ARTICLES

The Paralysis Paradox and the Untapped Role of Science in Solving "Big" Environmental Problems

JAN G. LAITOS* & CHRISTOPHER AINSCOUGH**

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* Professor of Law and John A. Carver Chair in Environmental and Natural Resource Law, University of Denver Sturm College of Law. Professor Laitos wishes to express his gratitude to the Hughes Foundation, whose support contributed to the research, development, and drafting of this Article. He also wishes to thank Diane Burkhardt, for her genius in researching and unearthing otherwise obscure principles that underlie some of the conclusions in this Article.

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INTRODUCTION

This is an Article about big problems, particularly big environmental problems. Policymakers have difficulty addressing, and correcting, big, complex environmental problems. Sometimes, the problems appear so complex that the policymaker seeking to solve it simply gives up. An odd paralysis then sets in among policymakers when the problems' scope appear so overwhelming and complicated that they seem unsolvable. The result is that the problems continue, despite near-universal acceptance of the reality of the problems and the need to remediate them. The paralysis prevents the development and implementation of effective policy. Each problem continues and perhaps even grows.

This Article offers a methodology aimed at addressing these big, seemingly unsolvable, environmental problems. It is a methodology based not on traditional command-and-control regulatory solutions, nor neo-classical welfare economics typically embraced by academics. Instead, it is based on science—or rather, science and math interwoven with law. The Article suggests that policy paralysis can be avoided, and big environmental problems addressed, by applying principles that scientists routinely use to understand and respond to extremely complex issues. These include probability theory, systems methodology, game theory, chaos theory, and finally, Occam's Razor.

This Article will use as a case study for its thesis the big environmental problem of abandoned mines, and abandoned mine lands ("AMLs"). The article focuses on the tens of thousands, perhaps hundreds of thousands, abandoned hardrock mines in the West.[1] These mines have proven to be an unmanageable, intractable environmental problem. The acid mine drainage from these mines causes harm to water-courses, ecosystems, aquatic life, and human populations.[2] The estimated cost of cleanup and remediation of all abandoned mines in the American West could be a staggering amount, $30–54 billion.[3] Because "good

1. The Mineral Policy Center, now named Earthworks, estimated that there could be as many as 500,000 abandoned hardrock mines in the Western states. *Publications*, EARTHWORKS, https://earthworks.org/publications/burden_of_gilt/ (last visited Apr. 7, 2018).

2. EARTHWORKS, POLLUTING THE FUTURE: HOW MINING COMPANIES ARE CONTAMINATING OUR NATION'S WATERS IN PERPETUITY 4, 12 (May 2013), https://earthworks.org/cms/assets/uploads/archive/files/publications/PollutingTheFuture-FINAL.pdf; RECLAMATION RESEARCH GROUP, LLC , ACID MINE DRAINAGE AND EFFECTS ON FISH HEALTH AND ECOLOGY: A REVIEW 5–6 (June 2008), http://reclamationresearch.net/publications/Final_Lit_Review_AMD_08-22-08.pdf.

3. Senator Tom Udall, *On Anniversary of Gold King Mine Spill, Tom Calls for Action on Hardrock Mining Reform*, YOUTUBE (Nov. 6, 2015), https://www.youtube.com/watch?time_continue=1&v=1H0v8B2_Rbg; PATRICIA NELSON LIMERICK ET AL., CTR. FOR THE AM. WEST, CLEANING UP ABANDONED HARDROCK MINES IN THE WEST: PROSPECTING FOR A BETTER FUTURE 31 (2005).

Samaritans" who clean up these mines can be still held liable under federal environmental statutes, existing law works at cross-purposes with those who in good faith wish to clean up abandoned mines.

Even though academic commentators, natural resources attorneys, and concerned government officials have for decades suggested an array of solutions to this depressing and ongoing environmental problem, none appear to be politically realistic or economically feasible.[4] The problem of abandoned mines has become a classic example of a near-intractable "big" environmental issue, where the standard recommended fixes appear nonviable. It is a problem that seems to ask that we "boil the ocean"—attempt the impossible.[5]

A paradox then arises. There is a ubiquitous and acknowledged environmental problem that desperately needs to be addressed. But, despite the known severity and urgency of the problem, and despite near universal agreement that something should be done, no effective strategy is seriously advanced to solve the problem. Without legal intervention, the problem continues, unabated.[6]

A central thesis of this Article is that this paradox derives from three kinds of paralyses that typically emerge when a seemingly unmanageable environmental problem becomes evident. Each form of paralysis has been played out in the case

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4. *See infra* Part III.

5. *Boil the Ocean*, URBANDICTIONARY.COM, https://www.urbandictionary.com/define.php?term=boil+the+ocean (last visited Apr. 7, 2018).

