hotspots may want to know their exposures. For them, high levels are what regulators should be monitoring (Ottinger 2010). Avoiding hotspots ultimately impacts data collection; specifically it lowers total levels measured.

When state regulators discussed how monitoring networks were designed, they regularly reiterated the goal of monitoring ambient air quality and that doing so required avoiding hot spots. One regulator explained how they tried to avoid clear sources when placing an instrument.

> Well if you go next to a gravel pit, and you put one [a monitor] in the middle of a gravel pit, you know you will get an exceedance, right? But that's not what we are monitoring. We are not monitoring the back of a tailpipe or a stack, or things like that. We are trying to monitor the ambient air. So we need to make that distinction between what is ambient and what looks to be something that is not healthy, but it's because there is a source there. You don't go to the back of a tailpipe and monitor, because you know that it is going to be in exceedance. You want to see what the largest number of people are breathing, the ambient air.

This regulator discusses how monitors need to avoid high emissions areas specifically. It is not an accident that many "hotspots" remain undetected and many regulators discussed not wanting to place monitors too close to dust sources that would slant the readings. Measuring hotspots, or high levels, would both offer information that was more geographically distinct; even the language of hotspot denotes a geographical specificity, which works against the scaling up that "ambient" requires. In this explanation the regulator also makes clear an additional reason for avoiding hotpots: exceedances. An exceedance of air quality standards, or violations, can result in significant regulatory action such as non-attainment designation that carries significant costs to the state. Thus, the same state regulators who would need to pay for the exceedance costs are also tasked with establishing the monitoring to detect them.

Perhaps the greatest influence of the ambient focus on air quality data is how it shapes monitoring frequency. CAA monitoring is missing dust storms and other air quality extremes because of the *timing* of measurements which is largely a product of the regulatory standards for PM_{10}. Instruments are constrained by the timing requirements of CAA standards, so that they produce information that can directly be usable for regulation. Otherwise, the standards could not be enforced. The timing element influenced by ambient aims is both in terms of the (in)frequency of samples and the sample length.

First, the *infrequency* of air quality samples makes it easy for dust events to remain undetected. Since the focus is on average air quality, the logic is that daily measurements are not necessarily required to get at ambient levels. While some instruments take daily samples, many operated less frequently on 3, 6, or 12-day schedules, which can miss large dust events completely. A dust scientist explained how this frequency shapes dust data. "One of the reasons you can miss some dust storms, dust events, is because most of the monitoring for PM_{10} is the filter basis, 1 day in 6 or 1 day in 3, except a few urban areas." Dust storms and other air quality issues can occur on the days that go unmeasured rendering the data partial. Another regulator stated it more specifically that "with a one-in-three monitor, you're logically expecting to miss two out of three dust storms." The instruments that operate less frequently—say one in six or twelve days—are significantly more likely to miss an event than to catch one. This is by design because events are antithetical to the "ambient."

Second, many instruments take samples of PM_{10} in 24-hour increments. The sample length is because PM_{10} standards are for 24-hour levels. However, a 24-hour sample can hide peaks in particulate matter by averaging it out over a longer (24-hour) period. One local regulator explained the consequences of this sampling timing:

> It's like every 24 hours it pulls a sample. But maybe that dust storm happens between the 24-hour periods. It's not set up to be tracking these short-term events that blow through here. Because they're usually like, I'd say they're less than 24 hours in duration.

This regulator lives in the Four Corners region that has high levels of dust and notes how the monitors are not designed to detect dust storms. Again, this scalar element of monitoring and measuring obscures dust. Just like scaling up from geographically specific information, 24-hour samples scale up from the smaller intense peaks. Other scholars have shown how this sampling timeframe can hide spikes and peaks in particulates by averaging them over a day and make it more difficult to show "non-compliance" (Ottinger 2010). Dust storms are events, often extreme events, and attempts to measure average air quality lead to dust storms going unmonitored.

3) Spatial gaps in monitoring based on population density

The CAA PM_{10} monitoring network has large spatial gaps, particularly in the rural areas. Gaps are areas without any monitors and therefore no data. The federal government establishes minimum monitoring requirements largely based on population density, so rural regions like the Intermountain West have many large gaps in monitoring. The Intermountain West, and Southwest in particular, is not only majority rural, but it is also arid and a dust source. For example, the

Colorado Plateau is one of the most iconic deserts in the country and a key source of regional fugitive dust, yet it has no PM_{10} instruments (see Chapter 4).

Monitoring gaps are well known by both scientists and regulators. When asked many questions about dust—where it was coming from, how much was being transported—scientists often would explain that those questions were hard to answer because of areas without data. One health scientist explained that he is left with a critical lack of data because "there is a huge area where there is nothing… The rural areas don't get a lot unless you happen to live near a national park." The lack of monitors in much of the Southwest prevents questions about dust as well as dust impacts from being answered. He does note that there are some monitors located in national parks, which are often the only ones in rural areas. However, those monitors are part of a different air quality system and cannot be used in regulation. Further, because the samples of that network can take years to process, they are ineffective in protecting public health.

Scientists and regulators recognize spatial gaps in monitoring. State regulators were familiar with these gaps as they were the ones designing the systems and constructing the monitors. Scientists who used particulate matter data were acutely aware because of how it impacted their models. Even federal regulators at the EPA were well aware of them. The gaps, however, were not similar across some states. Colorado, for example, has two to three times the number of monitors as its neighboring states and is well above the minimum federal standards. One federal regulator explained that people are

> lucky in Colorado to have a well-distributed particulate monitoring network throughout the mountainous part of the state. It's not true in Utah. In Utah, monitoring has always been focused on Provo, Salt Lake City, and Ogden. And it's rare to find monitoring data in the whole southern dry part of the state of Utah.

The disparity between monitoring systems in different states can be significant and as the regulator states, having more monitors is usually considered an asset. They also indicate how the gap in Utah is in the driest part of the state, which has implications for measuring—or mis-measuring—dust.

Gaps can be in part attributed to urban biases in the CAA standards that tie minimum monitoring requirements to population density. This is both due to the utilitarian logics and how regulators have come to think of pollution. First, utilitarian logics that ask regulators to serve the greatest good (where the most people are), often underserve rural populations for the "greater good" making these decisions a numbers game (Ashwood and MacTavish 2016). In these calculations that measure good by people impacted, rural areas never emerge victorious. Second, because of how regulators think of pollution (See Chapter 4) regulators often don't see monitoring gaps as a disservice for rural communities. In their view, rural communities often don't need monitoring because they lack pollution.

Of course, running monitoring networks is resource intensive and many states systems are constrained by limited resources that makes filling gaps difficult. It is not as though regulators do not care about unmonitored places; state and county regulators repeatedly described that they did care. However, limited resources usually led to rural areas remaining unmonitored.

> If you look at some of the areas like in [rural town], we have done monitoring in [rural town] in the past, and we did not find very high levels of PM. And so the decision was made in the past that we would not continue monitoring out there because their closest operator was either stationed in [larger towns more than 2 hours away]. So it would be operators having to drive 2+ hours one way just to reach a monitoring site. So some of that sometimes is a resource concern. We don't have the staff or the money to run monitors in all parts of the state.

This explanation shows how it is not only utilitarian logics, but also that rural monitoring itself is often more expensive and specifically more labor intensive. The isolated nature of many of communities makes it financially infeasible to monitor because it is such a resource intensive practice. Operators would need to drive hours each way to just to collect the sample, and depending on the frequency, they might need to do this multiple times a week. Rural communities again get trapped in a stacked calculation; the same labor could serve multiple urban monitors sited closely together, making the rural area never emerge as the rational choice.

Additionally, even with more resources, monitoring fugitive dust is an incredibly difficult task because of its dispersed, non-point source characteristics. It is not as if regulators are ignoring the obvious spatial configuration—they are not. Dust and large particles are especially spatially heterogeneous and can require greater instrumentation because they are less evenly spaced out than their smaller peers. Measuring dust is challenging and difficult, yet the current gaps are significant and have large impacts on the monitoring systems ability to detect dust specifically or air pollution in rural areas more generally.

Five Fixes: Addressing dust within the current legal system

The three elements of CAA monitoring described above work together to shape the system so that it fails to detect much of fugitive dust. A focus on small particles over large particles allows significant portions of dust to pass by monitors undetected. Thus, even communities with monitors and high levels of information about their air quality miss dust. Similarly, the focus on ambient air quality at the expense of extreme events leaves monitored communities unaware of cumulative dust levels. Many communities, however, do not even have monitors due to the large spatial gaps within the monitoring system particularly in rural areas, which precludes these communities from any information about dust or their air quality. Individually, each element conceals a portion of dust, but together the three elements work to leave dust largely undetected.

Not monitoring dust has real consequences for Southwestern communities. It endangers urban and rural populations and leaves communities and regulators blind to the broader impacts to public health to welfare. The CAA regulations are all built upon responses to *measured* pollution levels, so without monitoring, regulating is not possible. Thus, taking dust seriously and measuring it would be the first step to allow it to be managed.

Both small and large changes can be made to improve dust monitoring. One of the common challenges to measuring and managing dust is that it is "not feasible" and would require new legislation or a regulatory overhaul. Yet, improvements do not require a re-writing of the CAA and many could be implemented under the *current* regulation. I lay out five feasible ways that monitoring might be improved, starting with three immediate actions and then moving to two longer-term changes.

Most Feasible Actions

The most practical action would be small changes within the current monitoring system plans, which are largely controlled by individual states with federal oversite. The EPA sets minimum standards for monitoring, but many states have taken a much more aggressive approach that surpasses minimums leading to states with very different monitoring systems. Significant power rests in the hands of the state regulatory agencies to respond to dust.

First, one of the easiest changes would be to upgrade instruments from filter monitors to continuous monitors. This upgrade would provide constant measurements and a better picture of dust activity than infrequent measurements (taken on alternating days). Many states are already working on updating monitors and most currently have a mix of continuous and (less frequent) filter monitors. This upgrade, thus, would just speed up a process that is already underway. Additionally, the change to continuous monitors, while carrying an upfront cost associated with buying new monitors, saves overall costs as it decreases the labor needed for the retrieval of filter monitors.

Second, state regulators could identify large spatial gaps and work to increase monitoring coverage. Every year states are required to submit a new monitoring plan to the EPA where they access their current system and this process regularly includes the addition, removal, or relocation of monitors. Working within this established process, states could begin by using the small fleet of portable monitors to establish where within unmonitored areas would be best to focus resources. States would likely need to purchase additional monitors, but decreased labor costs from continuous monitors might make it more cost effective to monitor in isolated, rural areas. States could also partner with local governments on the upkeep and oversite of the monitors to lower labor costs of adding new monitors. Additionally, the federal government—which already provides support for state monitoring—might be able to provide matching funds or some financial support for additional monitors or to cover some of the upfront costs of this transition.

Third, regulators could utilize citizen science monitoring systems already in place to fill spatial gaps. While monitoring systems that democratize science and lower the cost of instruments for individual use are not as accurate as regulatory instruments, monitors could still be harnessed to understand trends and be used as a "canary in the coalmine." For example, Purple Air[17], a network of particulate matter sensors covers many of the gaps in regulatory monitoring and while not precise enough to use for regulatory decisions like nonattainment, can offer regulators a glimpse into air quality in unmonitored places. Proactive states have already begun discussing this idea; they can use monitors to look for high or increasing levels of particulate matter and place more accurate, mobile

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[17] The citizen science collected data can be accessed at: https://www2.purpleair.com/

monitors operated by the state in those locations. Citizen science might be a way for states to expand their reach and coverage to new geographies while not expanding costs. It could also have the additional benefit of engaging rural communities in air quality issues and management.

Larger Monitoring Changes

After the most accessible steps, the next phase would tackle larger changes to dust monitoring, all which still fall under the CAA as currently written. Two changes are particularly worth attention and greater exploration.

First, particulate matter standards (NAAQS) currently have two indicators, $PM_{2.5}$ and PM_{10}. The indicator originally was TSP (all sizes of particles) and over time evolved changed to two smaller indicators. The changes were made by regulatory review within the EPA as part of 5-year reviews and did not require new legislation, new amendments, or congressional approval. The EPA has the power to add an additional indicator for TSP so that it would be monitored and managed.

States outside the West likely do not have the same risk from dust, which might make a national TSP standard less critical. This raises questions of how states could be motivated to opt-in to monitoring TSP. Could the EPA make a regional indicator? Could states work together regionally to generate a bottom-up approach to monitoring TSP? Many still have their old TSP monitors from when it was the indicator, which might make monitoring TSP more cost effective.

Second, and perhaps most ambitious, a tactical option would be to rethink the way that dust fits into the CAA, specifically whether it represents a risk to public welfare (a secondary standard of the NAAQS). Advocates for dust management might be able to borrow from the playbook used by climate advocates fighting for the EPA to regulate greenhouse gasses as a threat to public welfare. It is worth exploring whether very similar arguments could be made for dust as there is a strong case it impacts both public health and public welfare. Currently, dust is thought of as beyond the CAA and not a key concern—in some cases with data being intentionally removed from the record[18]—yet its impacts are covered by the scope the CAA. The secondary standard of the NAAQS was established to "protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air" (42 U.S.C. § 109, 7409). Protections of the broadly defined category of "public welfare" included threats of decreased visibility, damage to animals, crops, vegetation, buildings, and environment[19]. Visibility[20] has been one of the main focuses of public welfare concerns for air quality within the CAA.

While public health has largely driven the standard changes, the secondary standard of public welfare has been the focus of significant discussion and controversy in the past decade. The category of "public welfare" is malleable enough to leave space for arguments about a range of threats beyond public health. Environmental advocates argue that the CAA was intentionally designed to evolved to protect against new risks and challenges that might not have been under consideration in the 1970s when the law was drafted (Doniger 2014). This flexibility would ensure that the EPA could respond to new problems as science identifies them.

The public welfare standard is a key focal point in emerging legal strategies to stretch the scope of the CAA to new and emerging issues, particularly climate change and the regulation of greenhouse gases like carbon dioxide. In 2007, this topic was taken to the Supreme Court in the case of *Massachusetts v. EPA* where a collection of states, cities and nonprofit organizations collectively sued the EPA to force them to regulate greenhouse gases. The court ruled that

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[18] The Exceptional Events Rule (EER) allows violations resulting from "exceptional events" to be removed from record. All fugitive dust events are considered exceptional. See Chapters 5 and 6 for additional discussion of the EER and its consequences.

[19] The 1990 CAA amendments further described secondary standards as protections for "public welfare and *environment,*" and asked that economic and energy costs be considered.

[20] In 1999, visibility was formally protected with the Regional Haze Rule that created the IMPROVE monitoring program.

greenhouse gases are air pollutants and subject to EPA regulation if scientific evidence showed they presented public health and welfare risks[21]. While Congress did not explicitly address climate change in the CAA, the Court ruled that the EPA had the flexibility to address new threats and that they had not evaluated if greenhouse gases constituted a *threat to public welfare.* In 2009 and in response to the ruling, a number of environmental organizations petitioned the EPA to list carbon dioxide as a criteria pollutant (adding it to the six under NAAQS). However, the EPA has not taken action[22] (Wold, Hunter, and Powers 2013).

Interestingly, the regional nature of dust might make it fit better under the CAA than other more global emerging issues (like greenhouse gasses such as CO_2). Even though dust often is dismissed by dust on scalar grounds *because it is local or regional,* the CAA was designed to focus on more localized than global issues. Congress designed the CAA to address more localized pollution issues that differ spatially rather than a pollutant that "is fairly consistent in concentration throughout the *world's* atmosphere up to approximately the lower stratosphere" (68 Fed. Reg. 52927). This local intention has been one of the key arguments against regulating CO2 under the CAA.

The legal battle's focus on the public welfare protections raises questions about how the CAA might evolve, stretch, and be flexible enough to extend to new or unregulated issues. And, perhaps even more feasibly, how might the CAA be able to address new issues of *already regulated pollutants* like particulate matter? Dust is an issue that impacts both public health and welfare yet is currently not a regulatory focus. However, if greenhouse gases can be regulated under the CAA because of impacts to public welfare, dust might be eligible too.

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[21] The decision was split on a 5 to 4 basis with a strongly worded decent written by Justice Scalia. The dissent argued that the case had no standing and that further, the CAA statue did not *require* the EPA to act. This dissent focused on the burden of the Administrator act if they had reasons for not wanting to take on a new issue such as scientific uncertainty.

[22] Carbon dioxide would have only been the second criteria pollutant to be added since the CAA was originally established in the 1970s; currently lead is only pollutant the EPA added.

These five changes—both discrete and immediately actionable as well as open-ended and longer-term—all can be taken within the CAA as written. Dust is not only an issue important to air quality, but one that is feasible to respond to. Both its monitoring and regulation are feasible. There are simple changes that would improve the monitoring and other legal levers to pull that do not require starting from scratch. The main addition needed is political will to make these changes.

Conclusion

The CAA is one of the most comprehensive and effective environmental regulations and has made significant improvements to air quality, yet its monitoring system continues to miss dust storms. Dust storms have serious consequences for Southwestern communities and the environment more broadly. Without measured dust levels, the CAA cannot respond; any regulatory action—particularly nonattainment designation—requires a measured violation. The result is that communities do not have access to information about their exposure and no regulatory action can be taken to decrease exposures.

Three elements of the CAA particulate matter monitoring design contribute to dust remaining undetected: 1) particulate size; 2) ambient focus; and 3) spatial gaps in rural areas. Individually each of the elements constrains monitors scope and produces blind spots, but together they largely remove dust from the prevue of the CAA. The many documented consequences of dust to economies, health, water security, and trade make dust an important airborne pollutant to track, monitor, and manage.

The argument is not that the CAA is ineffective; its impact is profound. Nor is this an argument that dust represents a greater risk than other airborne pollutants; it does not. However, these are not reasons to ignore dust, especially when it so clearly falls under the CAA—both a risk to public health and welfare. Productive changes to monitoring systems are possible and feasible within the current CAA system.

Steps can be taken to improve monitoring systems without significant policy changes. Monitoring improvements so that dust is measured will likely be more pertinent in the future with environmental and social changes likely to increase dust events in the Southwest. Increasing intensification of land use and new development on fragile, arid soils paired with increasing aridity from environmental change carry the promise of a dustier Southwest. A dustier Southwest will amplify the impacts already documented and could lead to new consequences. It also might make dust more than a regional issue; lore has it that during the Dust Bowl the federal government refused to take meaningful action until a dramatic storm carried dust to the steps of the nation's capitol. With such a provoking analog, it requires little imagination to think through the many risks associated with increasing dust and the benefits of regulating it.

CHAPTER 4

(UN)REGULATED RURAL SPACES: THE UNDERLYING LOGICS THAT SHAPE REGULATORY MONITORING

Introduction:

Images of the Colorado Plateau depict rich red sandstone mesas and towers, vast deserts, and deep canyons carved through the rock over centuries. Home to some of the nation's most prized national parks and monuments, the Plateau's pristine spaces evoke ideals of the untouched, natural, and safe. Absent from these images are signs of human life and activities. No postcards show the proliferating oil and gas development, long histories of ranching, growing networks of roads, new developments or the many towns scattered throughout the Plateau. Nor do they show the dust storms that obscure the sky, race through the desert and pollute southwestern communities.

Perceptions of urban and rural environments, which ultimately tie to perceptions of nature, culture and a presumed divide between them, have important impacts for our understanding and management of pollution. More specifically, perceptions and imaginaries about rural spaces become unquestioned assumptions that when embedded in knowledge, often become hidden, harden into "fact," and lead to a loss of environmental knowledge.

Assumptions about the Colorado Plateau specifically, and rural areas more generally, have problematic impacts on how we come to think of pollution and understand risk. Critical scholars generally define pollution as 'matter out of place' (Douglas 1966), and this definition is intimately intertwined with our understandings and constructions of place, including premises that are problematic and untrue about what counts as pollution and even what spaces deserve monitoring for pollution. Urban spaces are considered chaotic and dirty, rife with pollution and rural spaces as pristine and untouched, but a clear divide is not the reality. Recognizing the importance of these assumptions of place and their consequences raises questions: How do our expectations for rural places shape our understanding of pollution? And, how do those expectations shape our understanding and knowledge of dust on the Colorado Plateau specifically?

Imaginaries about rural places and pollution produce unquestioned assumptions that are rarely discussed explicitly, but guide understandings and expectations. Two such assumptions shape the pollution monitoring and knowledge on the Colorado Plateau. The first that pollution is "man-made"– the framing used by my interviewees—and a product of population density. The second that rural places are empty and uninhabited, which is built upon the false urban/rural divide. Together, they lead to a logical conclusion: rural environments are natural and unpolluted.

Thinking of rural areas as unpolluted shapes expectations so that we do not expect or look for pollution in rural areas. In addition, when pollutants are found in rural areas, this thinking leads to them being naturalized (and considered "in their place"), and thus discounted. Pollution then is rendered invisible in two ways: by leaving places unmonitored and by naturalizing pollution that is detected. The result is air quality monitoring networks that are limited to collecting man-made pollutants and looking for pollutants where lots of people are, that is urban areas. Rural areas, thus, are left largely unmonitored and unmanaged.

Ultimately, unquestioned assumptions about rural areas influence our understandings and expectations of pollutants so that we are left with a particulate matter monitoring system with large spatial gaps in rural areas on the Colorado Plateau. The result is the loss of environmental knowledge and a lack of regulation in rural areas.

The Matter of Polluting Places

Pollution is a problem that communities and governments have been trying to mitigate since early understandings of germs, disease, and toxicity more than 100 years ago. Yet, for most of this time “pollution” has lacked a clear definition. Some environmental harms fit clearly into the category of pollution—like vehicle emissions’ impact on air quality or lead poisoning in Flint’s water—yet the lack of definition makes others—like dust—difficult to define and categorize. This challenge of defining pollution is made increasingly obvious when moving across different cultural and social contexts, where the same entity is considered a pollutant by some and not by others.

Douglas (1966) showed that definitions of pollution were highly variable more than 40 years ago, highlighting the need for a definition that could work across different social and cultural contexts. She explores how dirt—a common everyday element of nature, much like dust—can be a nuisance, a health hazard, or a disaster. In exploring what pollution was, she proposed an alternative that could move beyond contexts: pollution could be understood as “matter out of place” (35).

What makes this definition malleable across different contexts is that it recognizes that defining pollution is as much about understanding environmental harms as it is about understanding social processes. Pollution reflects the underlying organizational structure of society, particularly how society understands disorder. Thus, ‘matter out of place’ links to boundary work (Gieryn 1983) about what does and does not belong in different contexts. “Where there is dirt, there is a system. Dirt is the by-product of a systemic ordering and classification of matter, in so far as ordering involves rejecting inappropriate elements” (Douglas 1966, 44).

Matter out of place—and the literature’s focus on order or disorder and belonging or not—moves pollution into the social sphere. Building on her example, dirt outside in the garden is just dirt, or nature, but when it enters the home it is dirty and out of place. Discourse hardens invisible boundaries around pollution, reinforcing and guarding the social and environmental order of certain spaces, particularly as a tactic to maintain purity of one’s space and one’s self (Bickerstaff and Walker 2003; Douglas 1966). Categories of “pollution” and “dirty” thus can be viewed, at least partially, as moral boundaries of what is (and is not) right, natural and normal (Carolan 2008).

The Douglasian framework—matter out of place—has become one of the dominate ways that critical scholars engage with pollution[23]. Bickerstaff and Walker (2003) examine air pollution with this approach and an explicitly constructivist lens to show how both lay and expert knowledge of air pollution is socially mediated. They argue that apolitical understandings of air pollution were problematic for determining what was a threat and what counted as pollution. Moffat and coauthors (1999) illustrate how the 'naturalness' of smells generally determine whether they were classified as pollution. Boudia and colleagues (2018) argue that chemical residues become matter out of place through accretion as displaced residues travel and slowly accumulate. Ward and coauthors (1998) trace how pollution policies for rural farmers are based on ideas of what is natural and unnatural.

This matter out of place framing helps explain how socially produced boundaries and expectations lead to some aspects of pollution being considered important, some ignored, and others contested. Garcier (2010) argues that understandings of the river—specifically that rivers were the appropriate place for industrial discharge—allowed water pollution to go unmitigated. Creswell (1992) shows how the same material object (matter) may display different attributes when it exists in different contexts (places). Nolan (2003) highlights how the same matter in the same location can simultaneously be viewed as in and out of place by different groups, often leading to power-laden negotiations.

Urban and rural areas are key spaces for these negotiations because they are often seen differently, contested, and carry divergent expectations for what belongs and is accepted. Many

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[23] Of course, the focus Douglas' definition almost solely on social context is at the expense of potentially significant material qualities of the matter in question. Liboiron (2016), though, argues the material quality of matter also impacts whether it is harmful. The socio-materialities of small ocean plastics, she argues, are challenging regulatory models of pollution due to their dispersed nature, longevity, size, and molecular bonding activities. Instead of examining a purely social understanding of pollution, scholars "need to wed the cultural aspects of pollution as matter out of place, as a way to talk about norms, morals, cherished boundaries, and citizenship, with the particular material agencies of industrial matter" (17).

people discuss rural areas as far away from pollution and in contrast to urban areas where pollution is somewhat more expected (Bush, Moffatt, and Dunn 2001). This linkage between pollution and urban areas has a long history, traced back to nineteenth century London (Brimblecombe 1987). Indeed, associations of the city as anthropogenic and "unnatural" and nature—or rural environments—as safe and pure continue to drive these divergent expectations for pollution in rural and urban settings (Grosz 1998). Ironically, views of rural areas as undeveloped, primitive, and pristine often lead to the targeting of rural areas for waste and industrial development (Ashwood and MacTavish 2016).

Expectations, logics, and place imaginaries are often not explicitly acknowledged, or recognized, yet influence how we understand these spaces. Simon (2018) calls these 'stealth unknown knowns' –or underlying influences—which shape how knowledge is produced and conceal or distort the true conditions of nature. Once embedded in environmental knowledge, stealth unknown knowns often remain invisible and the scientific claims that include them are considered fact and apolitical. Unknown knowns are similar to what Thrift (2004) calls the "background hum of thinking," or the invisible ideologies and judgements that shape interpretation and thought (601), and carry a political impact on measurement and interpretation of data (Pine and Liboiron 2015a).

Sayre (2017) refers to unacknowledged scientific assumptions as "blind spots," which ultimately leads to perplexing and problematic management actions when taken up by agencies and institutions. For example, the early range science framings of fire, fencing, and predator control all became part of range management orthodoxy despite their many flaws. Blind spots undermined rangeland science, and these landscapes repeatedly acted differently than science expected. Similarly, Bowker (2000) traces how uncharismatic species of plants and animals were largely excluded from ecological studies (becoming what Sayre would call blind spots), which led to these species being similarly left out of environmental protections. Other scholars have also showed how taken-for-granted assumptions and commitments have shaped scientific knowledge in a range of environmental systems (Davis 2016; Forsyth 2013; Goldman et al. 2011; Wynne 1998). In this paper, I understand these blind spots as the unacknowledged and unquestioned assumptions embedded in the understanding and monitoring of pollution.

In many cases, assumptions lead to a lack of knowledge and become entangled in circular logics. Circular logics are more than just not measuring or ignoring; they are intellectual traps that often work in tandem with unknown knowns or blind spots to further obscure new information being brought to bear. For example, Powell and collaborators (2011) highlight how government agencies and researchers justified not collecting data about toxic chemicals in certain Wisconsin lakes because they were not thought to be contaminated. A lack of data further reinforced the notion that the lakes were safe, and that monitoring was not needed, despite a complete lack of knowledge; this same type of confirmation bias shapes dust monitoring. Wylie (2018) explores how this type of logic hides the risks of fracking, explaining that "it is easy to argue that the extraction industry's environmental record is a good one when there have been no studies" (36). Similarly, it is easy to argue that rural areas are unpolluted when no data is collected in them. In this way, circular logics can make the unquestioned assumptions harder to detect and amplify their consequences.

The consequence of unquestioned assumptions making their way into science is that they distort and hide the true conditions of nature. More broadly, assumptions produce types of ignorance, or an absence of knowledge, especially in regulatory agencies (Frickel and Vincent 2007; Kleinman and Suryanarayanan 2013; Ottinger 2010; Sedell 2019). While ignorance can be produced intentionally and strategically (McGoey 2012; Oreskes and Conway 2011; Proctor and Schiebinger 2008), it is often produced unintentionally through a series of research choices, epistemological traditions, and taken-for-granted assumptions.

However, decisions about where to monitor environmental harms, and importantly where not to, produce selective ignorance in the regulatory agencies tasked with managing pollution (Elliott 2015; Frickel and Vincent 2007; Ottinger 2010; Powell et al. 2011). Certain sites often remain unmonitored because a lack of information confirms assumptions that those areas are unpolluted and do not need monitoring, producing a circular logic that perpetuates selective ignorance (Code 2012; Elliott 2015; Powell et al. 2011). In this case, assumptions about rural areas play an important role in monitoring in rural spaces, or rather the lack of monitoring. They are leading to large gaps in the PM_{10} monitoring network on the Colorado Plateau, producing regulatory ignorance.

While specifically focusing on rural areas in this analysis, I recognize the important and omnipresent linkages between urban and rural settings (Champion and Hugo 2017; Cloke 2006; Pellow 2016; Woods 2010) and that these divisions are somewhat contested and not apolitical (Woods 2009). The concept of rural has many diverse definitions and meanings making it a "messy and slippery concept" (Woods 2010, 1) and a "category of thought" (Mormont 1990, 40). Many understandings, including those used by the U.S. Census, are defined by low populations (US Census Bureau 2010). This paper, then, understands 'rural' as defined by areas with low population, particularly low population densities, in part because that is the primary metric the EPA uses in accessing pollution monitoring. Based on this definition, the vast majority of communities on the Colorado Plateau are rural.

Methods

This study uses a mixed-methods analysis to explore both the spatial patterns of particulate matter (PM_{10}) monitoring and the unquestioned assumptions that drive and direct monitor placement. Through combining and triangulating across spatial and qualitative data this analysis is able to help explain patterns and offer insight into monitoring maps.

There are no current federal or regional level maps of these monitoring networks (at least none known to the researcher or many of her participants), making it hard to determine where gaps exist and understand arrangements. To rectify this, individual monitoring GPS coordinates were collected from the state-level 2017 Annual Network Monitoring Plans from the Four Corners states (Colorado, Utah, Arizona and New Mexico). Coordinates were mapped (see Figure 1) to show spatial patterns. This map was used to direct interview inquiries about gaps as well as highlight the consequences of rural imaginaries.

A primary source of data came from semi-structured interviews. The majority of interview participants were regulators at the federal, state and municipal levels. This included Environmental Protection Agency (EPA) staff, both from the headquarters and regional offices. Additionally, air quality regulators from state-level environmental quality agencies were interviewed for all of the four-corners states as well as additional regulators from Western states, and a number of local—municipal or county level—regulators in the Four Corners regions. Together this sampling offered a glimpse into air quality regulation across the many scales of its implementation: from the federal policy development, to state level monitoring plans, to local managers who work with instruments and manage public health campaigns.

Interviewees were asked to explain how the air quality monitoring system was set up and explain the monitoring patterns. Managers were asked additional questions about rural air quality and pollution issues, spatial gaps, and their ability to know pollution in rural areas. Regulators were also asked to respond to claims that rural communities might be underserved, and questioned as to how they might know pollution levels in areas without monitors. Specifically, why are rural areas not monitored? Questions also focused on how regulators viewed rural areas and their risk. The bulk of the interview data came from a smaller sample of air quality managers from southwestern states. To maintain confidentiality for this small sample size, I removed all specific information about place, state and gender. I recognize this does limit some of the analytical power to understand this data, but it was required to maintain confidentiality of participants.

Most interviews consented to audio recordings, but for the participants who did not consent to recording because of concerns about professional consequences, real-time in-depth notes were taken. Recorded interviews were transcribed and notes and transcriptions were coded qualitatively using NVivo software (Bazeley and Jackson 2013) . During analysis, the two data sources were brought together. The spatial mapping of monitoring patterns identified *what* patterns exist, but not why. The semi-structured interviews built off these maps to help understand *why* these perplexing patterns emerged. Together they offer insight into the unquestioned assumptions and logics that influenced these patterns.

Air Pollution Monitoring Gaps on the Colorado Plateau

Air quality monitors have highly uneven spatial patterns because the EPA sets minimum monitoring requirements by population. PM_{10} monitoring, which includes dust as well as industrially produced particles, has large spatial gaps, particularly in much of the rural southwest. Figure 1 illustrates how the PM_{10} monitoring patterns map onto the Colorado Plateau, or more accurately fail to[24]. The Colorado Plateau is an arid region and importantly a regional dust source. Yet very few of

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[24] The mapping of the Colorado Plateau brings additional layer of uncertainty to the question of how many monitors are on the Plateau because its borders are rather ambiguous. The boundaries of the Colorado Plateau different significantly based on who is mapping them. The Plateau itself is somewhat unknown and imperceptible only complicating this story and representing a fruitful area for future inquiry.

the monitors are located on the Colorado Plateau[25]. The few on it are on the periphery, leaving one of the largest regional dust sources unmonitored.

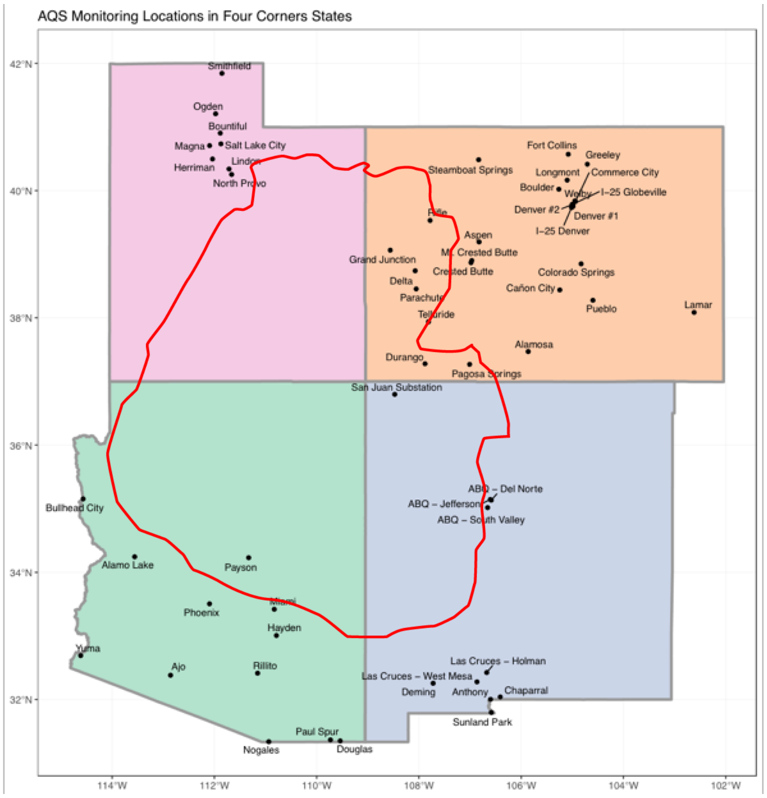

Figure 4.1: PM$_{10}$ Monitors in the Four Corners Region in 2017. Includes the outline of the Colorado Plateau shown in red (Map by Joe Trucillo and Plateau border added by Erica Clifford).

The uneven spatial patterns become even more perplexing when comparing monitor distributions of different states (see Appendix A for greater analysis on state-level spatial patterns). While all four states operate under the same federal regulations from the EPA, the number of PM$_{10}$

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[25] The monitoring patterns mapped for the four corners are somewhat partial. It only shows PM$_{10}$ monitors that are part of the NAAQS criteria pollutant system, which focuses on public health, not the IMPROVE network that focuses on visibility and has better distribution in rural areas. While the IMPROVE network fills in some of the spatial gaps in air quality understanding, it lacks any real time analysis and has no impact on non-attainment designations or regulation, making the data related and interesting from a scientific standpoint but unrelated from a regulatory standpoint.

monitors for each state differs significantly[26]: New Mexico with 10, Arizona with 12, Utah with 8, and Colorado with 26. Comparisons of probable metrics like population and geography (area) fail to explain divergent patterns (see Table 4.1). For example, Arizona has the highest population—more than three times New Mexico—yet only has two more monitors. New Mexico has the largest square miles to monitor, yet has a monitoring system much smaller than Colorado's.

	PM_{10} Monitors	**Population (millions)**	**State Area (square mi)**
Utah	8	3.1	84,899
New Mexico	10	2.1	121,697
Arizona	12	7.1	113,998
Colorado	26	5.6	104,185

Table 4.1: Comparison of the Four Corner states by three metrics: number of PM_{10} monitors, population size, and geographic area.

Further, these places are neither uninhabited or devoid of activity. The Colorado Plateau is primarily composed of public lands with a multi-use directive, creating a dynamic and shifting set of land use activities that are crucial to understanding dust because they disturb soils.

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[26] The state-level differences highlight an important element of monitoring: state control. While the minimum requirements are established by the federal government based on population, each state has the power to monitor beyond that minimum. Regionally, PM_{10} monitoring patterns largely show more similarities between Utah, New Mexico and Arizona, making Colorado somewhat of an anomaly due to its density of monitors, particularly in low population areas. Colorado's monitoring patterns are somewhat a legacy of past monitoring decisions because areas found in non-attainment (violation of their air quality standards) require "maintenance" monitoring for years after its reached safe levels to ensure long term recovery. Poor air quality in the 1990s carried a legacy through the current monitoring system. Colorado had a number of such maintenance sites on the more rural Western portion of the state, but they also have been proactive to responding to citizen complaints of air pollution and particulate matter.

The vast desert landscape of the Plateau is filled with cryptobiotic soils that are both incredibly strong and fragile. When the soils are undisturbed, they act as a "desert pavement" that glues the top layer down and keeps it in place, even when experiencing harsh winds. However, while resilient to wind, the cryptobiotic soil crust, a top layer of lichen, cyanobacteria, algae, mosses, and microfungi (Rogers 2015), js very sensitive to any disturbance that breaks it apart. This disturbance can come from a large range of different land use activities as long as something—a hoof, tire, foot, or well-pad—compresses the soils (see Appendix 2). Moreover, cryptobiotic soils take decades to regenerate so it is not just current land uses that may be causing dust, but decades to a century of changing land uses. For example, ranching activities decades ago might have broken soil crusts that are providing fodder for current dust storms.

Dust is exacerbated through dual forces: land use as well as increasing aridity. The current mosaic of land use patterns paired with the spatiotemporal dynamics of dust poses significant challenges: not only is it difficult to identify and track causes and sources, but also to trace the constant flux over time. Of course, uncertain and evolving climatic patterns only render key relationships more difficult to disentangle. Ultimately, even the most seemingly simple questions about the nature and causes of dust remain inscrutable.

Regulating Rural Places

When asked about uneven monitoring patterns, regulators repeatedly responded that "rural places are unpolluted." This was the same sentiment across multiple states, which raises new questions: what do regulators identify as pollution? And, if there are so few monitors, how do we know rural places are not polluted?

Thinking through the lens of "matter out of place" illuminates how expectations differ for air quality in urban and rural areas, specifically expectations for the Colorado Plateau and particulate matter in it. The unequal patterns of monitoring along with claims of rural places being unpolluted reveal how the discourse and material infrastructures evolved to this point. PM_{10} monitoring patterns reflect how we define pollution and may indicate underlying assumptions that produce circular logics and lead to a loss of data

I start by highlighting two unquestioned assumptions that are driving state regulators' understanding of pollution in rural areas. Next, I explore the logical conclusion built upon the assumptions and its resulting consequence to help explain uneven monitoring patterns.

Unquestioned Assumption 1: Pollution is man-made (and population-dependent)

State air quality regulators largely link population density with pollution levels based on a prevailing logic that pollution is man-made. The logic is two part: both that pollution is man-made, the product of human activity, and that the intensity of this human activity producing pollution is based on population density. The more people, the more pollution.

A fascinating degree of circular thinking is at play here: current monitoring standards and practices continue to be influenced by CAA regulations originally designed to protect the health of urban populations from industrial pollution. The EPA employs Metropolitan Statistical Areas (MSA) defined by population density to set minimum monitoring requirements for PM_{10} (see Figure 4.2). The minimum requirements further diverge based upon the *monitored* pollution levels, so that communities that have previously monitored high levels of PM_{10} have a greater burden—or higher monitoring requirement—than communities with a history of lower PM_{10} levels. In communities with a previous history of non-attainment for PM_{10}, a lower population of 100,000-250,000 triggers a monitoring requirement whereas an area that has always stayed below 80% of the standard is not required to have a monitor until increasing that population five-fold. With an initial monitoring requirement ranging from 100,000 to 500,000 residents, rural areas have no regulatory monitoring mandates.

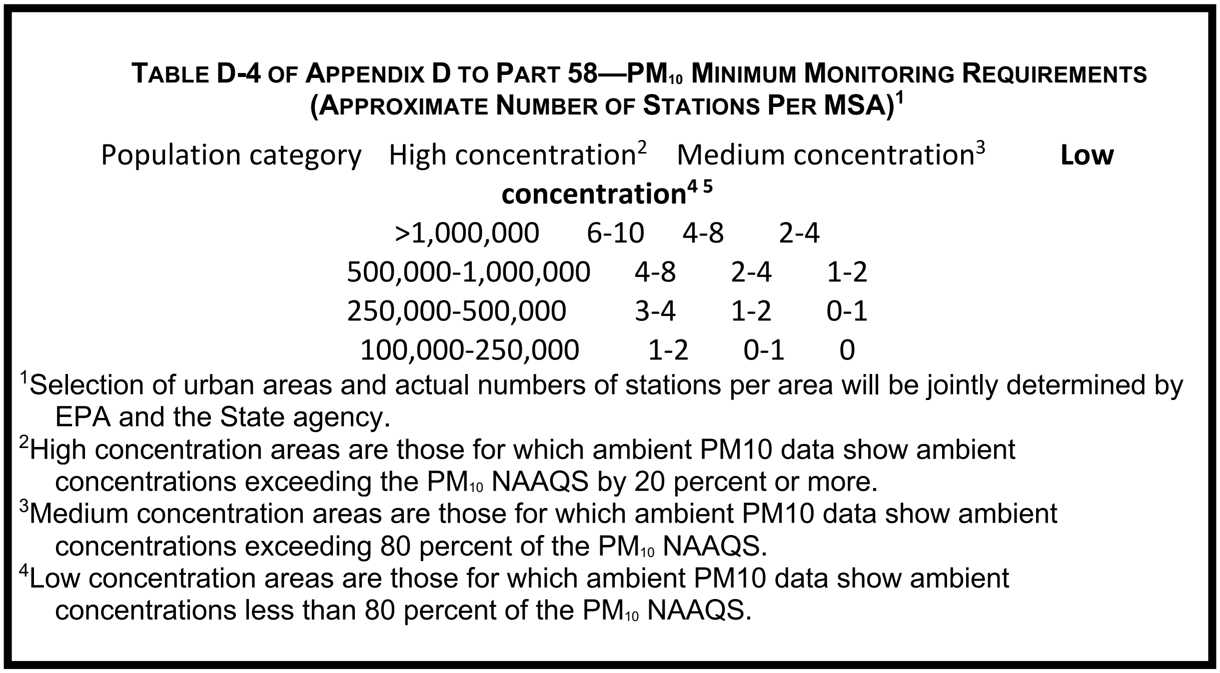

TABLE D-4 OF APPENDIX D TO PART 58—PM_{10} MINIMUM MONITORING REQUIREMENTS (APPROXIMATE NUMBER OF STATIONS PER MSA)[1]

Population category	High concentration[2]	Medium concentration[3]	**Low concentration[4 5]**
>1,000,000	6-10	4-8	2-4
500,000-1,000,000	4-8	2-4	1-2
250,000-500,000	3-4	1-2	0-1
100,000-250,000	1-2	0-1	0

[1] Selection of urban areas and actual numbers of stations per area will be jointly determined by EPA and the State agency.

[2] High concentration areas are those for which ambient PM10 data show ambient concentrations exceeding the PM_{10} NAAQS by 20 percent or more.

[3] Medium concentration areas are those for which ambient PM10 data show ambient concentrations exceeding 80 percent of the PM_{10} NAAQS.

[4] Low concentration areas are those for which ambient PM10 data show ambient concentrations less than 80 percent of the PM_{10} NAAQS.

Figure 4.2: EPA Minimum Monitoring Requirements for PM_{10}. These are based on population density and known contamination. Source: 40 CFR Part 58 Appendix D.

Of course, if an area has not been monitored previously it will have reduced requirements for monitors because it will fall into the "low concentration" category—a questionable a priori to say the least. Since significant areas remain unmonitored, no history of pollution is not equivalent to a lack of pollution (Powell et al. 2011), and this represents a challenging circular logic to break free from. Unmonitored areas remain at a disadvantage in a system that privileges and prioritizes resources to known threats, to previously monitored and recorded particulate matter.

While regulators differed in how overt they were in describing this relationship, pollution was consistently viewed as a human caused problem, specifically an urban problem. Some regulators refused to engage fully with the linkage when asked why population density was the main criterion for monitor siting. Instead, they punted responsibility and explanation of logic to the EPA, which sets the minimum criteria even though state regulators have significant agency over state monitoring patterns, at least to monitor above minimum values. One regulator responded that they "don't know why that's the regulation, why that's the rule. I don't know. I can't answer why EPA has that rule for PM_{10}, why it is population driven." Yet, despite this claim to not know why, the same regulators would go on to discuss pollution as having sources and causes that were human driven. This unquestioned assumption, even when not directly stated, persisted through responses in ways that made other configurations of pollution largely illegible.

Other regulators were much more overt in defining pollution as a product of human action and population density. One regulator explained that,

> Part of the reason the air is bad here is because of the population, the population drives everything. Part of the deal is, like for example, in the [urban area] for particulate pollution, 50% or more of the, the source of more than half the particulate pollution is from cars. We have a million plus cars on the road. We do so many million miles of driving everyday and that's the source, that is more than half the source of that pollution. In a rural area, you don't have that. You just don't have the pollution sources.

In this explanation, they discuss pollution as tied to individual human activity—driving cars—where total pollution increases as population – or car drivers—increases. This logic makes pollution a predominantly urban issue, and it also conversely makes pollution not a rural issue. At the end they explain that since fewer people—and fewer drivers—exist in rural areas, then they lack pollution sources. They are arguing that pollution is not a rural issue because it is tied to human behavior, thus making it an urban issue.