6. While this Article will focus on the perpetual threat to watersheds from acid mine drainage, the suggestions in the article have relevance to other "big" problems where anthropogenic threats to the natural environment seem equally incapable of being solved. For example:

1. It appears that an era of "biological annihilation" may be underway, creating a massive anthropogenic erosion of planetary biodiversity and ecosystem services. Gerardo Ceballos, Paul Ehrlich, & Rodolfo Dirzo, *Biological Annihilation Via the Ongoing Sixth Mass Extinction, Signaled by Vertebrate Population Losses and Declines*, 114 PROCEEDINGS NAT'L ACAD. OF SCI., No. 30 (July 25, 2017). The resulting decline in animal populations has been called a "global epidemic," caused in large measure by relentless, unstoppable human destruction of animal habitats. Tatiana Schlossberg, *Era of 'Biological Annihilation' is Underway, Scientists Warn*, N.Y. TIMES, July 11, 2017.
2. Another possibly uncontrollable environmental problem is anthropogenic climate change. Greenhouse emissions from human sources seem incapable of being stopped, or even slowed. Virtually all lines of evidence show that human activities, especially atmospheric loading of greenhouse gases, are primarily responsible for observed climate change. Lisa Friedman, *Scientists Fear Trump Will Dismiss Climate Reports*, N.Y. TIMES, Aug. 7, 2017. Even if humans immediately stopped emitting greenhouse gases into the atmosphere, the world would still experience increasing global warming over this century compared to current temperatures. DAVID WUEBBLES, DAVID FAHEY & KATHLEEN HIBBARD, U.S. GLOBAL CHANGE RESEARCH PROGRAM, CLIMATE SCIENCE SPECIAL REPORT 615 (June 28, 2017).
3. Yet another stubborn, seemingly unsolvable, environmental issue is the over-pumping of groundwater. Agricultural over-pumping from thousands of wells drilled into the High Plains Aquifer in the nation's midsection is slowly, but inexorably, draining that aquifer. And as it is drained, interconnected streams are drying up as well. Bruce Finley, *Water, Water . . . Barely There*, DENVER POST, Oct. 8, 2017.

of abandoned hardrock mines in the West. Each type of paralysis becomes a barrier to the development of meaningful legislative or policy action.

One manifestation of this paralysis can be termed "*problem aralysis*." When a social, economic, business, political, or environmental problem appears to be overwhelming, its sheer immensity and complexity can deter the emergence of rational, effective problem-solving.[7] Instead of action, policymakers either deny the existence of the problem, or make it such a low priority that it winds up at the bottom of the policy agenda. Hardrock abandoned mines in the West are a textbook example of an environmental problem appearing so complex and massive in scope that the formulation of effective policy seems futile.[8]

A second type of paralysis is *"Analysis Paralysis."* This condition is characterized by policymakers so over-analyzing and over-thinking a situation that action is never taken.[9] When Analysis Paralysis sets in, government administrators and academic commentators undertake studies and investigations, prepare plans and maps, and write endless research papers. The bigger the problem, the bigger the stack of reports analyzing it. But very little actual action is directed at the problem. Policy choices ordering on-the-ground changes are postponed. For example, in the case of the 2015 Gold King abandoned mine blow out, the Environmental Protection Agency's ("EPA's") response has been characterized as a "two year rolling disaster."[10] EPA generated copious government reports and held numerous meetings, but those down-river who were most affected by the spill remained without compensation and with little confidence about whether there might be future leaks.[11]

The third, and perhaps the most fatal kind of paralysis, is "*Proposal Paralysis*." If policymakers can overcome the inertia of Problem Paralysis, and if they can rouse themselves from Analysis Paralysis, the array of remedies finally proposed by commentators tends to be derivative, repetitive, and ultimately, unrealistic. Commentators who have articulated proposals on how to "solve" the threat of abandoned hardrock mines in the West repeat the same tired list of legislative fixes, which can aptly be termed "first-generation" solutions.[12] These inevitably

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7. Danusha V. Goska, *Political Paralysis: The Impossible Might Take a While*, SUN, Nov. 2004.

8. *See, e.g.,* Francie Diep, *Abandoned Uranium Mines: An Overwhelming Problem in the Navajo Nation*, SCI. AM., Dec. 30, 2010; U.S. BUREAU OF LAND MGMT.: FEASIBILITY STUDY FOR AML INVENTORY (July 2013); ABANDONED MINES, www.abandonedmines.gov (last visited Apr. 7, 2018).

9. Julian Birkinshaw, *Beware Data Overload: Don't Let Analysis Paralysis Stunt Your Business*, THE GUARDIAN, Apr. 22, 2017.