However, while regulators clearly link pollution to urban areas, some recognize that, in certain cases, man-made pollution can occur outside of urban areas. After discussing pollution as a largely urban issue, a regulator explored an important exception.

> Now that is not always true. The [rural, resource intensive area] that I have talked about doesn't have a city out there or MSA that's over 50k people, but they have some of the worst ozone in the country... It comes from all the oil and gas. All these natural gas wells and oil wells that are out there on all this big valley, and the topography, the valley, is such that it's a bowl and it gets trapped with these inversions,

Non-urban areas are recognized as having pollutants, but this is only the case when there is significant human or industrial activity. Thus, this recognition of rural areas as having pollution does not discredit previous associations with the city, but further reinstates the relationship between pollution and human action. In this case oil and gas creates pollution at the level of much larger populations because of the intensity of development. In this way, both examples—of population driven pollution and industrial pollution—cement that pollution is man-made. To be clear, this logic here is population equals pollution and with it comes an assumption that before a threshold is hit (of population density or industrial activity), air quality is good and safe. This logic also misses pollution like dust that is generated from a messy mix of anthropogenic and environmental drivers not tied to industry or population density.

Unquestioned Assumption 2: Rural places are empty

Another unquestioned assumption that threaded through discussions with regulators was that rural places were empty and uninhabited. Rural areas were discussed as unpopulated either explicitly or through discussions of monitoring where people are, which when paired with absences in rural areas seemingly translated to rural areas not having people.

These responses consistently glossed over the fact that rural areas in this region are highly disparate, particularly in regard to the class, infrastructure, resources, and isolation of areas. The rural areas in the Four Corners states often represent opposing poles of these categories: some are boom and bust

Western towns that get left behind and forgotten as well as tribal lands and significant swathes of public land. Others are exclusive mountain communities that represent some of the most concentrated affluence in the country and thus garner significant power and resources. Yet, both fall into the same category of rural in government classifications.

Many interviewees were less than subtle in their framing of rural places as empty. When asked why significant areas of the Four Corners region lacked any PM_{10} monitors, the response from a state regulator was illuminating: "um, nobody lives there." The regulator continued by adding more nuanced reasoning to their dismissal of any populations in rural areas with a comment that still characterized these places as largely unoccupied. "We're talking a county with a population of six thousand people. It's not very many people. So, by nobody I mean there aren't any population groups of 50k people or more. And so there are very limited numbers." This response clearly recognizes that rural places in fact do have people, but these small populations seem to round down to empty. Again, this regulator argues "nobody lives there" despite highlighting knowledge of people that do live there. Yet, despite this acknowledgement, the logic of rural places as empty persists due to comparisons with larger places with more people that superficially erase and overshadow smaller populations.

When I spoke with regulators at the EPA—the federal agency that sets the minimum requirements for states' air quality monitoring programs—I heard echoes of similar framings of rural areas. One EPA regulator responded defensively to a question of why there were huge spatial gaps in the Southwest. They said that the areas in question were "sparsely populated" and then followed up with a utilitarian response that many regulators gave. They acted as though the question of monitoring rural areas was not practical and responded that "we can't monitor everything." When questioned about why huge portions of the rural west are unmonitored, most regulators responded as though a more exaggerated question had been asked about why every town is not monitored.

These questions are different: asking why the Plateau remains unmonitored is not the same as asking for regulators to monitor everywhere. This repeated treatment of the inquiry as unreasonable is itself telling.

When rural places are viewed as empty, little space is left to discuss *who does live in them.* Even recognizing "sparse populations" does not attend to the population demographics and the Plateau's communities are not homogenous nor irrelevant. An exploration into rural areas in the Four Corners region and the Colorado Plateau cannot be done without engaging tribal lands and communities. Many tribal reservations are located on the Colorado Plateau[27]. All four states have reservations within the Colorado Plateau and none of these areas are monitored. The reservation lands are largely rural with lower population densities and are not equivalent to a major city and therefore do not meet the minimum requirements.

However, this is not a clear-cut case of environmental injustice, as state governments do not have sovereignty to monitor on tribal lands. The lack of sovereignty is a double-edged sword that both protects and undermines tribal communities. It protects them by not extending the regulatory gaze—and importantly recourses and costs—to tribal lands. Non-attainment status can cost governments millions of dollars and could potentially strain tribal resources or economies due to mitigation requirements. Yet, this leaves air quality fully unmonitored for tribal communities in an area with a long history of dust and increasing development for oil and gas and mineral extraction. The lack of monitoring in the Plateau cannot be explained by tribal lands alone, however, because adjacent public lands that are not entangled in sovereignty issues also remain unmonitored.

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[27] Tribal reservations located on the Colorado Plateau include including the Navajo, Hopi, Ute Mountain Ute, Southern Ute, Uinta Ouray Ute, Zuni, Jicarilla Apache, Laguna Pueblo, Acomo Pueblo, Kaibab-Paiute, Hualapai, White Mountain Apache, and Havasupai. However, since the borders of the Plateau are somewhat contested, this list should not be considered exhaustive.

Logical Conclusion: Rural places are unpolluted

If pollution is man-made and population dependent and rural places are empty, it can be assumed that rural places do not have pollution. This conclusion is made by many of the regulators tasked with monitoring and governing rural areas. The regulator describing pollution as man-made and the role of cars in driving pollution (unquestioned assumption 1) concludes with "in a rural area, you don't have that. You just don't have the pollution sources." Rural areas—they presume—do not have high amount of vehicle traffic and other per capita emissions and thus they do not have air pollution.

When asked if rural areas were underserved by a lack of monitors, another regulator pushed back because they claimed these areas did not have a problem. In their opinion, being underserved required a problem. They explained:

> just from my opinion, in these rural areas, we know that there is not necessarily a problem. And so, while the fact is that there may not be a monitor right there, we can have a good understanding of whether they are being impacted. And if they are being impacted, we want to hear about it.

Not only did they attest that rural areas do not have air pollution issues, but also that they did not need monitors to detect pollution levels. This regulator is defending a lack of monitors because rural areas do not have air quality issues. They do not explicitly link this to the unquestioned assumption, which might be easier to disprove or undermine, but nonetheless the assumption is guiding this assertion.

What is also noteworthy in this response is the assertion they do not need monitors to know pollution locations. This is untrue and the regulator somewhat back tracked when asked to explain how they would know without monitors. Air quality is modeled regionally to offer air quality predictions, but these models use data from individual monitors to piece together and interpolate across gaps. This can provide insight into areas with smaller gaps where nearby monitors are likely detecting similar levels, but these models are only as good as their data. Without data from the Colorado Plateau, models are using data from hundreds of miles away, which limits their ability to model dust in those places.

Another regulator responded to the same question about a lack of monitors in rural areas, stating that there was not anything to monitor in these places, so monitors were not needed. They continued on to explain why there was not anything to monitor in rural areas.

> When people come to the [urban area] from rural areas they will complain to me about how guncky the air is here and how clean it is back from where ever they came from. Because they are visiting, they are coming to the big city, and its like, "man, I hate coming here because the air is so bad." It's like "ok." Well we have all this stuff in place because the air is bad. When they go back home the air isn't bad there. So we don't need to have all this safety net stuff in place because the air isn't bad there.

The comparison of "guncky," polluted urban areas to rural areas creates an inaccurate dichotomy. This divide relies more on rural (and urban) imaginaries than a more nuanced understanding of their differences. This response also employs the same troubling thinking that if something is not known as bad, then it is safe (see Galt 2011). Rather than asserting rural areas are unpolluted with data, this thinking assumes there is no need for a null hypothesis.

Resulting Consequence: Rural areas do not need monitoring

The consequence of accepting rural areas as unpolluted (the logical conclusion based on unquestioned assumptions) is that rural areas are left unmonitored. The sentiment that rural areas do not need monitoring shows up explicitly in the maps and in the responses of regulators and was the starting place of this analysis that asked why and how that idea came to take hold.

Uneven patterns in monitoring networks are not explained by regulators not caring about rural communities. Regulators are not explicitly devaluing rural lives and places. Instead, regulators regularly stated their role in protecting them and taking that responsibility seriously.

> We consider all populations and all people to be of importance, of value. Right? And if you are impacted by something, we take complaints seriously. We are always trying to improve our practices and we are trying to have a balance, meaning it's environmental protection, so that we can protect and enhance the public in [state] as much as we can.

This response is genuine. Most of the regulators do care about rural populations and claim to care equally about all citizens. However, this commitment to protecting the public shows just how powerful unquestioned assumptions and their logical conclusions are when embedded in regulatory science. Logical conclusions that rural places are not polluted are obscuring true conditions and repeatedly leading regulators to act against their own commitments of protecting public health. It also leads to regulators denying the presence of a risk when it remains unknown.

The consequence manifests materially in monitoring patterns that leave large spatial gaps, but also in the responses from regulators. When asked specifically to examine their state's monitoring systems, regulators often explained that despite the large gaps, additional monitors were not needed. One regulator responded to inquiries about gaps in rural monitoring frankly "we don't monitor where there isn't anything to monitor." This highlights how clearly the uneven patterns in monitors are tied to the conclusion that rural areas not having pollution issues rather than any data or evidence pointing to that conclusion.

Regulators felt as though "underserved" was not the best way to look at the impacts of uneven monitoring on rural places. Many of them argued that rural places were different enough from urban areas that the comparison was unwarranted. Specifically, rural areas were unpolluted and safe and leaving them unmonitored was not a disservice. One explained that rural communities,

> may feel like they are underserved because they are not getting everything that [urban areas] get, but they don't have everything that is generally needed. So, it's kind of yes they are underserved, but there is a reason why they are underserved. And generally speaking, it's because they are not impacted and so the service doesn't really make sense for them.

This response shows how the notion that monitors do not make sense for rural places stems from the belief that pollution could not be in these places. This is an example of a circular logic: rural communities do not need monitors because they are unpolluted, yet it is impossible to know if that conclusion holds true because no data on pollution levels is collected. A community needs a monitor to determine if they have problem, but they need to have a demonstrated problem to get a monitor.

The current trend adds to uncertainty as regulators are more likely to remove monitors then add them. When I asked how they would know there was a pollution issue in these unmonitored places, regulators would often concede that they could not, somewhat recognizing the circular logic. One relented that "I guess the way you're looking at it… yeah, I guess you'd have to have to have a sampler there to see it [pollution]." This statement hints at a cognitive dissonance that allows regulators to claim that unmonitored places are unpolluted while lacking any data to support that claim. Yet, follow up questions made the regulator confront the circular logic held up by taken-for-granted assumptions.

Knowing the matter of places

Challenging the assertion that rural places are unpolluted is difficult because of a lack pollution data. However, both unquestioned assumptions can be undermined based on their own terms and more broadly. First, it is easy to undermine the logic that pollution is a product of population density (assumption 1). Many man-made pollutants *are* produced in places that do not have high population densities, and environmental justice scholars have long shown how rural areas are targeted in many cases *because of their lack of population* (Ashwood and MacTavish 2016). Rural areas are often the sacrificial grounds for mineral development, industrial activity, and other forms of man-made pollution (Harrison 2011; LaDuke 2017; Malin 2015; Bullard 1993). Additionally, rural areas can have population-driven pollution that is not related to their number of residents. For example, in 2017, Springdale, Utah had a population of 592 but it is located at the entrance of Zion National Park, which had more than 4.5 million visitors that same year—all who came to the park in a vehicle. Vehicle emissions are not necessarily tied to the population of residents, and therefore number of residents does not predict even individually-produced emissions.

Even more broadly, particulate matter in the Southwest comes from a broad range of sources with diverse drivers; this undermines the assumption that pollution is man-made (again logic 1). The EPA recognizes particulate matter as a critical air pollutant, and an airborne particle—be it from a dust storm or tail pipe—has similar health impacts no matter what causes it. From a public health perspective, the size of the particle is the primary determinant of its health risk due to how deeply it can be inhaled into the lungs[28] (Anderson et al. 2012). A focus on man-made pollution ignores the realities of the Southwest, which often has particulate matter pollution from dust storms and wildfires. Differences in landscape—from vegetation, to soils, to land use (see Table 1)—all impact air quality. Yet, an unquestioned assumption that insists pollution is necessarily man-made leads to particles from sources like dust and wildfire being ignored and rendered somewhat invisible.

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[28] However, while we have evidence that small particles are very dangerous, we actually have very little evidence about the health impacts of large particles, in part because we do not measure them making them difficult to study. In many public health spheres large particles are considered somewhat benign, but this largely stems from a lack of knowledge about their impact rather than evidence that they are safe (see Chapter 2 for more on this).

Second, rural places *do* have people (assumption 2). Many communities in the region have sizable populations and these remain unmonitored. What is more, cities with populations creeping towards 100,000 residents, like St. George, Utah (population 84,405), Flagstaff, Arizona (population 71,975), and Santa Fe, New Mexico (population 83,776) are some of the larger populations unmonitored. The assumption is undermined on its own terms: there are large populations in these areas, which deserve attention based on current assumptions about pollution.

Further, hundreds of smaller communities also are spread throughout this area; Winslow, Arizona (population 9,402), Monticello, Utah (population 1,995), or Aztec, New Mexico (population 6,566)—or other small communities living on and near the Colorado Plateau—would object to the notion that no one lives there. The Colorado Plateau also has a number smaller or "sparse" communities and their exposures and health risk are not decreased by their small population size. Even more broadly, viewing the Plateau as empty misses the diverse and intensive land use activities that play such a large role in the area.

Just as the two unquestioned assumptions at its foundation are problematic, so is the logical conclusion that rural places are unpolluted. Air quality forecasts are modeled based on empirical observations, so having significant areas without data undermine model outputs. The lack of pollution data does not equate to a lack of pollution. This logical conclusion does not only relate to pollution levels (i.e. they are low), but also monitoring needs (i.e. rural areas do not need monitors).

The conclusion that rural places are unpolluted has a second consequence beyond leaving rural places unmonitored. It makes dust in the rural southwest "matter in place" and thus not pollution; it naturalizes dust. Just as in cases of river discharges and "natural" smells (Garcier 2010; Moffatt et al. 1999), dust does not count as pollution in the Colorado Plateau because it is expected in deserts.

Beliefs about dust's naturalness further complicate its measurement and regulation. When dust is considered natural, it often works to hide the broad array of land uses that play an important role in the system and further allow the Plateau to be considered empty. In this way, dust is very different from other types of pollution. Dust is not natural nor man-made, but sits at intersection between the two which makes it hard to determine if it is matter in or out of place. It contorts the frameworks and logics used for approaching and thinking about pollution that often envision a point source and linear causal chain. And, equally important, dust diverges from other types of pollution by lacking a clear discrete tie to quantity of people.

Dust in the Southwest moves in and out of place as it moves through the landscape. Dust is considered in place in the desert: a dry, arid landscape that we expect it in. This expectation is built on questionable narratives around arid lands (Davis 2016; Duvall et al. 2018; Sayre 2017), and often relies a baseline of the Dust Bowl, even though that is considered one of America's greatest natural disasters (Worster 2004b). However, when dust is carried from rural communities on the Colorado Plateau to communities in Southwestern cities, we begin to see it as out of place. Cities regularly send out public health alerts reminding residents to stay indoors during dust storms. These Southwestern cities can often represent a middle ground, places where dust is both framed as catastrophic haboobs and natural nuisances. Dust is also carried from the Plateau eastward to deposit on the snowpack of the Colorado Rocky Mountains, not only painting the snowpack a dark red, but dramatically increasing the speed of snowmelt (Painter et al. 2007, 2010, 2018). When dust lands on snow it moves from being "in place" in the desert to "out of place" on snow. Efforts to mitigate dust on snow are, in part, hampered by notions that airborne desert dust is in its place, only to fall out of place when it falls on the snowpack. In this way, dust's relationship to place is always shifting.

Conclusion

This paper has shown how the assertion that "rural places are unpolluted" is driven by hidden unquestioned assumptions that prove problematic. The result is highly uneven monitoring patterns that leave much of the rural west—the Colorado Plateau in particular—unmonitored. Lack of PM_{10} monitoring produces persistent uncertainties as to exposures, traps communities in circular logic, and ultimately restricts rural communities' access to regulatory recourse.

The power of unquestioned assumptions is perhaps most telling in the way it has led regulators to act against their own goals in many cases. Regulators repeated that they cared for all people in their states and that a lack of monitoring was about a lack of pollution (and fiscal constraints) rather than devaluing rural lives. However, the conclusion that rural places were unpolluted becomes so hardened, in part because unquestioned assumptions are invisible, that regulators accept it as truth and base their management on it. Ultimately, they ended up working to protect populations and undermining them simultaneously.

Bringing stealth unknown knowns (Simon 2018) to a 'matter out of place' framework (Douglas 1966) allows us to not only think about the social roots of our definitions and categories for pollution, but also how they fit into larger processes of knowledge production and application (Duvall et al. 2018; Goldman et al. 2011). In this case, approaches to monitoring pollution are based upon unquestioned assumptions about place, which ultimately produces regulatory ignorance (Frickel and Vincent 2007; Kleinman and Suryanarayanan 2013). This case highlights how stealth unknown knowns about both place (rural places) and matter (particulate matter) influence what matter is considered in and out of place with important impacts on our ability to know pollution. They are not only shaping our *definition for pollution* (i.e., what counts and what does not), but also our *knowledge of pollution* by where we look for pollution, which ultimately has a critical impact on regulatory science and action

This analysis highlights the way that unquestioned assumptions shape the production of regulatory science and action, and conversely, ignorance and inaction. Regulatory ignorance, in this case, is propelled by how pollution is understood and defined, which is strongly influenced by furtive, taken-for-granted assumptions. Circular logics pervade this area of regulatory science and further impede detection of exposures. Circular logics – that require evidence in unmonitored areas to change course—allow unquestioned assumptions to persist even when untrue. Tracing the influence of unquestioned assumptions highlights how and why regulatory systems remain blind and unaware of certain environmental harms. And, because regulatory science is inherently action-oriented, why regulatory responses never occur. Regulatory science is explicitly designed for the purpose of regulation (action), and thus gaps in this information prevent regulations that are dependent on violations.

By tracing the assumptions at the foundation of repeated and taken-for-granted conclusion (e.g., rural places are unpolluted), hidden but important unquestioned assumptions can be brought to light. Made visible, unquestioned assumptions lose some of their power because encountered head-on they are easy to disprove. In many ways it is their stealth nature, their invisibility, that allows them to persist. When unquestioned assumptions are unraveled, the conclusions built on them begin to fray and teeter as well.

CHAPTER 5

PROBLEMATIC EXCLUSIONS:

ANALYSIS OF THE CLEAN AIR ACT'S EXCEPTIONAL EVENT RULE REVISIONS (A POLICY REVIEW)

Introduction

The Clean Air Act (CAA) is of one of the most successful public health laws in the United States. By 2020, it is estimated that regulations made in 1990 will save a total of 4.2 million lives and that the law will continue to save 230,000 lives annually (DeMocker 2003). The economic benefits of those same restrictions outpace costs by 30:1 (*ibid)*. Of these achievements, reductions of particulate matter are some of the most important (Anglides 2011). This success largely is due to a continued revision of standards.

However, the 2016 Exceptional Events Rule (EER)—a recent addition to the CAA—alters these standards in important ways by excluding "exceptional" pollution episodes from the regulatory dataset. Areas are either designated as "in attainment" if standards are met, or "nonattainment" if pollution levels violate standards. Nonattainment causes a suite of mitigation requirements and financial costs to the areas with poor air quality. "Exceptional" air quality episodes can include rare events like volcanic eruptions or factory fires, but also much more common and frequent incidences like dust storms and wildfire smoke. Excluding events that violate standards means that populations are exposed to dangerous levels of pollutants, pollutants *above* safe air quality levels.

Examining the legal discourse of the rule is critical to understand how events are justified as exceptional and what type of exclusions the rule produces. This policy review examines the unintended consequences of the "exceptional" categorizations, specifically how the rule excludes common and preventable events, as well as how well the new rule remains in the purview of the original goals of the CAA. Specifically, this analysis focuses on high wind dust events in the arid

Southwest because they are harder to fit neatly into the exceptional criteria and show some of the unintentional consequences of the rule's categorizations.

Making and Revising the Exceptional Events Rule

The key motivation for the EER is the significant consequences that violations and nonattainment status carry for local and state governments. Nonattainment status carries impacts that can stretch across decades including increased monitoring requirements, federal intervention, and significant financial costs. Nonattainment consequences also raise the stakes on how pollution is measured and specifically how violating events can be excluded as exceptional. If violations can be excluded, nonattainment status can often be avoided. Therefore, the EER is not only about data, but also about avoiding regulatory action.

While the rule itself has only applied since 2007, debates over what should be done with "exceptional" data have a longer history in air quality management. Since the early years of the CAA, the EPA noted a need for flagging air quality data impacted by "exceptional events." In 1986, the EPA issued guidance for such events and created the Exceptional Events Policy, guidelines that were less formal than its rule counterparts. The only criterion pollutant discussed in this early iteration was particulate matter, and the PM_{10} indicator specifically, which is largely indicative of dust events. The result was multiple amendments that created exclusions for dust (PM_{10}) rather than a broad range of ambient pollutants. In 1990, amendments allowed waivers for nonattainment violations due to "nonanthropogenic sources" of dust. In 1996, the EPA created the PM_{10} Natural Events Policy which added guidelines for excluding non-anthropogenic dust events. It was not until 2007 that the EPA finalized the Exceptional Events Rule.

The original rule lays out five examples of exceptional events. Of the five examples, three clearly fit unavoidable events: chemical spills and industrial accidents, structural fires, and terrorist attacks. Two, however, were more contentious. First, pollution crossing interstate and international boundaries—regardless of whether anthropogenic or natural—could count as an exceptional event. This hardly fits into an obvious understanding of an exceptional event, straining the definition of "exceptional". Second, the rule identified a number of "natural events" as exceptional. Within the category of "natural" are events that range across the spectrum from solely earth processes (i.e., volcanic eruptions) to those with large human contributions (i.e., dust storms).

Less than a decade later, the EPA revised the rule largely due to pressure from stakeholders. State regulators felt the burden for proving exceptionalness was too high and they wanted a better definition for what qualified under the rule.

The 2015 draft rule, while maintaining similar themes, altered the criterion for what counts as events:

(1) The event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation,

(2) the event was not reasonably controllable or preventable, and

(3) the event was caused by human activity that is unlikely to recur at a particular location or was a natural event. (40 C.F.R. § 50 and 51, 68217)

All three criteria must be met for an event to be designated as exceptional. However, attempts to offer a clear definition were complicated by contingencies that can be read in different ways, by multiple actors, with a range of motivations. For example, what is reasonable to industry might not be reasonable to public health advocates. The lack of clarity of criteria was a focal point in some of the public comments. After receiving more than 30 comments on the draft rule[29], the EPA promulgated the new 2016 Exceptional Events Rule that aimed to address issues from

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[29] Agency Docket: EPA-HQ-OAR-2015-0229.

stakeholders, including Western state agencies and governments, industry representatives, environmental groups, and tribes.

Two generally opposing positions emerged. Industry representatives and state agencies supported a streamlining process that decreased the burden of proof to make the process easier. Texas, for example, reported that required designation materials cost several hundred thousand dollars *for each exceptional event* (83 FR 29784). The environmental groups, however, argued that the changes proposed in the draft rule weakened important air quality regulations and ultimately increased pollution and risk. The broad definition of "natural" was a key concern and later the focal point of a legal case (NRDC v. EPA 2018). The rule was enacted largely as proposed despite criticism.

Exclusion Criteria of the 2016 Exceptional Event Rule

The specific language choices and regulatory details in the 2016 rule have critical impacts on how pollution is managed, and ultimately overall air quality in the United States. They also produce unintended consequences, which are particularly important to examine. This is especially the case in the arid West, where dust storms are frequent, dangerous, and often driven by land use practices. Exclusion justifications deserve scrutiny as they determine what data is designated as exceptional, and thus removed. Exclusions ultimately determine which areas are designated nonattainment and where regulatory action is taken.

The following section dives into four criteria of the 2016 EER to illustrate how the rule justifies exceptional events and their exclusions. Specifically, how might the rule be excluding events that are in fact quite ordinary? I show how changes in the rule—specifically to exceptional events criteria—have led to more events being deemed exceptional and then excluded.

A clear causal relationship:

The first criterion for establishing an exceptional event is that a "clear causal relationship between the specific event and the monitored exceedance or violation" be established. An exceptional event can only occur if there was a violation, and the state agency must establish that the event in question caused the violation. This means, however, that extreme events that do not lead to violations are not viable for designation. Establishing this clear causal relationship takes most of the labor of preparing demonstration materials for exceptional event designation.

The "clear causal relationship" criterion was designed to lessen the burden of proof by states and to allow more events to obtain exceptional status. The original rule required that the clear causal relationship show that the event was "in excess of" past events, asking for an analysis of the historic distribution of events. However, the change removes

> the requirement for air agencies to provide evidence that the event is associated with a measured concentration in excess of "normal historical fluctuations including background" and replacing it with a requirement for a comparison of the event-related concentration to historical concentrations. (40 C.F.R. § 50 and 51, 68225)

In other words, an exceptional event no longer needs to be proven outside of historic ranges of variability (i.e. infrequent). Now the state only needs to show that the event caused the violation, not that it is rare. This revision lowered the bar for causal relationships to one that no longer requires events be proven outside the historical range, or atypical. Cause but not rarity marks an important change for justifying exceptional events. For example, under the original rule seasonal dust storms, like those experienced for more than 100 years in the spring in Houston, Texas, would not be considered exceptional because they are a regular and predictable seasonal pattern. Under the new rule, the same seasonal storms would be excluded as long as they contributed to the violation. These small changes in the rule's language regarding a causal relationship significantly alter how the rule works and what events qualify. Ultimately, the revision leads to events that are not unusual based on historical distribution obtaining exceptional status.

Establishing a causal relationship is complicated when applied to most events that only contribute to a portion of pollution detected by monitors. What relative contribution represents a "clear causation relationship" between an event and a monitored exceedance? It is not as though areas experiencing a dust storm are particulate-free until a dust storm rolls in and violates standards. These locations have baselines particulates from local dust transport as well as anthropogenic sources like industry and cars. A dust event is not always the sole cause of the violation, making attribution much more murky. Violations often include a mixture of particulates from the event in question and from baseline sources. For example, in Houston, refineries emit levels of pollution that often bring particulate levels to just below the NAAQS so additional particulate from dust leads to violations. However, those violations are attributed to dust storms even though high industrial baselines also contributed, and this classification ultimately hides industrial sources. If, hypothetically, areas experiencing dust decreased their baseline levels with controls on dirt roads and industrial emissions, passing dust storms might not trigger violations and nonattainment designations. Thus, many of the violations with "a clear causal relationship" to dust also have a connection to anthropogenic pollution.

Reasonable Prevention:

The second criterion of the rule is that an event is "not reasonably controllable or preventable," but does not offer a clear definition for either qualifier. Logically, unpreventable events might reasonably be treated differently than anthropogenic pollution so that a community devastated by an explosion does not feel the second pain of regulatory action. Regardless of the events leading up to the hypothetical explosion, it is difficult to imagine a scenario where air quality regulations – not counter-terrorism—could have prevented the explosion.

Yet in most cases, events are not so clearly unavoidable, and this revision raises questions about what counts as "reasonable" and by whose measure. What is reasonable under a pro-business logic might different from what is reasonable to impacted communities. Similarly, environmentalists might think restrictions on public lands use is very reasonable, in fact preferable. The ultimate question becomes whose reason counts and based on what underlying logics and priorities.

The rule also states that "anthropogenic sources that are reasonably controlled shall be considered to not play a direct role in causing emissions." In other words, if reasonable controls were in place at an open pit mine, then the rule allows analysis to exclude the mine as a source; it is assumed that the mine plays no direct role in the dust storm. While questions are raised about what counts as "reasonably controlled," the second clause is just as important. As currently written, the EPA does not require the control itself to be effective. The rule continues:

> we believe that if reasonable controls were implemented on contributing anthropogenic sources at the time of the event and if, *despite these efforts and controls, an exceedance occurred,* then we would consider the human activity to have played little or *no direct causal role* in causing the event-related exceedance. (40 C.F.R. § 50 and 51, 68231 *emphasis added)*

In other words, it is not the effect (i.e. a well-working control that limits emissions), but the intent (i.e. a control put in place) that determines its influence on the data. Under this rationale, an ineffective control could be added to an anthropogenic source—an open pit mine or smelting plant—and repeated violations would be erased. Adding "reasonable" controls essentially erases the cause as well as the event because without an anthropogenic cause, the event is considered natural and therefore unpreventable and exceptional.

Events originating beyond jurisdictional boundaries are also not considered "reasonably preventable." The malleable, contingent language of "reasonableness," and its consequences, are made visible when applied to events that cross borders. The rule argues that events from across borders are "not reasonably controllable or preventable" and that

> air agencies generally have no obligation to specifically address controls if the event was due to emissions originating outside their jurisdictional (*i.e.,* state or tribal) border (40 C.F.R. § 50 and 51, 68217).

In other words, pollution's origins remove an obligation to manage the causes of the event. State regulators do not need to show efforts to prevent such events, including future events. It is important to remember, too, that these are not just nuisance events. Violations expose people to unsafe levels of pollution, making the stakes of removing responsibility for meeting air quality standards are high.

Evoking reasonableness, the rule explains why cross jurisdictional events are not the responsibility of the downwind regulators.

> It is not reasonable to expect the downwind air agency (*i.e.,* the state or tribe submitting the demonstration) to have required or persuaded the upwind state, tribe, or foreign country to have implemented controls on sources sufficient to limit event-related air concentrations in the downwind state or tribal lands (40 C.F.R. § 50 and 51, 68237)

This discussion of reasonableness is similarly questionable. For whom is it not reasonable that states and government entities work together on cross boundary issues? This passage actually discusses two different scenarios. Working across international lines between countries that have different air quality standards might be less reasonable. For example, the U.S. and Mexico not only differ in the amounts, but also the indicators, or sizes of particulates they regulate, meaning that a violation in the US may not be a violation in Mexico. However, in cases where pollution crosses the boundary between U.S. states, both state entities have the same standards and fall under the same federal law. The law is written so that it utilizes state boundaries as the important jurisdictions which make sense politically, but not ecologically.

Ultimately, this assertion of reasonableness is more a reflection of political will than on whether preventions are possible or reasonable. Part of the unreasonable nature is due to the regulatory system that the CAA sets up. The CAA sets the requirements for air quality but leaves most of the operations to the states. However, it is this management unit—the state—that makes cross jurisdictional events unmanageable. These are events that cross somewhat arbitrary political boundaries that divide up ecosystems like the Colorado Plateau that might benefit from a unified rather than splintered management strategy. These events themselves are not uncontrollable or unmanageable. If states were not the primary mangers or if there were roles for regional and federal actors, some of these events might become preventable. Their unreasonableness largely stems from the mismatch between the political system designed to manage air quality and the air quality events themselves.

The assumption here is that the upwind state, the state at fault, will also be in violation, so removing the downwind state's violation will not remove the event in its entirety. However, the piecemeal monitoring system can lead to just that: exclusions can lead to the entire event removed. For example, the southern two thirds of Utah has no air quality monitors, so dust storms that started in southern Utah would only be measured in Southwestern Colorado. Based on this rule, an ensuing violation in Colorado could be removed because the storm did not originate there. However, since Utah has sparse monitoring, Colorado's removal would discard the entire event from regulatory data.

Recurrence Frequency

Discussing the exceptionalness of an event is difficult without evoking rarity, and simultaneously frequency. While the term exceptional is slippery in many ways because of its multiple, somewhat opposing definitions, when applied to an event most people assume it refers to frequency. Moreover, the qualifying criteria of the rule itself discusses events that are unlikely to reoccur, tying frequency and reoccurrence to the core of exceptionality. Part of the criterion for anthropogenic events is that they are "unlikely to recur at a particular location," but what does that mean?

During public comment periods, stakeholders asked questions about accepted recurrence frequency. For anthropogenic events, which are specifically required to be unlikely to reoccur to count as exceptional, the rule clearly outlines a recurrence interval of no more than two events over three years[30]. Many readers interpreting "unlikely to reoccur" might be surprised to learn that approaching a yearly occurrence would still qualify as exceptional. The relationship between reoccurrence and exception is further stretched when applied to natural events.

The recurrence frequencies for natural events deviate significantly from the yearly average of the anthropogenic events. More specifically, "the concept of recurrence only applies" to anthropogenic events, not natural events. The rule goes a step further to

> clarify in regulatory language that *natural events can recur, sometimes frequently*, without affecting the approvability of a demonstration for the identified natural event. (40 C.F.R. § 50 and 51, 68217 *emphasis added)*

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[30] The rule states that if no other events of that same type occurred in that same place in the three previous years, that the it will be considered a "first" event and unlikely to reoccur. However, if there have been two similar events in the past three years in that location, the third event will be considered recurring.

The logic that an event can recur frequently and still be considered exceptional is challenging and seems to contradict the very definition of exceptionality, or rarity. Based on the language of the rule, a natural event can happen regularly, seasonally, you might say normally, and still be considered exceptional and removed from the regulatory sphere.

Natural events

Critical to the third statutory qualification was the determination of type of event, specifically if an event is "natural" or "anthropogenic." What is a natural event? The rule is written so that all events that are considered natural are exceptional events. Of course, that logic has some gaps: exceptional and natural are not synonyms. Instead, events can be natural and common or any combination of frequency and human influence. The rule gives examples of "natural" events including wildfires, volcanoes, and dust storms and specifies that these types of events are beyond the regulatory scope.

Part of the designation of natural events involves dissecting events to establish their naturalness, identifying anthropogenic and natural ingredients. While volcanoes can pretty reliably be categorized as natural or located on the biophysical end of the spectrum, both wildfire and dust sit at the human-nature divide. Currently, the largest driver of wildfires is human ignitions (Balch et al 2017) and fire severity and frequency has been impacted by increasing temperatures due to anthropogenic climate change (Westerling et al 2006) and forest management practices (Arno and Allison-Bunnel 2013), making fires in many ways hybrid or natural and anthropogenic.

The same applies to dust storms. A dust storm needs both particulate matter that can be carried from one place to the next, and winds strong enough to carry them. To make a dust storm an exceptional event, the rule requires states to categorizing those ingredients.

> The meteorological phenomenon (i.e., wind) is purely natural and thus can be classified as a natural event, but the pollution from the event may be a mixture of natural sources (e.g., undisturbed soil) and anthropogenic sources (e.g., soil disturbed by human activity, emissions from sand and gravel facilities, etc.). The EPA generally classifies high wind dust events as "natural events" in cases where windblown dust is entirely from natural sources or where all significant anthropogenic sources of windblown dust have been reasonably controlled. (Interim Guidance 2013, 5)

This excerpt from the rule shows that dust storms are divided into two key parts where wind activity is considered unquestionably natural, and source of dust is the critical criterion for the event's naturalness. While climate scientists might take issue with wind being considered fully natural, it is the least complicated or problematic of the two elements. The source is the especially complex element. Dust can come from many dispersed sources, rather than point sources. How can all the different land use actions and histories be evaluated to determine its human drivers? In the Southwest, much of the land is publicly owned with a variety of uses and subject to legacies from previous land use, especially since the soils are fragile and take decades to recover from disturbance (Belnap 2003). The law as written concedes that even if the source is anthropogenic but actions are in place to try to stop dust, then the event is natural. This is the case even if the preventative actions *do not stop* dust emissions. The rule states that,

> dust controls on an anthropogenic source shall be considered reasonable in any case in which the controls render the anthropogenic source as resistant to high winds as natural undisturbed lands in the area affected by the high wind dust event. (40 C.F.R. § 50 and 51, 68279)

This guidance engages an even broader discussion about how we think of arid lands, particularly those that have been used as rangelands. Setting the bar for controls to match a baseline of undisturbed lands requires that remaining undisturbed lands. Many would argue that we have naturalized the conditions of a "degraded" landscape or at least that we might not really know what healthy soils look like in the arid West because of the combination of fragile soils, long and widespread grazing histories, and long restoration timelines.

Case Study: Lamar, Colorado

These four exceptional events criteria work together to shape air quality data and regulatory action. To highlight the unintended consequences of this rule, my analysis draws on the case of dust in Lamar, Colorado. Lamar is located on the eastern plains of the state and is one of the state's poorest communities. Lamar averages 15 inches of rain a year—significantly drier than the national average—and has experienced a string of severe droughts that have increased local water stress and contributed to dust issues. While the city made statewide and even national news for a number of intense dust storms in 2013, this is not its first experience with dust. Southeastern Colorado, where Lamar is located, was one of the regions hit hardest by the Dust Bowl in the 1930s.

Yet, with this long history of dust in the region, why is it surprising or unexpected that dust events occurred? Why are these viewed as exceptional? The case of Lamar highlights how specifics of place and historical record should make dust an expected air quality issue to be managed rather than an exceptional one to be excluded. Furthermore, it also shows how exclusions that allow air quality levels to meet standards ignore drivers—like local land use practices—that could be altered but remain largely unregulated and unchanged.

A number of severe dust storms hit Lamar in 2013, gaining media attention and resulting in seven exceptional event requests by the state of Colorado, four in the month of May alone. While this year represents one of the dustier years, it did not violate any of the air quality regulations: this makes 2013 particularly useful for examining the treatment of exceptional events. Exclusions significantly changed the dataset that year; the original range was from zero to more than 1220 μg/m^3 and the resulting range was capped at 160 μg/m^3, conveniently just under the standard. It is important to note that these events fell under the original law, not the revised one. The designation of exceptional events is a time intensive process, so it is too early to analyze the effects of the 2016 rule revisions in a case study.

The consequences of modifying datasets amplify as they are used to determine regulatory action. Lamar was not designated as nonattainment despite the numerous dust storms that repeatedly violated standards. In fact, all of Colorado's counties are in attainment despite violations within the state (see Figure 5.1). Lamar had seven violations in one year, but data exclusions allowed it to appear as in attainment. Exclusions allow Lamar's air quality to appear safe.

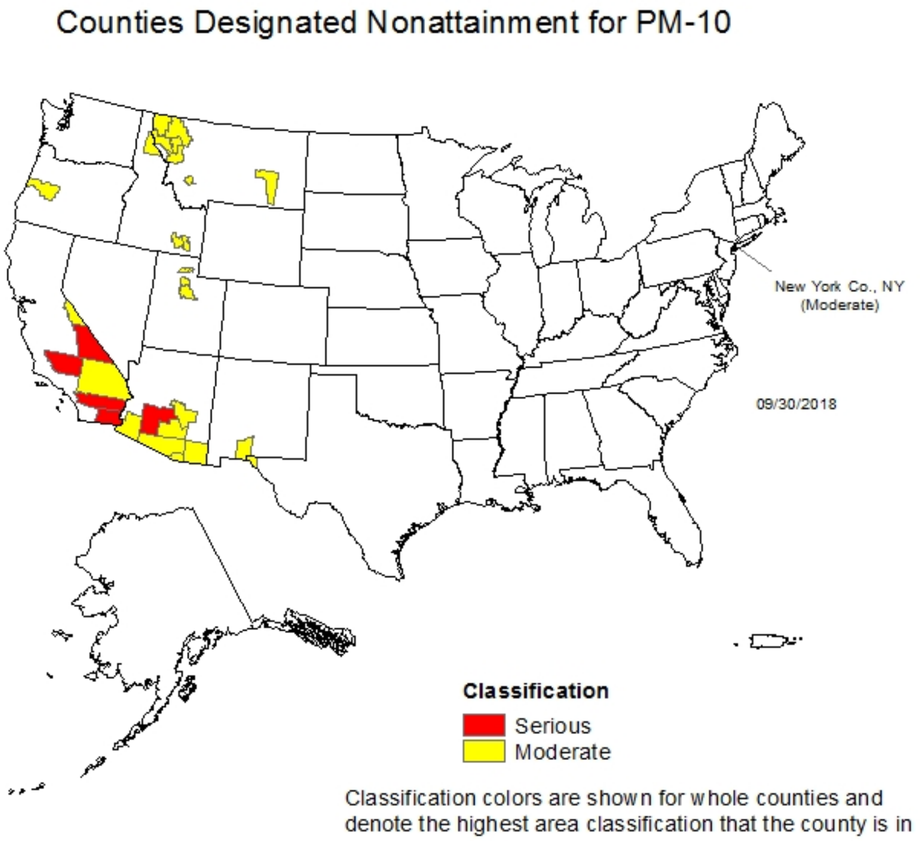

Figure 5.4: EPA map of PM10 nonattainment areas from January 31st, 2019. From U.S. Environmental Protection Agency. Green book. https://www3.epa.gov/airquality/greenbook/mappm10.html

Further, without nonattainment, the state is not required to change any practices that might contribute to the air quality violation. According to the state's application for EE status, "the PM10 exceedances in Lamar would not have occurred if not for the following: (a) dry soil conditions over source regions with 30-day precipitation totals below the threshold identified as a precondition for blowing dust; and (b) meteorological conditions that caused strong surface winds over the area of concern" (Technical Support Documents, 2015, 184). However, this is a case where some of the dust events would have been avoided if agricultural practices were different, for example if no-tilling practices were used. In fact, while different government actors are working with farmers to *encourage* no and low till practices since tilling is largely associated with dust sources, these remain opt in and voluntary rather than required changes *(ibid*, 180). Allowing exclusions that keep air quality levels in attainment reduces pressure to require and enforce changes and ultimately reduces accountability.

This case highlights many problematic elements of the exceptional event criteria discussed in this analysis. First, the fact that all of these storms are considered *natural* is problematic. It is an area with high soil disturbance from agricultural practices that are known to produce dust. Second, these dust storms have a very high *recurrence frequency*. Yet since frequency only pertains to "anthropogenic" events, it does not factor into the assessment of these storms. Therefore, frequency is not relevant under this rule applied to dust. Third, since dust is treated as natural, it is not considered *reasonably preventable* and thus regulators are not required to enact changes to agricultural practices that might mitigate dust.

Dueling Priorities and Goals

This analysis aimed to ask two questions about the consequence of the new rule and how they impacted the aims of the CAA. Are these revisions leading to normal events being excluded? Yes and often. Further, it is important that the regulation ultimately be evaluated by how it achieves the goal of the CAA, which is to improve air quality, primarily for protecting public health. Does the EER support this goal? Unequivocally no.

There is no interpretation of the EER, or its motivations, that prioritize public health, public welfare, and environmental quality. The exclusions under the rule allow states to remain in attainment when their air quality violates standards and should be in nonattainment. In this way, the rule might actually lead to a worsening of air quality because it removes incentives and requirements for mitigation efforts. Jurisdictions with poor air quality are allowed to maintain levels or even increase levels of pollutants, as long as they can be classified as exceptional.

Of course, there are cases of exceptional air quality events that truly fall outside of the control of air quality managers. However, the way the rule is written and most of the cases where it is applied in the Southwest are not such situations. Instead, the decreased burden of proof of the new rule allows regular, repeated, and foreseeable events to be ignored, and most importantly, exposes populations to health risk.

This analysis can provide new insights and a starting place to evaluate the rule and spark discussion about its contents and consequences. Rules are revisable; the EER was just revised in 2016 and has the potential to be revised again. Another option is that the EPA could offer new guidance to go along with the rule that would not require a total overhaul. Regardless, the first step needs to be a larger discussion about what type of work this rule does and if it's in accordance with relevant goals. A discussion needs to weigh the benefits and the problematic elements of this rule; there might not be a win-win option, but tradeoffs need to be more explicit to promote a sound evaluation. This analysis concludes with a number of policy recommendations to improve the rule.

Policy Recommendations

- <u>Provide better information about the use of rule:</u> Currently, requests for exceptional event designation are made on an event-by-event level and remain largely disaggregated, which obscures trends of use and impact. More research needs to collectively look at how the EER has been used at state and regional levels and creating a national database of exceptional events would make analysis much easier and cumulative impacts legible. A particularly important area of inquiry would be how the rule has been used to move communities from nonattainment to attainment.
- <u>Prioritizing Public Health:</u> If we consider dust emissions natural—despite many complexities—and we recognize some places and regions have high natural levels of a

pollutant, it is imperative to decrease *anthropogenic emissions*. In areas with high baselines of dust, we should require anthropogenic emissions to decrease so that total levels remain at safe levels.

- <u>Making the EER Adaptive to Environmental Change:</u> Environmental change is expected to increase the variability of earth systems and the frequency of extreme events. Greater attention needs to be given to how the EER might be excluding events that are becoming increasingly more common.
- <u>Resolving the frequency problem with exceptionality</u>: Currently, there is no limit on frequency of exceptional events that can occur in a place if they are considered natural. Allowing frequent exclusions works against the intended purpose of the rule—to exclude *exceptional* events—and more broadly the mission of the EPA. A recurrence limit on natural events would prevent uneven impacts on communities based on their different physical environment.
- <u>Focusing on Effect Rather than Effort:</u> The rule allows for anthropogenic sources to be treated as "natural" if mitigation is put in place, even if ineffective. Instead, efforts should be evaluated based on effectiveness.

CHAPTER 6

NATURAL EXCEPTIONS OR EXCEPTIONAL NATURES?: REGUALTORY SCIENCE AND THE PRODUCTION OF RARITY

"The database itself will ultimately shape the world in its image: it will be performative. If we are only saving what we are counting, and if our counts are skewed in many different ways, then we are creating a new world in which those counts become more and more normalized" – (Bowker 2000, 675)

Introduction

The Environmental Protection Agency (EPA) has recognized the importance of tracking and regulating air quality for decades based on an understanding that what is in the air matters for public health. The Clean Air Act (CAA)[31] established a national monitoring system considered so successful that other nations have modeled their networks after it. Since the 1970s the CAA has been credited with reducing air pollution and saving millions of lives (Tucker 2011). The EPA, which enforces the CAA, has the primary goal of protecting human health from environmental harms. However, the EPA has a problem, striving to separate natural from unnatural, and routine from exceptional. EPA's classification of "natural" and "exceptional" events compromises the efficacy of its air quality regulations. This paper examines how common things are made unusual via regulatory classifications, and how this in turn creates new natures, specifically focusing on dust in the Southwest.