10. WILLIAM PERRY PENDLEY, MOUNTAIN STATES LEGAL FOUND., GOLD KING: EPA'S TWO-YEAR ROLLING DISASTER AND A PATH FORWARD TO FIX IT 6–26 (July 31, 2017).

11. Andrew Westney, *Gold King Spill Vows Could be Fool's Gold For Pruitt*, LAW360 (Aug. 18, 2017), https://www.law360.com/articles/955636/gold-king-spill-vows-could-be-fool-s-gold-for-pruitt; Bruce Finley, *Gold King One Year Later: Colorado's Mustard-Yellow Disaster Spurs Plans for Leaking Mine*, DENVER POST, July 24, 2016 [hereinafter Finley, *One Year Later*].

12. *See, e.g.*, Andrew C. Lillie, Elizabeth H. Titus & Jessica Black Livingston, *Drip, Dribble, or Deluge: Managing the Legacy of Mine-Water Discharge from Inactive and Abandoned Mines in the American West*, 62 ROCKY MTN. MIN. L. INST. 15-1, 15-29 to 15-31 (2016); Cameron M. Leonard & Stephanie M. Regenold, *The Spectre of EPA Bonding of Hardrock Mines Under CERCLA*, 62 ROCKY

call on legislators to (1) spend more money; (2) enact new laws that impose command-and-control rules; or (3) amend an array of existing laws that do not work. Such first-generation proposals, unfortunately, will likely never be politically embraced by the United States Congress in the foreseeable future. Furthermore, these proposals, especially the academic proposals, are often grounded in a neoclassical economics model of how humans behave and the rest of nature functions—models which increasingly have come under fire, or have been debunked.[13]

These three kinds of paralysis have chilled policy development and inhibited meaningful solutions to the abandoned mine problem. The purpose of this article is to advance alternative solutions that avoid the various iterations of the paralysis paradox. These proposed solutions, termed "second-generation" solutions, are not grounded in the same ideologies or methodologies underlying standard first-generation responses to serious environmental challenges. A second-generation response does not call for more expenditures, or more command-and-control laws, or more solutions based on private individual ownership, using neoclassical economic tools like cap-and-trade rules. A second-generation response to complex problems like abandoned mines would be a *science*-based, rather than a *regulatory-and-economics-based*, model of the natural world, and humans' place in it.

Such second-generation policies would rely on science-based tools, like probability theory,[14] systems methodology,[15] game theory[16], and chaos theory.[17] These theories permit policymakers to find order in complex systems, patterns in chaos, and predictability in the midst of randomness. In other words, a second-generation approach to problem-solving uses methodologies which are not overwhelmed by a complex, nonlinear, chaotic environmental problem, like the problem of AMLs and abandoned mines. Systems methodology, game theory,

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Mtn. Min. L. Inst. 28-1 (2016); Kelly Roberts, *A Legacy No One Can Afford to Inherit: The Gold King Disaster and the Threats of Abandoned Hardrock Legacy Mines*, 36 J. NAT'L ASS'N ADMIN. L. JUDICIARY 361, 402–06 (2016); Burt Lounsbury, *Digging Out of the Holes We've Made: Hardrock Mining, Good Samaritans, and the Need for Comprehensive Action*, 32 HARV. ENVTL. L. REV. 149 (2008); John Seymour, *Hardrock Mining and the Environment: Issues of Federal Enforcement and Liability*, 31 ECOLOGY L. Q. 795 (2004).

13. *See, e.g.,* RICHARD H. THALER, THE MAKING OF BEHAVIORAL ECONOMICS (2015) (challenging the standard neo-classical economic model for human behavior as being based on the faulty assumption that humans inevitably make rational choices based on individual welfare maximization – the *homo economicus* model); ROBERT SAPOLSKY, BEHAVE: THE BIOLOGY OF HUMANS AT OUR BEST AND WORST (2017). First generation proposals also often presume a model of how Nature functions which is similarly outdated. Simon A. Levin, *Ecosystems and the Biosphere as Complex Adaptive Systems*, 1 ECOSYSTEMS 431 (1998) (challenging the standard view of nature as being linear and seeking stationarity and stability, when in fact nature is nonlinear, dynamic, unstable, with uncertain unpredictable outcomes).

14. *See generally* EDWIN T. JAYNES, PROBABILITY THEORY: THE LOGIC OF SCIENCE (Cambridge Univ. Press 2013).

15. *See generally* DONELLA H. MEADOWS, THINKING IN SYSTEMS (Diana Wright ed., 2008).

16. *See generally* ELLIOTT MENDELSON, INTRODUCING GAME THEORY AND ITS APPLICATIONS (2004).

17. *See generally* STEVEN STROGATZ, NONLINEAR DYNAMICS AND CHAOS (1994).

chaos theory, and probability theory disaggregate complexity. They permit policymakers to find underlying order and simplicity within environmental systems.