While even the earliest form of the CAA included some exceptions for certain natural events, this practice was formalized and made explicit in 2007 through the Exceptional Events Rule

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[31] 42 U.S.C. § 7401

(EER)[32]. The rule allows the impacts of "exceptional events" that might increase measured pollution levels to be excluded from the dataset used to manage air quality, and specifically used to take regulatory action against communities with bad air quality. If pollution levels rise above regulatory thresholds, an area can be designated as a "non-attainment," which carries with it a suite of fines, restrictions, and increased monitoring. The EER lays out the criteria for an "exceptional event" and the process for securing its exclusion from the regulatory record.

The EER allows poor air quality episodes to be excluded based on their "exceptional" character, which the dictionary describes as rare, atypical, or uncommon[33]. Such exclusions have critical impacts for managing and understanding air quality. Exclusions alter regulatory data by making pollution less visible, obscuring environmental changes, and clouding our understanding of variability, extremes and emerging trends. Exclusions can also alter a community's attainment status, typically shifting from non-attainment, which includes fines and requirements for air quality improvements, to attainment. Thus, significant financial savings from avoiding air pollution fines often motivate state agencies to exclude events.

Surprisingly, one of the categories under the EER is "natural" events, which are often common, typical, and quite unexceptional. Besides the issues with this ill-fitting categorization, claiming events as natural has at its foundation in the myths of the nature-society divide and is deeply entangled in the politics of this false divide (Escobar 1999). The naturalness of dust is challenging to assess, and, in most cases, dust is produced from hybrid causes, giving dust elements of both nature and society.

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[32] 40 C.F.R. § 50 and 51

[33] As defined by the Merriam Webster Dictionary. "exceptional." 2019. In Merriam-Webster.com. Retrieved August 5th, 2019: https://www.merriam-webster.com/dictionary/exceptional.

Through the EER, the EPA gets entangled with the politics of classification (Bowker and Star 2000; Duvall et al. 2018; N F Sayre 2015). Discursive framings not only have profound impacts on how we come to think about nature—how it works, what belongs in it, its value—but alter how we interact with nature, often shaping the material world to match the discursive framing (Cronon 2013; Simon 2010). Classifications shape data analysis, interpretation of environmental systems, analysis of risk, and regulatory knowledge and action. In regulatory spheres, classification and data management become very important—and political—practices (Bowker 2000; Fortun et al. 2016). Regulatory data practices, in this case the EER classifications, can contribute to the production of regulatory ignorance (Frickel and Vincent 2007; Harrison 2011; Kleinman and Suryanarayanan 2013; Murphy 2006; Gwen. Ottinger 2013; Wylie 2018).

This paper uses the EER and the regulatory practices associated with it to examine the consequences of how we frame nature and our management of data about it, specifically focusing on dust storms. More specifically, the case illuminates the production of new natures—exceptional natures—that are a distorted picture of environmental systems. By diving into the regulatory datasets, I examine the production of a disingenuous rarity, or in other words, a false representation of unusualness. I argue that producing "natural exceptions" has an important unintended consequence: it inadvertently creates what I call "exceptional natures." That is, disingenuous natures (Simon 2018), despite their frequency and existence, are considered rare and unusual.

Data, Categories and Regulatory Ignorance

Regulatory science is a particularly important sphere to examine the production of ignorance because of how it shapes and directs regulatory (in)action (Frickel and Vincent 2007; Harrison 2011; Kleinman and Suryanarayanan 2013; Murphy 2006; Gwen. Ottinger 2013; Wylie 2018). Regulatory ignorance not only shapes a lack of knowing, but directly maps onto a lack of regulatory action, which requires evidence of a violation or threat.

Monitoring systems produce the data that allow environmental quality and change to be tracked and affects how those systems are understood, but data are also wrapped up in how understandings become distorted, partial, or uncertain. In many cases, the ways regulatory science is made generates problematic understandings or disingenuous natures. Disingenuous natures are distorted representations of nature that are nevertheless understood, managed and regulated as if they were accurate (Simon 2018). This type of regulatory ignorance—false understandings—proliferates as it repeats and becomes ingrained in legal and knowledge systems.

Regulatory intervention is directly shaped by evidence, or lack of it, making data political. As Fortun reminds us, "environmental politics are also data politics" (2016, 5) and how data is managed, compiled, excluded, and interpreted have political as well as scientific consequences. Data have important material impacts. "The database itself will ultimately shape the world in its image: it will be performative. If we are only saving what we are counting, and if our counts are skewed in many different ways, then we are creating a new world in which those counts become more and more normalized" (Bowker, 2000, 675).

Data that remains excluded from the dataset similarly shapes the world in its image. Data inclusions and exclusions are constantly entangled and interacting to make some things visible and others invisible (Pine and Liboiron 2015b). Wylie (2018), for example, highlights how non-disclosure agreements not only erase the history and evidence of industrial harm, but also shape the industry's accountability and need to respond. Oreskes and Conway (2011) describe how the ozone hole remained undetected for years despite being monitored because "unrealistic" data was thrown out because it was thought to be an error, rather than detecting an emerging issue.

Data exclusions that produce regulatory ignorance are often justified on the grounds of how we classify nature. Environmental categories that are embedded in science and policy are often social constructions linked to narratives and imaginaries (Duvall et al. 2018), value-laden (Tadaki et al. 2014), oversimplified (Sayre et al. 2017), and situated (Haraway 1988; Harding 1992). Categories simplify, enabling action and interpretation: "messy realities are framed and stabilized so that they may circulate in the world as homogenous units. These choices are value-based judgments" (Pine and Liboiron 2015, 4). Invisibility of how categories are made and do work in the world through ordering human interactions is part of the reason they are so powerful and persist (Bowker and Star 2000). Combining deep engagement with materiality and scientific claims paired with attention to their situated nature, politics, and power relations can better illuminate the politics of environmental categories and knowledge more broadly (Lave et al. 2013).

"Natural" is of the most prevalent and contested categories (Williams 1977). While scholars can reject the nature/culture divide conceptually (Escobar 1999), it becomes more than an intellectual project when "naturalness" and these false categories are written into law. Classifying certain elements and practices as "natural" or "unnatural" is a powerful act that serves political and economic purposes (Bowker and Star 2000; Davis 2016). Discursive battles about the social construction of categories, such as "feral" and "wild" (Rikoon 2006) and "native" and "alien" (Warren 2007), have important material consequences. Categories that may appear unproblematic and obvious are frequently imbued with histories, meanings and impacts that are often left unchallenged (Robbins and Maddock 2000).

Categories of "exceptional" and "natural" in the context of air quality regulations carry this same baggage. When written in law, they hide and protect false dualisms, alter management actions, and co-produce new hybrid relationships between people and nature (Cronon 1992). Categories can also reinforce government hegemony and hide important clues about drivers of environmental change (Robbins 1998). Indeed, a number of problematic legal categories have produced false and distorted understandings of nature in monitoring and regulatory science, understandings that result in unintended, yet equally problematic social and ecological consequences. The 1964 Wilderness Act relies on an artificial boundary in its construction of wilderness as pristine, untouched, and natural, which largely erases histories of human and leads the environmental movement to overlook human dimensions of environmental issues (Cronon 1996). The farm bill and other funding laws treat the 100th Meridian as an ecological boundary, when it is equally a social boundary, creating inequitable outcomes for farmers (Simon 2010).

This essay describes how the categories of natural and exceptional, as written into the Exceptional Events Rule, are leading to regulatory ignorance. More specifically, repeated data exclusions are rendering new and distorted understandings of nature: exceptional natures. As a result, dangerous air quality goes unregulated and communities are exposed to greater levels of particulate matter than is deemed safe. All of this remains obscured and, at least somewhat, invisible to the regulatory system while markedly visible to the residents breathing dirty air.

This analysis raises new questions about regulatory ignorance at the intersection of science, law, and action, by examining the politics data management and classifications in the production of ignorance.

Methods

This research is part of a larger project aimed at understanding the CAA's treatment of dust data in the American Southwest. Employing mixed qualitative and quantitative methods allowed me to triangulate across different types of findings and build a more robust understanding of the regulatory politics and consequences of dust management (and mismanagement). More than 70 semi-structured interviews were conducted with regulators, research scientists, stakeholders, and the general public to understand how dust science is produced and used, and specifically how uncertainty and contradictory claims about dust trends persist. As a participant observer, I followed scientists and regulators into the field to document how different instruments collected dust particles, and to reveal the concrete implications of using particular methods and instruments. These observations were part of nine months of ethnographic fieldwork living in communities impacted by dust in different ways. I built upon this work and engaged broader scales through textual analysis of legal and regulatory documents, as well as public comments, pollution maps, technical support documents[34] and news articles. I also analyzed the particulate matter data collected by the EPA, including the unmodified data that contains exceptional events. While this paper primarily draws upon textual analysis of legal and regulatory discourse and statistical analysis of particulate matter data, it is informed by the larger project.

This study first focused on a discursive analysis of legal and regulatory documents. I collected the multiple iterations of the Exceptional Events Rule, public comments, and legal briefs and opinions and analyzed them using qualitative coding. I coded documents for a few main categories of discursive politics. First, to explore the discourses used to divide nature and culture, framings of natural vs anthropogenic were coded. These codes included explicit framings of natural events and human activities as well as more nuanced or connotative framings. These codes were designed to identify explicit framings of natural events and human activities as well as less overt or synonymous framings. For example, "unpreventable events," is used by the rule to indicate natural events, and "disturbed soils" is used to indicate human activity. Second, to assess areas of potential uncertainty

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[34] State environmental quality agencies create "technical support documents" that explain and justify each exceptional event. These are the documents that include the analysis of the event and an articulation of why it should be excluded.

in the criteria for exceptional status, I coded for ambiguous or open-ended language. For example, the rule calls for "reasonable" prevention measures without defining what is reasonable and for whom. Third, I coded for language about exceptionality, including discussion of frequency, normalcy, and rarity. Other codes were used to identify discussion of dust and particulate matter, skewed data, and consequences from exceptional natures.

Additionally, I analyzed data from two case studies (Maricopa County, Arizona; and Houston, Texas) that had repeated exceptional event exclusions. I selected these case studies based on the frequency of EER application (Arizona) and based on the stakeholder engagement in fighting the designation (Texas). Using EPA regulatory data, I selected data sets for individual monitoring sites and collected daily summary data and hourly sample data. Both of these datasets were constructed pre-exclusion. I was then able to create two datasets from each original case study: one that included the total data and a second (the official regulatory record) that excluded exception events. I compared each dataset to highlight the consequences of data exclusions.

To understand impacts of the EER rule in each case, I also examined analysis from state agencies and stakeholders. Utilizing prior analyses required reading data, maps, and figures not only as scientific evidence about dust and its impacts, but also as texts to understand their politics, messages, and subjectivities. Examining the data produced by states and stakeholders provided additional narratives and assertions about dust system behavior. These maps and figures included analyses conducted by environmental nonprofits that oppose exceptional designations, by state environmental agencies to support designation or inform the public about air quality, and by the EPA to show where air quality violations take place. Together, these figures and maps highlight the contested nature and politics of data manipulations and exclusions. They can also be triangulated with the textual analysis of regulatory documents and data analysis of daily EPA particulate matter data.

The Exceptional Events Rule and its Language

Dealing with so-called 'exceptional events' has always been part of Clean Air Act work to manage air quality albeit in less formal substantiations. The practice of deeming events "exceptional" and excluding them from regulatory consideration was recently made much easier by a 2016 revision of the EER, which lowered the burden of proof for that designation (see Chapter 5). While exclusions date back to the first text of the Clean Air Act and following amendments, the 2016 rule revisions provide guidance on how exclusions will be made and the type of events that are eligible for exclusion.

The 2016 rule returned to the three original statutory elements of the CAA that addressed exclusion of exceptional events (section 319(b)):

(1) The event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation,
(2) the event was not reasonably controllable or preventable, and
(3) the event was caused by human activity that is unlikely to recur at a particular location or was a natural event. (40 C.F.R. § 50 and 51, 68217)

If an event meets all three of these criteria, state agencies can apply for its designation as "exceptional", likely resulting in its expunction from regulatory datasets. Most of the changes made to the 2016 rule were based on feedback and lobbying from federal and state agencies and other stakeholder groups, although the feedback itself was very divided, meaning that revisions in response to one stakeholder often drew complaints from others. Most notably, the environmental organizations that submitted public comments objected to many of the revisions made in the 2016 rule because they decreased the burden to establish exceptional events.

The rule revisions were largely motivated by the state agencies' complaints about the lengthy process, ambiguity of criteria, and difficulty of producing the Technical Support Documents required to apply for exceptional status. Many state agencies lamented that there was uncertainty and a lack of clarity for what counted as an exceptional event in the 2007 rule, and that there was not a clear process or evaluation test for how to prove an event was exceptional. States argued that staff time and resources were unduly taxed by the excessively high burden of proof to obtain exceptional status.

Financial costs of exceptional designations and nonattainment status were a primary motivator for states to secure a revised and denuded rule. For example, the Texas Council on Environmental Quality (TCEQ), which is the state entity that prepares materials to demonstrate that an event was exceptional, claimed that some of the scientific requirements to show exceptionality required hiring a consultant costing several hundred thousand dollars *per demonstration* (EPA HQ OAR 2018-0365). However, this was minimal compared to the costs of being in non-attainment (from not securing exceptional status for an event) which the TCEQ estimated would be more than $2 million per non-attainment area (*ibid*). These financial costs show the high stakes of how dust is categorized. In a revised rule, states asked for a clear definition of an exceptional event, a description of the expected practices and assessments, and a streamlining of the process of for establishing proof. This ask also was request for a denuded rule. Many Western states felt that the designation process was too difficult, and the burden of proof was too high. The "streamlining" requested was meant to make it easier and cheaper to designate events, and ultimately resulted in a lowered burden of proof (see Chapter 5 for analysis of the rule revisions).

One of the key revisions requested through stakeholder and agency comments was to better define what an "exceptional event" was so that the agencies requesting designation had a better understanding of what they were aiming for. However, the definition and criteria include many contingencies that can be interpreted differently and leave many elements still lacking clarity.

A common-sense example of an exceptional event might be a factory fire that was demonstrably accidental and not the product of gross negligence that had led to repeated fires. As long as state agencies showed that the factory had a causal relationship to the violation and that it was not reasonably preventable or likely to happen again, it would likely gain exceptional status. However, the same cannot be said for many other examples of exceptional events in the West. Take, for example, a dust storm in the arid West that grew especially from public lands with a long history of poor grazing practices and intensities (Donahue 1999). Under the 2016 revisions, this storm would also count as an exceptional event, even if it occurred weekly or had increasing frequencies due to land use practices like overgrazing, as long as "reasonable" prevention measures were in place. The logic here is telling: the designation of an event as natural and therefore unpreventable does not factor in the frequency of events nor the efficacy of the prevention measures. Further, the rule makes a problematic calculus that human actions can be fully mitigated by prevention measures and that this renders them natural. The outcome is very anthropogenic or high frequency events (or both!) that produce significant dust can be designated natural and thus expungable under the EER.

Upon examination, the three criteria for designation are puzzling and questionable at best, problematic, undermining, and contradictory when applied to particular cases. First, while the "clear causal relation" requirement seems prudent, the devil is in the details. One of the revisions no longer requires that states show an event was "in excess of" past events nor that the violation would not have happened "but for" the exceptional event. While these are small semantic changes they significantly change—and lessen—the state's burden for proving the infrequency (and exceptionalness) of an air quality event, and that it caused the violation. Second, states must demonstrate that the event was "not reasonably controllable or preventable," which rests on different logics of reasonableness, all which are political. For example, it is deemed "not reasonable" to control events that cross state boundaries because requiring states to work together to manage air quality is too significant of a burden. Third, while the rule discusses events that are "unlikely to reoccur again" this only applies to "man-made" events and explicitly allows "natural" events to recur frequently. For most, an exceptional event is defined by a lack of frequency, so this naming distorts environmental risk.

The exclusion justifications ultimately play a deciding role in determining what data is designated as exceptional, and thus excluded from the regulatory record. Equally important, exclusion decisions determine which areas are determined to be in non-attainment. The difference between a status of attainment and non-attainment for pollution standards is significant and determines which areas are required to improve their air quality through new management plans and expensive interventions.

Beyond concerns of exceptionality, there are also concerns of the natural. One of the most political, problematic, and challenging aspects of this rule is its reliance on the category of naturalness and "natural events." The third statutory qualification requires an air quality event to be categorized "natural" or "man-made". This criterion raises two questions. First, what does naturalness have to do with exceptionality? Second, what is a natural event? First, under the current rule, all events that are considered natural are also considered exceptional. Of course, this logic relies on an awkward marriage between exceptional and naturalness, but the two are not synonymous. Indeed, events can be natural and common. Thus, even the question of naturalness seems somewhat unrelated to determining exceptional events, even if their natural status remains questionable. This awkward coupling might reflect the fact that air quality regulations were originally intended to focus on "typical" man-made pollution. As a result, dust and industrial accidents are similarly categorized as exceptional—outside the expected norms of regular, intentional practices such as vehicle emissions.

In addition, determining what *is* a natural event is a more complicated task and requires boundary work to delineate the line between nature and people and broad categorization, which often results in inaccurate characterizations. The naturalness of air quality events, however, can be understood as a spectrum, ranging from relatively little human influence, to a mix or hybrid, to clear human causes[35]. Volcanoes, for instance, remain largely on the physical side of the spectrum and factory fires or explosions fall far to the human side. Wildfire events are driven by complicated, intertwined set of human and physical processes making it hard to call them anthropogenic or natural (Pyne 1997; Simon 2016).

The same can be said for dust storms which are driven by a range of ingredients including land use, temperature and precipitation conditions and wind patterns. Dust storms highlight the very impossible task of disentangling the human from the natural in complex systems. Yet, the rule requires this dissection, even if it is somewhat awkward. The rule divides dust storms into two components: "wind" and "soil", as though they can be viewed independently.

> The meteorological phenomenon (i.e., wind) is purely natural and thus can be classified as a natural event, but the pollution from the event may be a mixture of natural sources (e.g., undisturbed soil) and anthropogenic sources (e.g., soil disturbed by human activity, emissions from sand and gravel facilities, etc.). The EPA generally classifies high wind dust events as "natural events" in cases where windblown dust is entirely from natural sources or where all

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[35] Another form of naturalness and boundary work is also at play here. The thresholds used to divide safe and unsafe levels of dust at deeply social. The regulatory concern is assigned to different levels of dust is also shape by conceptions of what is natural.

> significant anthropogenic sources of windblown dust have been reasonably controlled (Interim High Wind Guidance 2013, 5).

Thus, this rule requires dissecting events into their subparts to determine their naturalness. Wind activity is always natural—at least according to the rule—and sources can be either natural or anthropogenic. Yet, even this description highlights how dust storms are not natural, but rather a complicated combination of drivers.

The rendering of complex events like dust storms as natural has been the focus of a number of public comments and litigation. The Natural Resources Defense Council and the Sierra Club sued the EPA over how it designated events as natural and specifically whether recurring "natural" events should be included. At the center of this case were definitions of natural. The opinion explored naturalness explicitly:

> an ordinary reading of "natural event" summons images of natural disasters such as tornados and volcanic eruptions; cosmic episodes, such as comets and harvest moons; and organic processes, such as viral epidemics and seasonal changes. These examples leave little room for human causation (NRDC vs EPA).

Yet, despite this notion that natural events "leave little room for human causation," the rule itself and the court decision both allow natural events to include anthropogenic contributions. If the source and cause of dust is anthropogenic and actions were made to control emissions, then it is considered "natural" because actions were "reasonably" preventing it.

> dust controls on an anthropogenic source shall be considered reasonable in any case in which the controls render the anthropogenic source as resistant to high winds as natural undisturbed lands in the area affected by the high wind dust event (40 CFR § 50.14 2016).

In other words, effort counts over efficacy. Strangely, the greater human intervention is (i.e., disturbance and good faith mitigation) the closer to natural it becomes.

This guidance engages even a broader discussion about how we think of arid lands, particularly those that have been used for livestock grazing. Setting the bar for controls to match a baseline of undisturbed lands requires remaining undisturbed lands and that we know their dust emissions. Many would argue that we have naturalized the conditions of a "degraded" landscape or at least that we might not really know what healthy soils look like in the arid West because of the combination of fragile soils, long and widespread grazing histories, and restoration timelines (Davis 2016; Sayre 2017).

Exceptional in Name Only: Case Studies of Consequences

Examining how the rule has been used, affects data, and alters regulatory action illuminates the consequences of natural exceptions. I turn now to focus briefly on two cases that illustrate the influence of natural exceptions, the manipulation of data, and the new natures—exceptional natures—produced. This analysis explores case studies where the EER has been used (particularly focusing on "natural exceptions" as opposed to infrequent "man-made" exceptions), and examines events deemed exceptional in their broader context. Each case reveals a different element of the politics of the EER's use. The first case (Phoenix, AZ) shows how the rule is employed politically for the explicit purpose of avoiding non-attainment status. The second case (Houston, TX) examines how the way the rule is written makes challenging exceptional status almost impossible and stacks the deck against impacted communities.

Case 1: Maricopa County, Arizona

Phoenix, Arizona has the fifth largest population of U.S. cities and the largest in the Four Corners region. The City describes itself as "unmatched desert character meets big-city sophistication," highlighting its dry characteristics[36]. With only 8 inches of precipitation annually, the City landscape is arid; it is surrounded by deserts with fine and fragile soils. Phoenix also offers a telling case study about how the EER has been by the State of Arizona for the direct purpose to avoid non-attainment status and therefore regulation.

The more than a million and a half people residing in Phoenix have significant exposures to $PM_{10.}$ Dust storms regularly make the local news as they lead to respiratory distress and multi-car crashes on freeways. In fact, after extreme heat and flooding, over the past 50 years, dust storms are the third largest cause of weather-related fatalities in Arizona[37] (Lader et al. 2016; Shoemaker and Davis 2008). Maricopa county, which includes Phoenix, has been in nonattainment for 23 years and its non-attainment status is rated "serious" by the EPA. The state, though, actively downplays this seriousness, describing on their website that the PM_{10} concentrations in Phoenix are "occasionally above federal standards" ("Phoenix PM-10 Nonattainment Area" 2019).

The state claims that above-standard levels are "often…the result of large-scale dust storms, which cannot be controlled." Yet the same document undermines this assertion with many examples of human sources ("Phoenix PM-10 Nonattainment Area" 2019). The listed "sources of pollutants" include unpaved roads, paved roads, construction, unpaved parking lots, and agricultural activities—sources that are in fact are very controllable. The stealthy nature of fugitive dust often evades measurement (see Chapter 3), which makes the causes imperceptible and hard to pin down. Since soil disturbances can result from many different land uses, many narratives work to tie dust different socioenvironmental changes, even if speculatively. One of many potential culprits was the housing boom and following bust in the 2000s. The crash left large portions of the landscape stalled in

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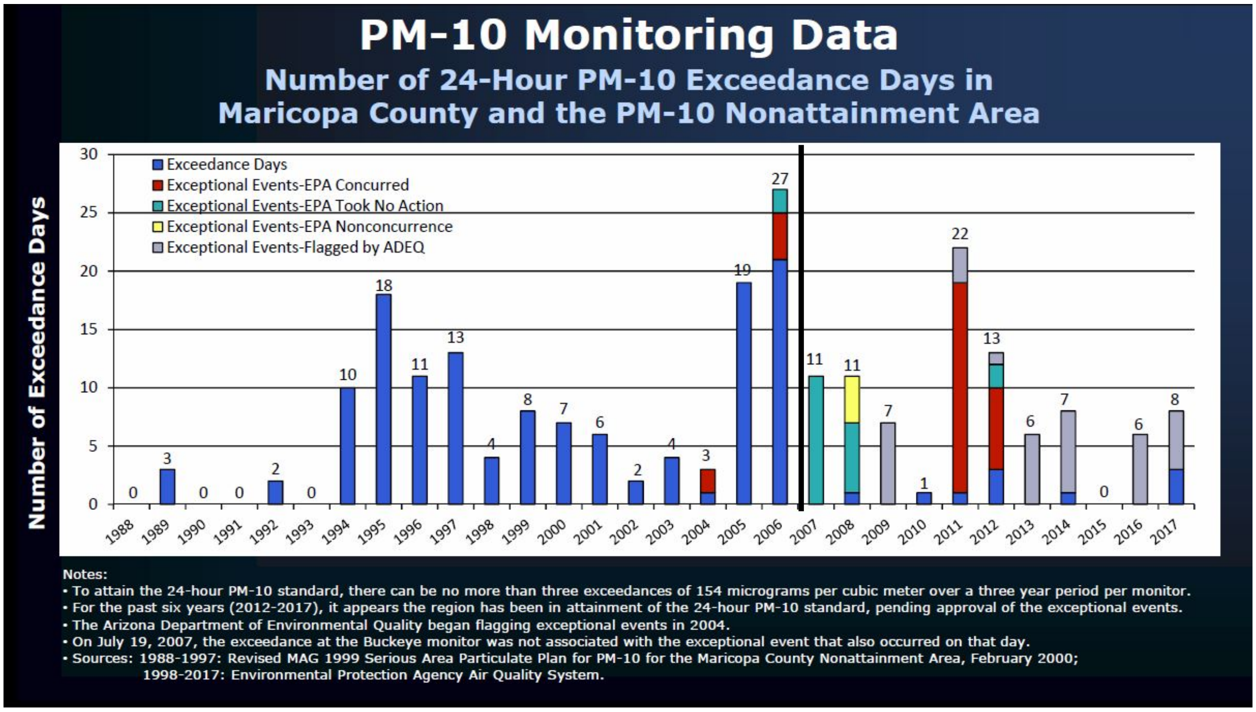
[36] As described in the *Visit Arizona* webpage to support tourism in the state. Retrieved on August 5, 2019: https://www.visitarizona.com/cities/phoenix-and-central/phoenix

[37] The majority of dust related fatalities in this report come from large, multi-car pile ups. However, dust impacts to health are not well studied or understood and are likely not included in this calculation.

partial development where projects had begun but many properties were un-built, leaving disturbed soils. Most land use on fragile soils will lead to dust, so it can be difficult to establish direct causes, but one only needs to examine land use and development in the lands outside of Phoenix to see that human imprints and potential sources abound.

Phoenix, because of its long and intense history with dust (and specifically PM_{10}) nonattainment, is a compelling case study of the impact of the EER. In 2011, Maricopa County applied for 20 exceptions for PM_{10} exceedances, eight in the month of July alone. This raises the question: how have natural exceptions under the EER impacted both the dataset and the attainment status of Phoenix?

This question can be mostly answered by examining the state's own analysis. Fig 6.1, which is publicly available on the state's website, analyzes PM_{10} exceedances in Maricopa County from 1988 through 2017. The first noteworthy element of this analysis is exceedance trends over time. While a clear trend in the quantity of events does not exist, it is clear that the county has had problematic dust levels for decades, levels that potentially could be increasing (average of 5.6 a year from 1988 – 2002 and 8.6 a year from 2003 – 2017) or at least persisting.



PM-10 Monitoring Data

Number of 24-Hour PM-10 Exceedance Days in Maricopa County and the PM-10 Nonattainment Area

Notes:
- To attain the 24-hour PM-10 standard, there can be no more than three exceedances of 154 micrograms per cubic meter over a three year period per monitor.
- For the past six years (2012-2017), it appears the region has been in attainment of the 24-hour PM-10 standard, pending approval of the exceptional events.
- The Arizona Department of Environmental Quality began flagging exceptional events in 2004.
- On July 19, 2007, the exceedance at the Buckeye monitor was not associated with the exceptional event that also occurred on that day.
- Sources: 1988-1997: Revised MAG 1999 Serious Area Particulate Plan for PM-10 for the Maricopa County Nonattainment Area, February 2000;
  1998-2017: Environmental Protection Agency Air Quality System.

Figure 6.1: PM$_{10}$ exceedance days in Maricopa County, including exceptional event designations, requests, and rejections. *Source: Maricopa Associations of Governments (http://azmag.gov/Programs/Maps-and-Data/Air-Quality). Black vertical line indicating when the EER was enacted was added by author.*

The more important element of their analysis is the use of the EER rule. The number of exceptional events significantly increased when the rule was formalized in 2007[38]. Their analysis breaks the exceptional events into four categories: 1) EPA Concurred—which means that the EPA accepted their designation request, 2) EPA Took No Action—meaning the EPA neither approved nor rejected the proposed exceptional event request (which can happen if it is not "regulatorily significant"), 3) EPA Nonconcurrence—the EPA rejected their application for exceptional status, and 4) Flagged by ADEQ—which means either it has been submitted but not evaluated or that a full application was not created but the events were still flagged for EPA review. Just focusing on the EPA Concurred (red), EPA Took No Action (teal), and Flagged by ADEQ (grey) categories

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[38] The categories other than exceedance days (blue) actually start before 2007 when the rule was established. This is likely not because this designation predated the rule, but rather indicative of the long timeframes involved in regulation. It is a time-intensive process and these earlier events were probably designated as exceptional once the rule past to avoid nonattainment status.

shows that the majority of exceedance events are being framed as exceptional, leaving 0-3 events/year as exceedance days since 2007 rather than the original exceedance tallies totaling up to 22 a year. Importantly, the Clean Air Act NAAQS allows three exceedances averaged over three years and that standard appears to be influencing exclusion patterns. For example, 2017 had three exceedance events, but 2015 and 2016 had none, so the recorded exceedances fall *below standards for nonattainment.* This is part of a larger pattern produced through recategorizing exceedance events.

The consequences of this become more obvious in the second note of the figure, which states that "for the past six years (2012-2017), it appears the region has been in attainment of the 24-hour PM_{10} standard, *pending approval of the exceptional events*" (emphasis added). The number of events has not changed nor improved, but the events have been reframed—powerfully so—in a way that removes them from the regulatory sphere and produces a new story, a new nature. The state's own figure shows how they are manipulating the data to achieve specific regulatory goals, but creating new categories and dividing up exceedance events decreases exceedances in name only -- they are still occurring, just with new titles that allow them to be ignored.

Case 2: Houston, Texas

Houston may be one of the most contested sites for "high wind dust storm" exceptional event designations. The City has a long history of seasonal dust storms originating in the Saharan desert and significant industrial pollution, both which fall under the same pollution category of particulate matter and are measured together. It also is one of the few cases[39] where the exceptional

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[39] It is hard to find these cases because there is no national database of exceptional events materials and not all state governments post the community dissents. There also are not as many community dissents as in other cases because these exclusions are not often something communities are aware of. I have found another example of the Sierra Club in Kansas also fighting the designation: http://kansas.sierraclub.org/chapter-calls-for-epa-to-deny-request-to-exempt-pollution-from-flint-hills-burning/. Others likely exist, but I am not aware of them at this moment.

classifications have been contested by civil society. This case offers insight into how the rule makes exceptional status nearly impossible to overturn. The burden of proof to contest exceptional status was already high under the original rule and the 2016 rule revisions raised it further out of reach of community groups. Under the rule, proving that an event is typical (i.e. not exceptional) carries a significantly higher burden than designating it as exceptional. The result is that legally fighting exceptional status is an uphill battle with little chance of victory.

A collaborative effort from non-profits protested designations based on their lack of exceptionality. The Air Alliance Houston and the Lone Star Sierra Club chapter in collaboration with the Texas Environmental Justice Advocacy Services (TEJAS) and Public Citizen—Texas Office mounted an appeal to the EPA against the designation request for exceptional events in Houston made by the Texas Commission on Environmental Quality. Their main points primarily focus on the meaning of exceptionality and how it is incongruous with the events it is applied to because they are in fact common, and thus not exceptional.

The appeal focused on fine particulate matter ($PM_{2.5}$)[40] levels over three days in June and July 2010. Fine particulates are subject to two sets of regulations: one that focuses on daily (24-hour) averages and one that focuses on the yearly average, which often results in an event being a violation of one but not the other. For example, a factory fire might cause a violation of standards for particulate matter the day of the fire but not violate the annual standard because it got averaged out with low pollution days. The contested case in Houston was the opposite; all three days in question were *individually below* the 24-hour standards but together bumped the annual average above standards. All three events fall below 24-hour violation levels raising significant questions about

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[40] The definition of dust is not well defined (see Ch. 2), so while many people think of dust as PM10, PM2.5 can also include particles that would be considered dust but likely mixed with a greater concentration of particles made through combustion (by cars, industry, etc.). In general, smaller particles travel much further and might be considered "fine dusts" from further sources than larger particles that might represent regional or local dust systems.

whether they can be considered exceptional while not in violation. The argument was that "removal of these days would artificially bring the designation of the Houston area to 'attainment' even though ambient concentration of particulate measured in the city is above" the annual standard (Shelley et al 2013, 1). Further, the plaintiffs claimed, the events in question failed to meet the rationale for exceptional events and were unsupported by data.

The main argument put forth was that the events were not exceptional because they fit within historical variation and were part of seasonal events. Further, they argued that industrial emissions should decrease so that air quality remains safe. To challenge the TCEQ request, the complainants presented a number of statistical analyses to show that the events in question were common, expected, and typical. Most analyses drew on a full, unaltered, distribution to highlight high frequency of peer events and place these individually-framed events into their larger context.

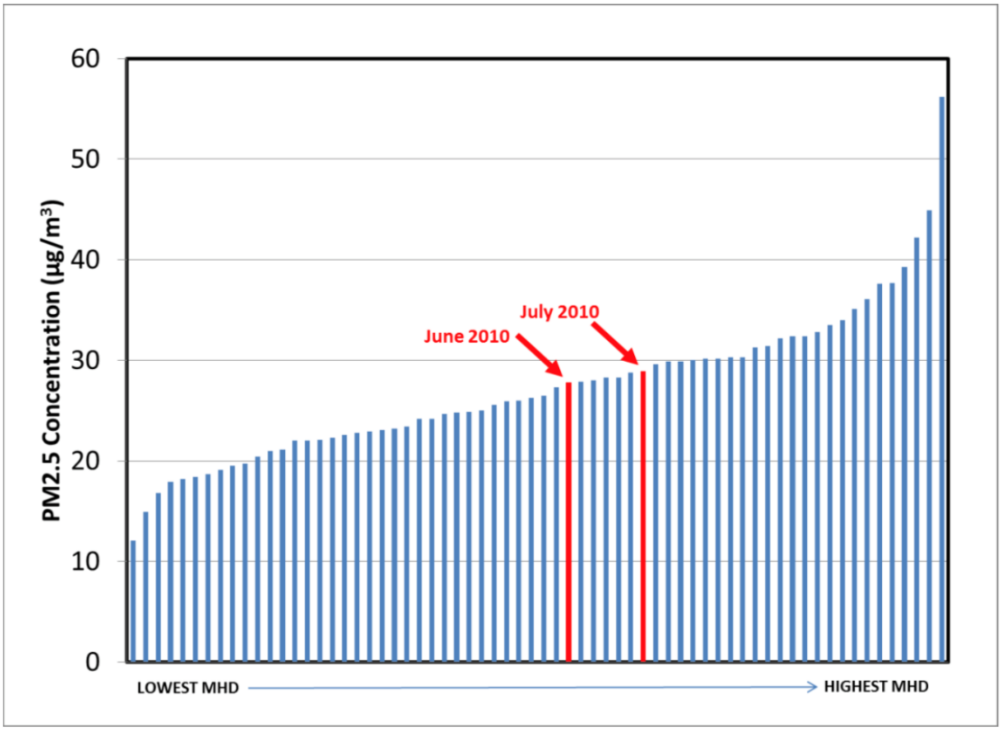
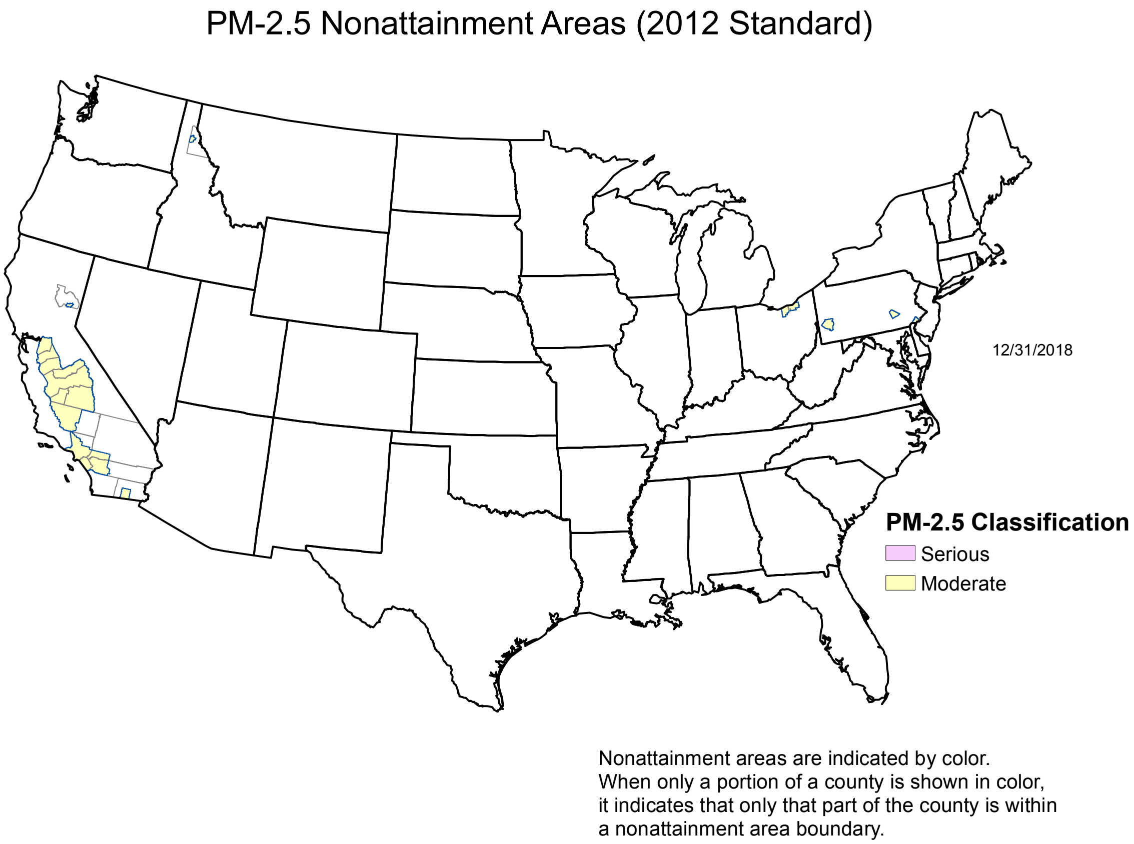


Figure 6.2: Daily Average Concentrations of the 66 Monthly Highest Days from 2002-2012. *The days in question are highlighted in red to show their placement among historic extremes* (Shelley et al. 2013).

For example, Figure 6.2 shows that these events fall within the typical range for the past decade; that they are not even at the far end of the tail of the distribution nor among the more extreme events in the system. The appeal argues that these events are part of a regular, predictable, seasonal phenomenon where African dust is transported to Houston. If Saharan dust events have occurred in Houston for more than 100 years, can an event be considered exceptional?

Ultimately, these analyses led the appellants to conclude that the events in question are "hardly the kind of singular, special, or rare event[s] for which the exceptional events regulations were written, and it is part of the background for this region" (Shelley et al. 2013, 2) and therefore should be included in the regulatory calculus. Critical to their argument is the assertion that even if events are "natural," if they are regular and part of the areas baseline, the *anthropogenic* sources should be limited so that air quality is maintained at a safe level. Those sources, they argue, are reasonably controllable. In other words, if "natural" particulate matter (dust) levels are high, the emphasis should be on reducing the anthropogenic sources (i.e., industry, cars, etc.) to accommodate dust, not expunge the natural dust from the record and pretend it does not exist. Dangerous air quality is the only outcome from this type of pretending.



Nonattainment areas are indicated by color.
When only a portion of a county is shown in color,
it indicates that only that part of the county is within
a nonattainment area boundary.

Figure 6.3: EPA PM2.5 Nonattainment map. Note that no counties in Texas are in either serious or moderate nonattainment. From U.S. Environmental Protection Agency. Green book. (January 31st, 2019) https://www3.epa.gov/airquality/greenbook/mappm25_2012.html

The coalition of environmental organizations argued that TCEQ was using the exceptional events rule as a way to administratively circumvent air quality regulations. In response to their comments, the EPA sided with the state (TCEQ) and excluded all events in question. The impacts of this decision are clearly apparent in the EPA nonattainment map (Fig 6.3), which show no non-attainment designations in Houston—due to these and other exclusion—nor in the rest of the state. Despite 100 years of experiencing Saharan dust storms coupled with emissions from the numerous, large oil and gas refineries in Houston, the area appears safe from dust on the EPA map.

The comments were written against the exceptional designations under the first iteration of the rule (the 2007 version), which carried a higher burden of proof for states to prove exceptionality than the revised rule. Under the revised rule (2016), the same arguments could not be made because the burden of proof has been substantially lowered. For example, their main argument centered on how these events were not "in excess of" historical fluctuations nor infrequent (and thus not exceptional). Both of those standards were in the previous iteration of the rule and were removed under the current one[41].

Leveraging of the EER to avoid non-attainment status, and difficulties that activists face in challenging the EER, are not limited to big cities like Phoenix and Houston. Even small agricultural communities with longstanding dust histories that include the effects 1930s Dust Bowl face these issues. This illustrates in a rural context how the EER ignores well-known histories of place and a variety of land use trends, bringing grazing practices to the fore in addition to suburban development, and calling our attention to the ever-presence of "local" dust in addition to dust from the Sahara. Examples include Lamar, CO, Deming, NM and Ajo, AZ[42].

Exceptional Natures

The two cases above clearly demonstrate the consequences of the EER in different contexts. Specifically, they show how the EER is employed to meet political ends—namely attainment status (Case 1), and how the way the rule was revised makes it easy to dismiss questions about problematic exclusions. or contestation of exceptionality (Case 2).

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[41] Additionally, these events surpass standards for $PM_{2.5}$, which are finer particles than the PM_{10} events in Lamar and Maricopa. Generally, smaller particles travel further, so local and regional dust is often larger (i.e. PM_{10}) and global dust events like the Saharan events experienced in Houston are finer (i.e. $PM_{2.5}$). While they have important differences, including different standards, both can be elevated by dust storms.

[42] The Arizona Department of Environmental Quality (ADEQ) highlights a similarly political use in the rural southern part of the state to what it used in Phoenix. "The concentration of PM_{10} in the air in Ajo has been below federal standards for several years. ADEQ is developing a re-designation request so that EPA will reclassify the area as an attainment area. As part of this request, ADEQ will provide an updated emissions inventory, modeling demonstration, *strategy for Exceptional Events and rules for PM_{10} controls*." Retrieved at: https://azdeq.gov/ajo-pm-10-nonattainment-area

As we see, repeated regulatory "natural exceptions" that prune outliers from the regulatory dataset render such data partial and, importantly, skewed. Typically, a distribution of data from an environmental system shows the frequency of different types of events and how much variability is in the system. The tails of the curve, or the extremes, provide important information about how intense extreme events are in a system and how likely they are to occur. Similarly, calculating standard deviations on distributions can analyze how often events deviate from the norm.

A distribution that has all of its extreme events removed will seem to have very limited variability, small standard deviations, and little evidence of extremes. A partial dataset is an inauthentic representation of nature, or a disingenuous nature (Simon 2018), because it hides a more accurate and empirically substantiated record of dust levels.

> "Disingenuous natures are the management interventions and coinciding social-ecological conditions that emerge from faulty science, partial data and erroneous environmental narratives. They are disingenuous because – despite being constructed by surreptitious knowledge – they are understood and managed as if they were a legitimate, authentic and thus genuine depiction of social-ecological conditions" (Simon, 2018, 72).

Critical to the concept of disingenuous natures is how partial or incorrect information works to produce representations of nature that do not reflect reality, and despite this are accepted as truth. As Simon notes, in many cases the elements that undermine the accuracy of understanding nature (i.e. partial data or problematic narratives) are often obscured, implicit, and hard to see from the outside. The most significant consequences arise not just from a misunderstanding of nature, but when these disingenuous natures harden as they are written into laws and regulations, in many cases altering the systems materially to represent these distortions (Simon 2010). It is at the science-policy nexus that disingenuous natures particularly wreak havoc (Kleinman and Suryanarayanan 2013; Sayre 2017; Sedell 2019).

Creating “natural exceptions” through the Exceptional Events Rule has an important unintended consequence: it inadvertently produces “exceptional natures.” That is, natures that regardless of their frequency and existence are considered rare. By repeatedly removing data and undermining the quality of the dataset, our understanding of normal or expected events—like dust storms—changes. In the words of Pine and Liboiron, “exclusion *makes* things” (2015, 3).

Exceptional natures are similarly disingenuous—or partial, erroneous, and faulty— while being legitimized by regulatory actors who treat them as genuine in their management actions. Thus, data that shows dust storms as rare, unlikely, and improbable are based on faulty information and partial data, but still used by the EPA in their attainment designations. Simon offers a compelling concept in disingenuous natures, which can be multifaceted with its distortions that alter representations of nature in different ways, some more intentionally than others. Particularly sharp is the attention to furtive influences that produce these disingenuous natures and how they do work in the world when taken up in management and regulation. Disingenuous natures are quite similar to exceptional natures as they both key into why, and with what consequences, misleading representations of nature emerge.

However, exceptional natures are more specific about the type of distortion that changes how the behavior of an entire system is understood and focus on produced rarity and unusualness that is largely fictitious. Exceptional natures alter how we think of a system behaving, specifically in terms of variability and extreme events (Figure 6.4). Natural hazards are one lens to look at extreme events and exceptional natures. Risk analysis of natural hazard requires understanding a probability that an event is likely to recur, which is estimated based on historical frequencies. While this method has clear biases and limitations (most notably that historical variability may not represent future variability as climate changes), it is how risk assessments determine where is safe to live, how many resources should be allocated to hazard mitigation, and ultimately how much risk a system poses.

Exceptional natures can be applied to different hazards to highlight the consequences of viewing hazards as unusual, rare, and low risk when they actually present a much larger risk. Similarly, exceptional natures are a sharp analytic to examining *changing* distributions during the Anthropocene, which might produce even more exceptional natures as many scientists predict extreme events will increase in the future. Thus, distorted notions of unusualness stemming from exceptional natures may obscure important clues of environmental change.

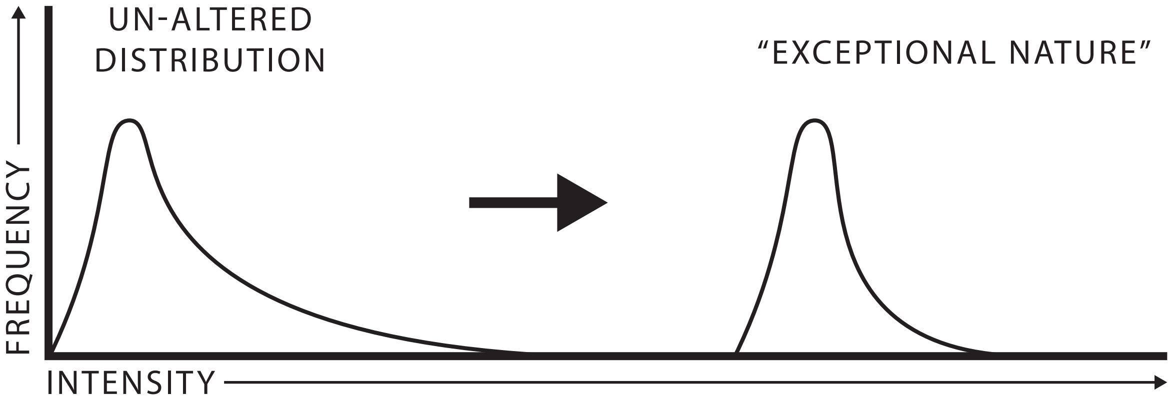

Figure 6.4: The Production of Exceptional Natures. This figure shows (A) a positive skewed distribution (left), as you see with many natural events including dust storms, with a long tail of low frequency, high intensity events, or exception events, and B) a similar shaped distribution (right) that lacks its tail of extremes and has a much smaller variability. If extreme events are removed from the original distribution (A) you produce a new distribution (B) which is an exceptional nature.

It is worthwhile to examine the meaning of "exceptional" since in this context it does important work. Exceptional is defined as rare, atypical, or uncommon[43], unusual and not typical[44], and not likely to happen very often[45]. While it carries a second definition, of superiority (e.g. an exceptional student), its primary definition means uncommon. In the case of the rule, exceptional

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[43] In the *Merriam-Webster Dictionary*: https://www.merriam-webster.com/dictionary/exceptional

[44] In the *Oxford English Dictionary*: https://www.oed.com/view/Entry/65727?redirectedFrom=exceptional#eid

[45] In the *Macmillan Dictionary:* https://www.macmillandictionary.com/us/dictionary/american/exceptional

events are specifically tied to a low recurrence frequency, which largely negates this second definition. Based on this primary definition, events that are both common but not recorded appear very exceptional when looking at a distribution based on partial data.

Exceptional natures are produced in two ways; they are created both through our explicit framing of them, and by our manipulation of the data so they appear as an outlier. In other words, we make these exceptional by calling them such. Similarly, when we call something an extreme event or a 100-year flood, we make it seem unlikely, out of the ordinary, and unexpected. Naming events as exceptional does important discursive work in how it shapes our understanding of both individual events and the system on a whole.

However, these events are not only made exceptional discursively, but they also truly become exceptional—at least based on the problematic dataset—because they lack peers and deviate from a norm in a system that appears to have low variability. By erasing the other extremes in one-off "natural exceptions," the data left all remains close to the average, and importantly *under* the regulatory threshold for a violation. Thus, each new extreme event appears as an outlier (see Figure 6.5); the more extremes are excluded the easier it is to continue to exclude future extremes. As Bowker (2000) reminds us, the database—and one with manipulated data in this case—will "shape the world in its image: it is performative" (675). Particulate matter pollution maps that show no history of air quality violations present safe air quality and where you do not expect to have regular violation events. In response, people with health sensitivities like asthma may move there and fictious understandings of rarity might increase the risk. In this way, their classification of exceptional—a discursive tactic—becomes justified through their exceptional, or outlier, relationship to the data. Exceptional natures are made both through naming and making evidence to support their naming.

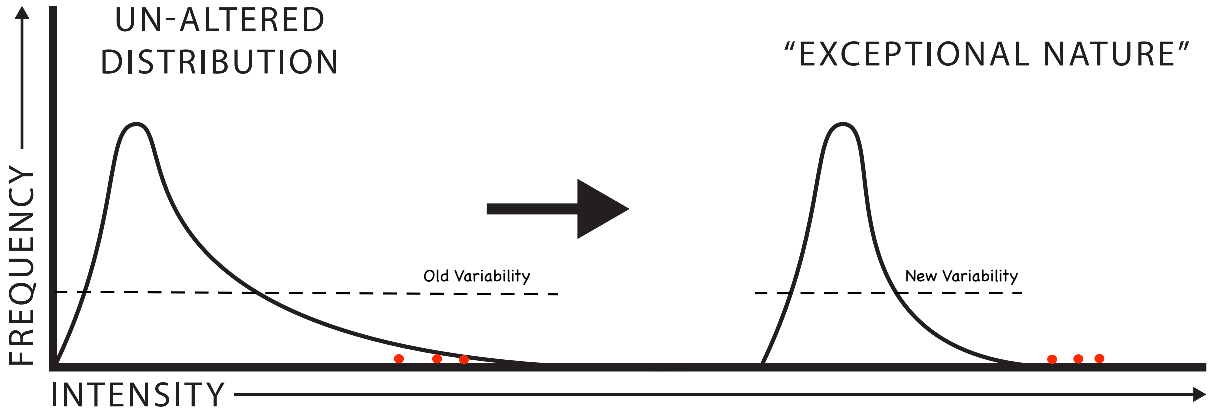

Figure 6.5: Continued Reproduction of Exceptional Natures. This figure shows three exceptional events (red dots) in an unaltered distribution (left) and an altered distribution (right). The dotted line represents the variability in system, which is significantly larger in the unaltered distribution because it includes extreme events. This figure shows how in the unaltered distribution all three extreme events fall within the historical variability, but in the new exceptional nature distribution these events fall outside of the variability of the system, making them *appear unmatched, abnormal, and exceptional.*

The EER can become a tool for state governments to avoid regulatory recourse and accountability. States can—and are—using the rule to ignore and exclude events, reshaping regulatory systems. The aim of the Clean Air Act was to protect communities against air quality above safe standards, and this rule is creating a significant loophole that allows states to avoid the consequences of bad air quality. States are using the EER in ways that serve them by helping them avoid fines and higher management requirements, but this works against the people they are charged with protecting by allowing repeated, and unknown, exposures.

This paper reveals a recursive process, which reproduces and maintains exceptional natures through discursive and material work. Calling events exceptional justifies their exclusion from the dataset, and these exclusions, in turn, *make* extreme events appear more exceptional then they truly are. They take abstract concepts of exceptionality and produce concrete exceptionality. With each exclusion, it becomes easier to exclude future events as the legacies of variation and causality disappear. In this way, reproductions and reifications "create actual 'permanances' in the social and material world around us" (Harvey et al. 1996, 81). Scientific knowledge, and the planning and regulatory actions based on it, can be considered 'permanances' because of how they further ingrain exceptional natures into our policies, actions and perceptions (Simon 2018). These permanaces—like the EER—can make exceptional natures not only widespread and reproduced, but also hegemonic.

Ironically, exceptional natures are both produced through environmental regulations and simultaneously undermine them. The EER asks state and federal regulators to carry out a process to designate and name air quality events as natural and exclude these events, a twofold production of exceptional natures. However, the primary mission of the EPA is to protect humans from environmental harms, which is undermined by repeatedly excusing harmful events hide the true exposures and risk of southwestern communities. Furthermore, exceptional natures lead to regular and repeated surprises, unnoticed hazards and signs of environmental change, and undetected exposures, all which trouble and thwart regulatory efforts to protect public health.

Conclusion

By employing categories of "natural" and "exceptional," the EER allows for data exclusions that in turn create Exceptional Natures. New natures are a distorted representation of environmental variability: the repeated removal of outliers makes events that are sometimes common appear rare. Yet, since the data in question is part of regulatory monitoring, the consequences stretch past discourse and representation. Exceptional natures are changing regulation in ways that halt regulatory action, hide exposures, and may lead to greater air pollution.

This analysis and the cases show the important role that categories and data exclusions have in producing regulatory ignorance and inaction. Troubling categories can be harnessed to justify the exclusion of data, that produce these exceptional natures, which then are transforming the material world. The formation of categories is always political, but especially so when embedded in laws and when used to alter data.

Research on regulatory ignorance has importance in this political moment marked by political efforts to decrease regulation. In an era where the EPA is changing the math on how to calculate risk and exposure and changing what counts as evidence (Friedman 2019), critical scholars need to explore the data involved in regulation— its use, management, and exclusion. Diving into the calculations and the intricacies of data help expose *how* regulatory ignorance is produced and highlight the critical but often black-boxed politics upstream of scientific assessments. Further, while political ecologists have long challenged categories that rely on false dualisms conceptually, more attention needs to be focused on the role these categories have in producing ignorance, particularly when written into law.

This work is not only particularly relevant due to the current political climate, but also environmental changes where the variability and behavior of environmental systems are expected to change and transform. More specifically, the Anthropocene will likely usher in greater extremes, and data exclusions like those described will limit our ability to detect and respond to emerging hazards. Combined, exceptional natures and increasing variability has the potential of leading to greater distortion of system behavior and likely to more surprises and unanticipated events, ultimately undermining climate adaptation, environmental laws, and infrastructural projects. Future work should explore this intersection—exceptional natures and the Anthropocene—to illuminate how regulatory ignorance is generated about the impacts and risks from climate change.

CHAPTER 7

CONCLUSION

This dissertation explores the politics of inscrutability in environmental knowledge through the lens of fugitive dust in the American Southwest. I started with the question: why is fugitive dust able to escape many elements of scientific and regulatory knowledge? Said differently, why did fugitive dust remain inscrutable? This question led me to engage with inscrutability and inscrutable natures more broadly, to trace their production to their consequences.

To illuminate the inscrutability of dust, I did not just focus on the outcome, such as ignorance (Proctor and Schiebinger 2008) or a lack of knowledge, but also on how it came to be that way or was produced. Inscrutability is not just an end product, or something that is not known, but is a condition stemming from the knowledge systems in which it operates. Inscrutability is shaped by limitations in knowing and refers to something that is impossible to interpret or understand in a specific context. In this way inscrutability focuses on the process of knowing rather than the outcome and requires opening up the black box of knowledge production. But rather than looking at how we know nature (Goldman, Nadasdy, and Turner 2011), inscrutability reflects how we are unable to know it. Instead of asking questions that start with dust as unknown, I was motivated to understand the upstream processes that made it that way. How did this lack of knowledge come to be, and how did natures—dust in particular—become unknowable?

I traced the processes that produced inscrutability and, it turns out there were many. Inscrutability is not produced in just one way. To analyze the different ways it is made, I built a typology that keyed into 4 types of inscrutability: *disciplinary, intentional, material and discursive.* These four types overlap, converging and diverging, with one often leading to another, or multiple types working in tandem.

This typology speaks to more than just fugitive dust. While it came to fruition through deep analysis of the specific case of dust, the types of inscrutability speak to a greater set of questions about why some natures are beyond reach of knowing. By examining the many different dimensions of why dust remained fugitive from so many different angles, the types became clear. In this way, my dissertation is ultimately about a politics of inscrutability in environmental knowledge; it has required a deep engagement with dust's inscrutability to highlight more foundational processes. Thus, my research has constantly tacked back and forth between examining the intricacies and specifics of dust to thinking generally about environmental knowledge. This dual engagement refined and sharpened both aims as thinking about systems beyond dust helped me ask new questions of it and trace new threads, and the concrete findings about what rendered dust inscrutable helped me engage with a subject that is abstract and often hard to theorize and study (Frickel 2014).

The four types of inscrutability ran through each of my chapters, intersecting and splitting in different ways, but all contributed to dust's inscrutability. Since the processes that produce inscrutability do not operate in isolation, my chapters do not each map onto an individual type but are a product of entanglements of many. Collectively, different modes of production—different types of inscrutability—kept dust inscrutable. Each chapter highlights an important piece of the story, but together they make dust deeply knotted and entangled in ways that keeps it from being fully known.

Chapter 2 examined how an accepted ambiguity about "what is dust?" and more specifically about a working and collective definition for dust, stalled a greater understanding of dust. A lack of definition made dust inscrutable in two ways: it prevented a cohesive field of science around dust, which slowed new scientific findings, and it made the problem of dust hard to decipher. This chapter highlighted the politics of defining nature and the entanglements between disciplinary and material inscrutability.

Chapter 3 analyzed how and why the Clean Air Act (CAA) monitors systematically miss or under detect dust storms. This analysis showed how instrument design, specifically with a focus on small, ambient, and urban particles, made broader dust trends inscrutable in both scientific and regulatory spheres. This inscrutability was largely produced through disciplinary forces but also through material forces because instruments failed to engage with dust's movements through time and space.

Chapter 4 examined the unequal monitoring patterns that left dust largely unmonitored on the Colorado Plateau. It traced unquestioned assumptions and logics that led regulators to think of rural places as unpolluted and undeserving of monitors and highlighted the circular logic that trapped rural communities in unequal access to exposure information and regulatory recourse. This chapter was entangled in discursive inscrutability centered on the false divides of nature/culture and urban/rural.

Chapter 5 and 6 both focused on how the Exceptional Event Rule's exclusion of air quality violations produced inscrutability about air quality, exposures, and changing extremes. Chapter 5 analyzed *how* the 2016 revisions of the EER changed the criteria for exceptional events and led to more events being excluded from the regulatory record. Through deep discursive analysis of the rule, this chapter highlighted how altered exclusion criteria made changes in air quality and exposures inscrutable. The EER rendered dust inscrutable through intentional actions of states excluding air quality violations and the EPA allowing them to do so, as well as through discourse in its reliance on categories that are somewhat ill-defined and carry multiple meanings (i.e. natural, exceptional, reasonable, etc.).

Chapter 6 took the next step to examine the *consequences* of these exclusions, particularly how they reshaped our understanding of dust variability and produced exceptional natures. Exceptional natures, which are distorted pictures of environmental systems where common events are considered rare, have broader consequences for how we regulate air, calculate risk, and express safety, and may actually lead to increasing air pollution exposures. This distortion made the true air conditions inscrutable through categories and data politics, which were largely as a result of intentional actions as well as discourse.

Contributions

As I previously acknowledged, questions about dust's inscrutability are enmeshed in larger questions about how we know and do not know our environment, and with what consequences. Thus, research findings make dual contributions. Findings contribute to better understandings of inscrutability, how it is rendered and what consequences it has in science, regulation and society more broadly. Findings also contribute to the case of fugitive dust in the Southwest, an issue with high stakes that I have explored intimately.

Theoretical Contributions

The politics of inscrutability do not only impact dust, but are pervasive in other areas of environmental science, particularly those on the edge of regulatory systems or part of large, hard to know spaces like oceans, outer space, the subsurface or atmosphere (Kroepsch and Clifford 2017). Environmental science and knowledge of environmental systems can be messy, hard to categorize and differs in important ways from lab-based science (Goldman et al. 2011; Kohler 2002; Kuklick and Kohler 1996; Latour 1999). Field-based research increases "the complexity of the research endeavor, the diversity of knowledge claims, and the persistence of scientific uncertainty. Such complexity is associated with a *multiplicity of knowledge productions"* (Goldman and Turner 2011, 26 emphasis in original). This similarly impacts inscrutability and what is left unknown.

Consistent with Murphy (2006), I observed how inscrutability functions within the same domains and regimes as imperceptibility: the limits to what can be known based on knowledge fields (domains), but also the larger forces (regimes) that direct knowledge to evolve in the way it does, the series of decisions that render some things within reach of knowing, and others out of reach. My work is not only consistent with her theories, but highlights how there is more than just disciplinary and intentional drivers at play by bringing in the materiality of the focal nature and taking it seriously. I also take seriously spatial and temporal forces that shape inscrutability (Sedell 2019). Rather than being different or in contrast to Murphy, I come at the question of inscrutability from a different vantage point of thematic types rather than domains and regimes. My approach might offer a new lens to view what can't be known that might be more suited for examining and explaining different inscrutable natures than regimes of imperceptibility.

This research also contributes to a growing – and timely—field of regulatory ignorance and uncertainty (Frickel and Vincent 2007; Kleinman and Suryanarayanan 2013; Ottinger 2013; Wylie 2018). Unknowns in the regulatory system can be more acute than in other spheres because regulatory science sits at the nexus of knowledge and action. More traditional forms of scientific knowledge have their production separate from their application, often to the frustration of scientists wanting their findings to be policy relevant and influence decisions. Regulatory science, however, has much less space between the two. Data from a regulatory monitor triggers action directly. It is knowledge generated to guide action. Inscrutability in regulatory science thus leads to inaction in much more direct ways than in other fields of science.

The recognition that inscrutability affects action and application moves questions from the study of knowledge (and in the field of STS) to questions of inequality and unequal consequences (and the fields of political ecology and environmental justice). Inscrutability is important for understanding and rectifying issues of environmental justice. A lack of knowledge about an emerging issue, an ignored issue, or a new technology hinders the ability of communities to engage in decision making, which is an issue of procedural justice (Gwen Ottinger 2013), and generates broader inequalities (Frickel, Gibbon, Howard, Kempner, Ottinger, and Hess 2010). Thinking this way, brings inscrutability to the heart of critical studies of the environment, its resource allocation, conflicts, injustices, and understandings.

This approach to examining the politics of inscrutability may offer insight and analytical power for other branches of environmental science and perhaps scientific inquiry more broadly. Is the structured erasure of an obvious air pollutant repeated in other areas of the science-policy nexus? Findings can help us rethink how we defer to expertise and instrumentation over informal ways of knowing and rethink the structures and protocols that create a circular relationship of regulations shaping science, and science in turn shaping regulations. Many of our scientific protocols used to measure elements of the environment may be ill-equipped to detect unanticipated changes and blind us to new, emerging issues of environmental change, stunting efforts to respond. This is likely not confined just to dust, and investigation into other complex environmental systems—like groundwater, climate, or oceans—might point to an underlying pattern and highlight a more universal phenomenon. While I have focused on dust and environmental systems in this analysis, these types of inscrutability might offer analytical power to inquiries beyond human-environment geography. Future work should explore new cases in different contexts to build upon this typology and perhaps identify new threads and themes beyond the four types I have explored.

Broader impacts for the management and study of dust

While this dissertation makes contributions to theories of inscrutability in environmental knowledge, it also illuminates regulatory gaps in the management of fugitive dust. This research addresses a salient issue in Southwestern communities and may offer insight on a path forward.

Fugitive dust is a multifaceted problem for those in the Southwest, with impacts spanning from public health to natural resource management. Both short- and long-term exposures to particulate matter increase mortality and morbidity (Anderson, Thundiyil, and Stolbach 2012; Dockery et al. 1993; Pope et al. 1995). Furthermore, particulate matter generally, and dust specifically, has an important effect on water resources and security (Deems et al. 2013), visibility in protected areas (Sisler and Malm 2000), transportation safety (Morganroth 2017), and respiratory infections such as valley fever (Tong et al. 2017). Climate models predict increased aridity particularly in the Southwest (Cook, Ault, and Smerdon 2015; Prein et al. 2016; Schubert et al. 2004; Seager et al. 2007), which will produce more dust (along with changing land use patterns) and increase the risks associated with dust.

Dust is an issue of the environment, economics, water security, culture, health, and it is not a stretch to say it is sometimes an issue of life or death. It is a nuisance, a risk, and part of the environment. Just as dust itself is hard to define, so are the issues related to dust, because dust does many different things.

The consequences associated with fugitive dust are not equally distributed. Rural communities are largely left unmonitored for dust events. This not only removes their ability to know dust levels and act accordingly (if they have that privilege and the ability to remove themselves from exposures), but it also removes them from regulatory recourse. This double burden of not knowing and not being able to react and mitigate leaves rural communities with little agency. However, this is not just a case of rural inequities. Urban areas in the Southwest are also being exposed to more dust than is deemed safe by public health records, which impacts significant populations. And, in the Southwest, both urban and rural communities are largely in the dark as to dust exposures, risks, consequences and trends.

I analyzed key gaps, maladaptations and unintended consequences of how the CAA monitoring network and regulations are being enacted in the Southwest. Alongside critiques and illumination of gaps, I offer specific and feasible recommendations that can improve monitoring and management of dust at many different scales and across multiple aspects of the CAA. These improvements may help Western communities begin to confront and mitigate the challenges associated with dust.

Dust's inscrutability allows it to hide in plain sight and hinders both new knowledge and management. This research highlights an important, current regional issue that deserves attention. My analysis helps us understand how we got to a place where our ability to understand dust was impeded, or at very least partial. By shedding light on knowledge gaps and regulatory issues in regard to dust, we can begin to either make it known or at least recognize the uncertainty surrounding it. This illumination also makes it easier to make dust more scrutable and thus able to be managed.

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APPENDIX A:

QUANTIFIED SPATIAL GAPS IN PM_{10} MONITORING IN THE FOUR CORNERS STATES

Overview

This appendix presents spatial analyses of the PM_{10} monitoring in the Four Corners states that quantifies spatial inequities at the state level. Since PM_{10} monitoring maps are not available at the national or regional level, I worked with Joe Trucillo to not only map the monitoring locations but conduct spatial analysis that quantified the difference in how well communities were served. I am very grateful for Joe's work on this project.

Analysis was conducted at the state-level because that is the unit that air quality is regulated. Take, for example, a community that sits adjacent to a state border. The community might only be miles from a monitor, but if it's in another state, that data is not relevant to the community and they have to draw from their closest monitor *in state*, even if its hundreds of miles away.

Visual examination of the spatial trends of PM_{10} monitor locations in the Four Corners states clearly shows that there are spatial gaps and that monitors are not evenly distributed. The Colorado Plateau has a glaring gap in monitoring. Further, the difference in quantity and density among states is significant.

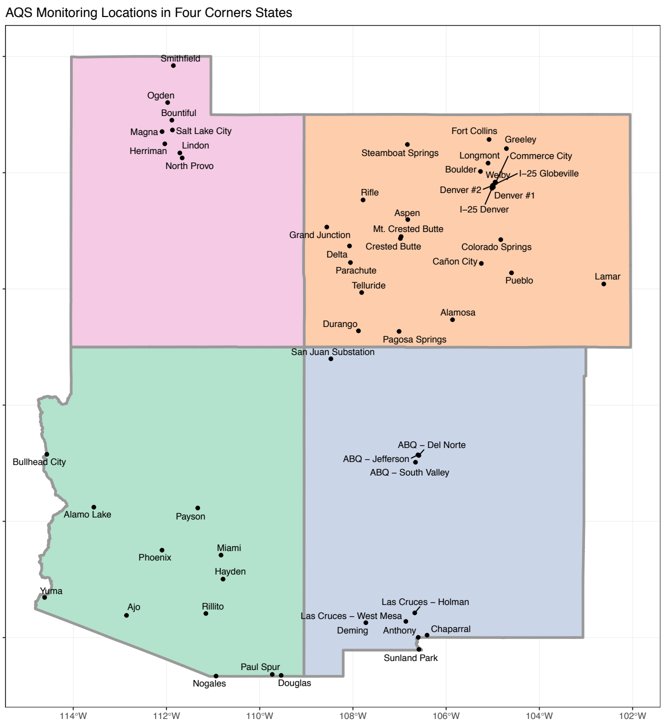


Figure A 1.1: Map of PM_{10} Monitors in the Four Corners states.

However, there are limits to how much can be said by just looking at gaps. How unequal are these patterns? That is a question that cannot be answered through looking at the map. What can spatial and quantitative analysis offer for measures of inequality? What is the difference in access to monitors within and among states?

This analysis starts from this map of the Four Corners and their PM_{10} monitors and examines the spatial patterns more closely to illuminate spatial inequalities to both access of information (about exposures, risk and dust) as well as regulatory recourse (since all regulatory actions require a violation which can only take place where there are monitors). In the remainder of this appendix, I offer individual state-level analysis of PM_{10} monitoring patterns and a discussion about how this contributes to thinking about spatial inequities and issues of rural environmental injustice.

Approach

To quantify the difference in access to monitors—or spatial inequities—service areas were created. These were unique polygons that divided up the area of the state based closest area to a monitor. In other words, we found the nearest monitor to all communities (or Census Designated Populations (CDPs)) and then grouped the CDPs based on that metric. This allowed us to quantify how large of a space, how many CDPs, and how many people a single monitor served and compare across service areas.

For each for the Four Corners States (Arizona, New Mexico, Utah and Colorado) two sets of spatial analysis was conducted, producing two maps. The first divided the states into services areas (i.e. boundaries drawn to reflect all the area that is closest to that monitor rather than other monitors). The second calculated the distances between each CDP and its nearest monitor. It is important to note the spatial representativeness intended for monitors; regulators told me that monitors were only accurate and representative to 4 KM.

Results

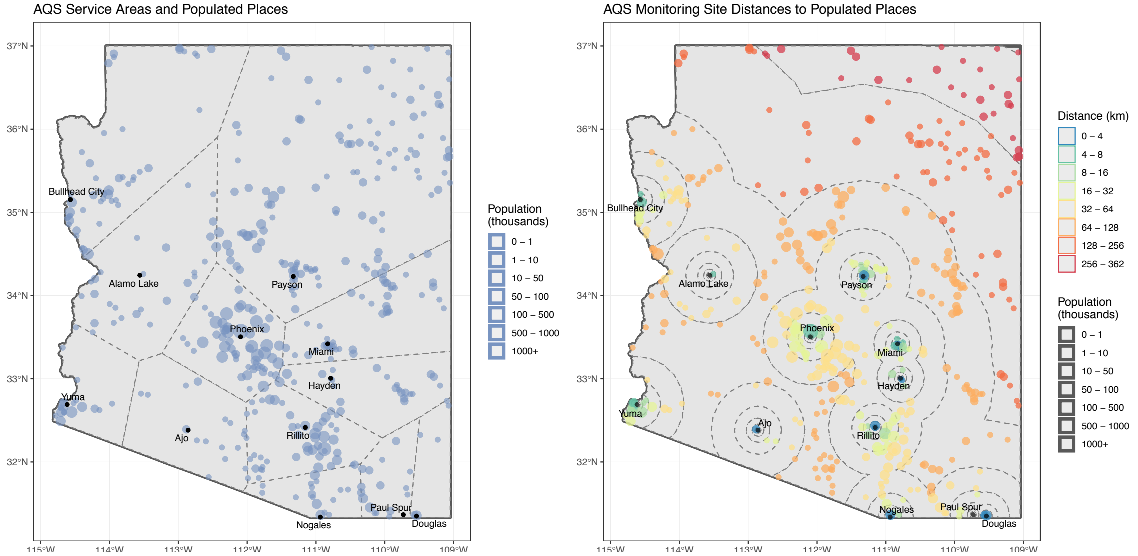


Figure A1.2: PM$_{10}$ Monitor Analysis in Arizona: Arizona has 12 PM$_{10}$ monitors. The map on the left has CDPs in blue and has service areas constructed for each monitor. The map on the right shows the proximity of CDPs to monitors.

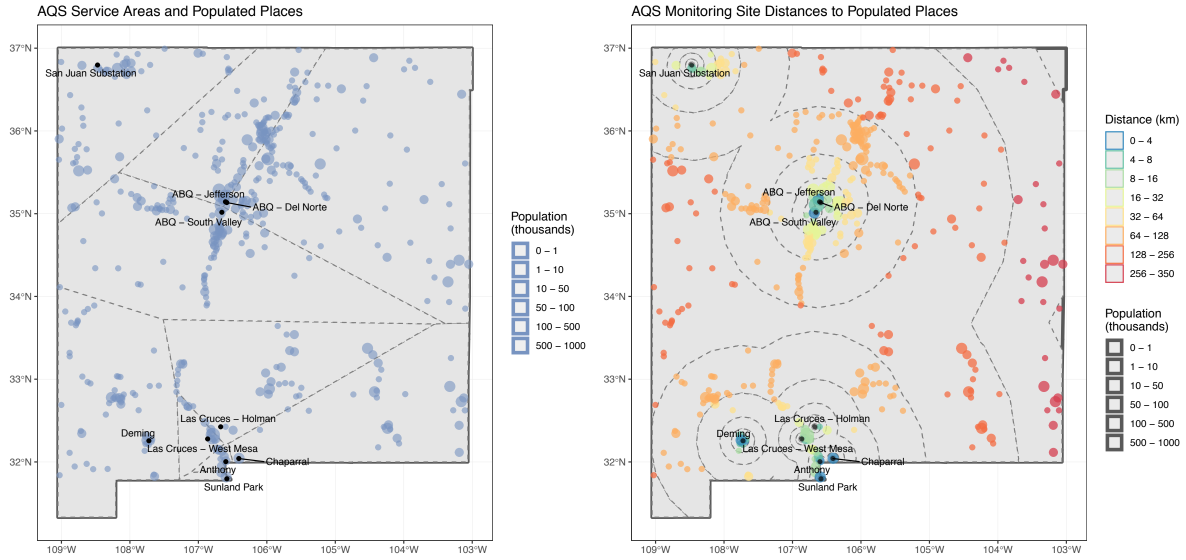
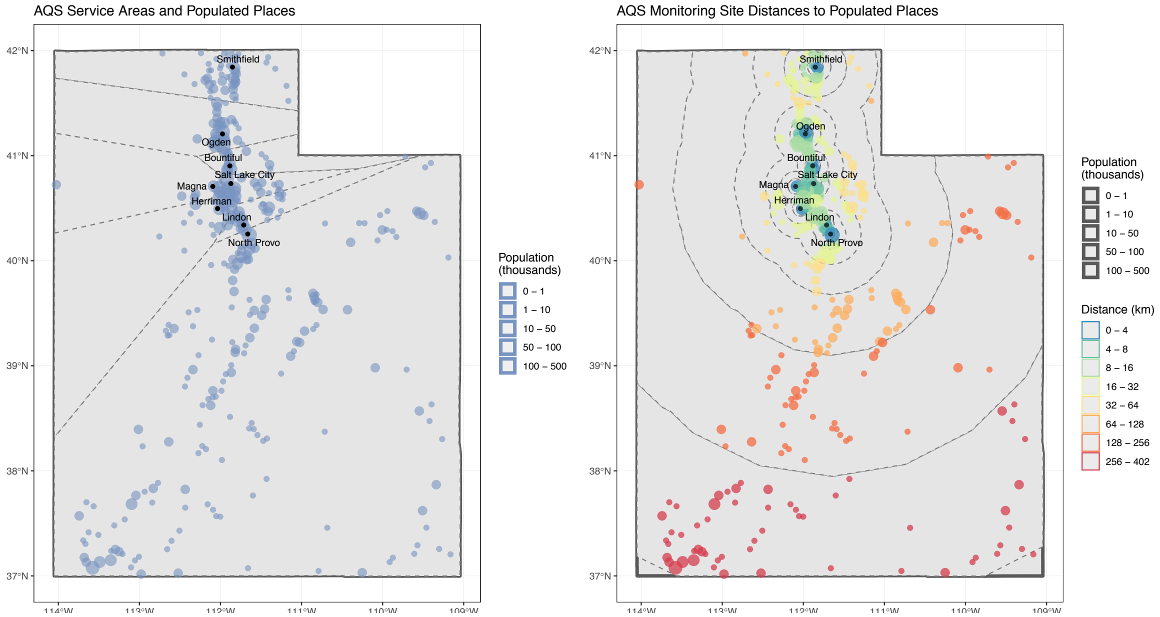


Figure A 1.3: PM$_{10}$ Monitor Analysis in New Mexico: New Mexico has 10 PM$_{10}$ monitors. The map on the left has CDPs in blue and has service areas constructed for each monitor. The map on the right shows the proximity of CDPs to monitors.


AQS Service Areas and Populated Places

AQS Monitoring Site Distances to Populated Places

Figure A 1.4: PM_{10} Monitor Analysis in Utah: Utah has 8 PM_{10} monitors. The map on the left has CDPs in blue and has service areas constructed for each monitor. The map on the right shows the proximity of CDPs to monitors.

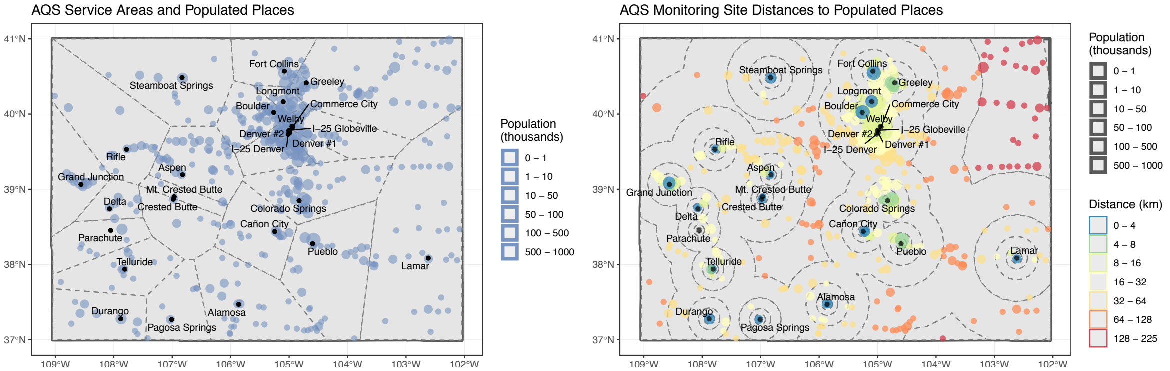


Figure A 1.5: PM$_{10}$ Monitor Analysis in Colorado: Colorado has 26 PM$_{10}$ monitors. The map on the left has CDPs in blue and has service areas constructed for each monitor. The map on the right shows the proximity of CDPs to monitors.

	Monitor	Area (KM^2)	Number of CDP	Population
Arizona				
1	Ajo	20916	17	7907
2	Alamo Lake	32079	29	133271
3	Bullhead City	38860	46	133350
4	Douglas	7080	6	19474
5	Hayden	17102	24	79827
6	Miami	22874	44	73785
7	Nogales	7701	16	68098
8	Paul Spur	7813	16	84661
9	Payson	95032	128	357495
10	Phoenix	17847	57	4143057
11	Rillito	16075	48	955377
12	Yuma	11787	20	181561
New Mexico				
1	ABQ - Del Norte	82818	107	243538
2	ABQ - Jefferson	25032	71	759028
3	ABQ - South Valley	57342	80	147758
4	Anthony	1037	7	16886
5	Chaparral	38304	27	123680
6	Deming	41457	56	44820
7	Las Cruces - Holman	33515	31	119905
8	Las Cruces - West Mesa	3797	13	117056
9	San Juan Substation	31012	49	135990
10	Sunland Park	641	2	19976
Utah				
1	Bountiful	4269	14	160121
2	Herriman	22810	18	460944
3	Lindon	3482	20	312934
4	Magna	12201	7	221535
5	North Provo	149822	172	583553
6	Ogden	13525	32	434488
7	Salt Lake City	2398	20	516002
8	Smithfield	11302	43	134481
Colorado				
1	Alamosa	16866	28	27188

2	Aspen	10699	31	78816
3	Boulder	6285	48	202642
4	Canon City	10367	18	37458
5	Colorado Springs	13471	37	617638
6	Commerce City	7005	13	1084327
7	Crested Butte	8087	5	7561
8	Delta	4138	7	18633
9	Denver #1	1579	2	5637
10	Denver #2	220	6	165186
11	Durango	9966	9	33947
12	Fort Collins	6997	8	264373
13	Grand Junction	9274	9	121398
14	Greeley	28766	50	210740
15	I-25 Denver	4851	47	814708
16	I-25 Globeville	32	2	6969
17	Lamar	40098	36	30473
18	Longmont	1683	14	172977
19	Mt. Crested Butte	2488	2	1012
20	Pagosa Springs	8557	7	3403
21	Parachute	7326	6	20884
22	Pueblo	20018	24	165178
23	Rifle	18551	13	40407
24	Steamboat Springs	21674	12	27260
25	Telluride	10011	13	7930
26	Welby	600	11	441835

Table A 3.1: Comparison of service areas among and within states

State	**Average Service Area Size (KM^2)**	**Median Service Area Size (KM^2)**	**Ratio between Median and Average (KM^2)**	**Difference from "1"**
Arizona	24597.17	17474.27	0.7104	0.29
New Mexico	31495.55	32263.95	1.0244	**0.02**
Utah	27476.09	11751.52	0.4277	0.57
Colorado	**10369.51**	**8321.71**	0.8025	0.20

Table A 1.4: Comparing metrics of inequality. This table calculates the size of the average and median service area and then calculates a ratio between the two. The bolded numbers show the smallest numbers in three categories useful in measuring access.

Key Findings

There are many ways to compare these data and different metrics for measuring inequality, but I find two especially useful: size of service area and range in service area size per state. Of course, there are many other compelling ways to examine uneven monitoring but many while insightful can disadvantage rural communities that have smaller populations or communities that remain unincorporated. Instead, my analysis aims to give rural communities even standing.

The size of service areas is one of the most important metrics for examining inequality. Service areas show how much area a single monitor must serve. Overall this analysis shows significant difference of service areas and proximity to monitoring within individual states as well as among states. The size in service areas differs significantly from 32 KM^2 in the metro area for Denver, Colorado (monitor: 1-25 Globeville) to nearly 150,000 KM^2 in the Southern half of Utah (monitor: North Provo) with a wide range in between. State-level analysis of service area size shows that Colorado has both the smallest average size and the smallest median size (see Table A 1.2). Compared to the other three states, communities in Colorado appear to have better access to information and to regulatory recourse. The fact that Colorado has smaller service areas (less than half or a third of the average size of other states) is not surprising because it has two to three times as many monitors.

However, the median and average size of service areas does not help us understand potential differences among different communities within a state, particularly between urban and rural areas. A ratio of average and median service area sizes was calculated for each state to show the level the distribution skewed. The idea is that a value closest to one -- closest to them matching up--might be indicative of less disparity in size differences between service areas in a community. In other words, even if a state had low average sizes, there might still be large differences among communities and perhaps a more "equal" monitoring system would have similar sizes, even if they were larger. In this case, New Mexico had a ratio that departed least from 1 at (0.02). Even though they have less access than Colorado (i.e. greater areas per monitor), there is less differentiation between communities, particularly between urban and rural communities.

We see two important and different measures of environmental injustice in this analysis. The first measures the *level of* environmental harm/access and the second a measures *of distribution* of environmental harm/access.

Contributions

This analysis primarily makes three main contributions:

1. Improving equity of PM_{10} monitoring

The PM_{10} monitoring network in the Four Corners region is highly uneven and represents a current and critical policy issue that has remained largely unexamined. Other scholars have pointed the unintended consequences and disincentives of the Clean Air Act (CAA) (Hendryx and Holland 2016; List et al. 2004) that are compromising its ability to protect air quality; this analysis highlights another. The spatial gaps in monitoring are leading to uneven air quality protections. Significant portions of the Four Corners region fall outside of regulation and have no recourse for the numerous consequences that accompany increased PM_{10} levels. However, now that these disparities are understood, state regulators can begin working to overhaul their monitoring systems so that they are more equal and more representative.

2. Highlight rural dimensions of environmental justice

Historically, environmental justice scholarship EJ has focused on disparities along racial and class lines (Bullard 2000; Gwen. Ottinger 2013). Further, many of these studies have also taken place in urban and suburban environments (McClintock 2015; Ottinger 2010). While race and class are sharp lenses to understand inequities and often carry important analytical power, there have been recent calls to examine how rurality shapes environmental inequities (Ashwood and MacTavish 2016; Pellow 2016). It is not revolutionary to suggest that rural spaces are often the sites of environmental injustices or become sacrificial grounds (Bell 2016; Harrison 2011; Malin 2015), yet the rurality of the place is not the key analytical interest. Instead, Ashwood and MacTavish (2016) propose we look at how the "tyranny of the majority" shapes EJ and repeatedly leaves rural communities with the greatest environmental burdens and risk. They argue that the utilitarian logic that serves the "greater good" also always serves greater populations. Based on this thinking, it always means that it "makes sense" to distribute harms where there are less people. This study shows a concrete example of how this utilitarian logic often manifests as a tyranny of the majority and leaves many rural communities without access to environmental monitoring and thus environmental regulation. Further, this case study departs from many of the more recent rural EJ studies that focus on environmental harms of a big industry—be it coal, uranium mining or agriculture—to look at the other side of the coin: the distribution of environmental goods. PM_{10} monitors are environmental goods; they provide information that can help communities understand risk, protect themselves, and detect changes of emerging issues (see third contribution). Ultimately, monitors allow communities to engage the state and access state interventions that require areas with air quality violations (nonattainment) to mitigate pollution.

3. Bring together studies of the politics of knowledge (and inscrutability) with EJ

CAA monitors are the main way that PM_{10} is understood and knowledge is generated. While scientists have other ways of studying particulate matter, many rely on the CAA public datasets to understand air quality (see Chapter 3). A lack of monitors creates an inscrutability about dust levels, changing levels, and the consequences associated with dust. And, this inscrutability is an issue of justice because access to environmental knowledge is an environmental justice issue (Frickel, Gibbon, Howard, Kempner, Ottinger, and Hess 2010; Gwen Ottinger 2013). My analysis highlights how uneven access to environmental risk information (an environmental benefit) is just as part of environmental justice as the siting patterns of environmental harms. They both represent two areas of where distribution of environmental consequences can be unequal. And, this case like many others, highlights how they are interlinked; a lack of information about environmental risk allows greater risks to proliferate. This study can contribute both to growing literature of rural environmental justice as well as the politics of knowing and not knowing.

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APPENDIX B:

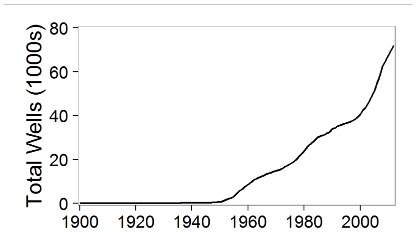
LAND USE PRACTICES AND TRENDS THAT PRODUCE DUST ON THE COLORADO PLATEAU

Dust is produced by many different processes including climatic and weather conditions as well as human activities. This makes it very difficult to identify relative contributions of different drivers and sources and is a key feature of non-point source pollutants. However, land use practices do produce dust, play an important role in dust storms on the Colorado Plateau, and are a key part of the story of PM_{10} pollution.

It is important to note that these land use patterns are constantly in flux and changing in time and space, making them particularly difficult to analyze. Since much of this dust is produced through breaking the cryptobiotic crust (i.e. a common mechanism across land use types), both current and previous land use activities can be causing dust. Further, unlike other types of pollution sources driven by per capita use (e.g. cars), a large population is not required to produce dust and carry a large spatial footprint. Dust can be produced from a small family ranch or even activities by visitors.

This table includes a range of land use practices that produce dust on the Colorado Plateau. It is not an attempt to offer an exhaustive list nor assign relative contributions, but rather illustrate the complex matrix of land use that might contribute to dust levels. For each activity, the mechanism of dust production is included as well as any known trends for that land use.

Disturbances	Mechanism	Trends
Grazing	The primary mechanism is the cattle themselves that roam huge territories. Secondary contributions come from the ranching activities, including	Grazing was unmanaged on the Colorado Plateau until the Taylor Grazing Act of 1934. Studies have shown that the Act significantly decreased dust levels (Neff et al. 2008), indicating that grazing played an important role in dust emissions. Since the Act, there

	hauling water, herding, trucking, etc.	has been an attempt to manage cattle numbers at a sustainable carrying capacity, but fragile soils still produce dust from legacies of past grazing practices. This means that even areas that currently not grazed are likely emitting dust due to historic grazing patterns.
Oil and Gas	Oil and gas development practices encompass many activities across large geographies that can produce dust (Haggerty et al. 2018). First, the sites of resource development (well pads) create substantial disturbances. Additionally, they are accompanied by significant additions of dirt roads and traffic that further produce dust. Another issue can be that areas are not always decommissioned and rehabilitated after extraction activities.	Oil and gas development began in the early 1900s and has had a continued through a series of booms and busts in the Plateau. However, the development has significantly increased in the past 20 years (see below)  (Copeland et al. 2017, Appendix SI).
Dirt Roads	Dirt roads are common in this area because of lower construction and maintenance costs. Dust is kicked up when they are driven on, especially at high speeds.	The Colorado Plateau has always had dirt roads. However, the mileage of dirt roads as well as the traffic on them is likely increasing alongside the increase in other land use practices.
Motorized Recreation	Off Road Vehicle (ORVs) are a form of motorized recreation. Designated trails are meant to control soil disturbances, but some places do not require trails and some drivers do not obey rules.	ORV recreation is a growing industry and is the focus of criticism of wilderness and non-motorized recreationalists. This is part of a larger battle over recreation access on the Plateau.

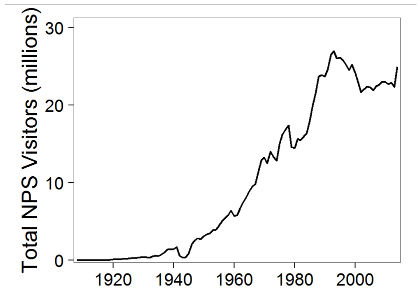
Non-motorized Recreation	Non-motorized recreation includes mountain biking, hiking, climbing, and horseback. These forms of recreation often travel shorter distances than motorized recreation, decreasing imprint per recreationalist.	Many communities on the Plateau are trying to increase recreation tourism and restructuring their economies to invite it. The Plateau is becoming an increasingly popular site for recreation with visitors (and use) growing. For example, the number of visitors to National Parks on the Plateau has increased substantially in the past century (see figure below of National Park Service (NPS) visitors on the Plateau)  (Copeland et al. 2017, Appendix SI). Even if non-motorized recreation has less impact per capita, there are arguments that their large numbers might make their effects approach or even outweigh motorized recreation.
Housing developments	The Southwest has seen faster population growth than other areas of the country and this has been a catalyst for new building projects, which often involve development on fragile soils.	The Plateau specifically has not seen as much development as other areas of the Southwest (like Phoenix or Las Vegas), but even populations in smaller communities like Moab, Utah are increasing.

Table B1.1: Land use practices that contribute to dust on the Colorado Plateau

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