When such second-generation methodologies are applied to the exceedingly complex problem of countless leaking hardrock abandoned mines in the West, a counter-intuitive non-complex solution emerges. It is based on Ernst Mach's version of the Occam's Razor principle: when facing a complicated and complex problem, we must use the simplest means to arrive at a solution.[18] This view of the Occam's Razor principle suggests to policy makers, "[i]f you have many possible solutions to a problem, always choose the simplest."[19] Or, in the context of intractable environmental problems, less is more. Such an approach avoids the paralysis paradox. This article offers and advances a much simpler solution, and most likely the best solution, to the problem of abandoned mines.

Part I considers the daunting scope and extent of the environmental problem addressed by the article. The "problem" consists of an enormous number of abandoned mines and AMLs in the West, affecting numerous rivers and watersheds, where the cost of mine cleanup seems astronomical, and the source of the money to pay for the cleanup elusive. In Part I, probability theory is used to assess the true scope of the AML problem, by estimating the impacts and risks to people and their environment. Part II addresses the state of current law as it applies to abandoned hardrock mines. A review of this law reveals that (1) it does not serve to correct or even deter the continuation of the problem, and (2) it in fact makes it far more difficult for good Samaritans or government entities to begin cleanup operations. Part III explains the "paralysis paradox," which to date has prevented effective responses to the problem. Part IV offers alternative methodologies for policymakers to embrace as more realistic—science-and-math-based solutions to the problem. In Part IV, the AML problem is made more manageable through use of systems methodology, game theory, and chaos theory. Part V concludes by recommending a much simpler science-based approach, consistent with the Occam's Razor principle, which steers clear of the paralysis paradox. Counter-intuitively, this simpler approach of doing less has a more realistic chance of eventually doing more to correct the complex problem of abandoned mines.

I. THE SCOPE OF THE PROBLEM

The environmental problem of abandoned mines can be better grasped by considering its scope. One can best appreciate this scope by (a) identifying the large number of abandoned mines and AMLs, (b) calculating the equally great number of affected watersheds, (c) using probability theory to assess the risk of harm to

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18. E.C. Banks, *The Philosophical Roots of Ernst Mach's Economy of Thought*, 139 SYNTHESE 23, 23–25 (2004).

19. *See generally* CAROL BATCHELOR, OCCAM'S RAZOR: THE SIMPLEST SOLUTION IS THE BEST SOLUTION (2016). Occam's Razor is also sometimes known as the Law of Parsimony. *See also* CASS SUNSTEIN, SIMPLER: THE FUTURE OF GOVERNMENT (2013).

watershed ecosystems, aquatic life, and human health, and (d) evaluating the unprecedented cost of mine and AML cleanup. These factors define the nature of the big environmental problem that needs some legal or policy response.

A. THE NUMBER OF ABANDONED MINE LANDS

Modern economies are driven by mineral extraction.[20] To further appreciate the scale and scope of the mining industry, consider all the trappings of modern life in America. Hardrock mines are responsible for many components of cars, smart phones, laptops, computers, solar panels, wind turbines, electric transmission lines, trains, golf clubs, batteries, and even lawn mowers. If you look around the room you are currently in, virtually every object you see comes from a hardrock mine, or from an oil well (anything made of plastic), or was grown and harvested (e.g., wood and paper).

In the 19th century, Congress passed the 1872 Mining Act, an Act which, though antiquated, survives largely in its present form.[21] That Act opened up over 240-million acres of public land to potential hardrock mining claims.[22] Discoveries of valuable hardrock mineral wealth—gold, silver, copper—drove the westward expansion of the United States. Miners staked claims to thousands of ore bodies, and hand-dug mines in the 19th and early 20th centuries. When those miners had removed the minerals that it was economical to remove, they abandoned the mines. This lengthy history of mining extraction-and-abandonment means that the problem of neglected and deserted mines stretches back in time over a hundred years.[23] Many of these mines are centuries old, their creators long dead, yet their toxic legacy lives on.[24] These abandoned mines come in all sizes, from small, unassuming holes in a rock face, to enormous pits where mountains once stood.[25] There are so many of these mines in the mountainous West, that it is difficult to know the true scope of the problem, and estimates vary.

The U.S. Bureau of Land Management ("BLM") believes there are up to 500,000 AMLs in the United States.[26] In 2011, the U.S. Government Accountability Office ("GAO") estimated a total of 161,000 abandoned hard rock mines in the American West.[27] The GAO found that about 20% of these mines "degraded the

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20. Lillie et al., *supra* note 12, at 15-4.
21. Kris Wernstedt & Robert Hersh, *Abandoned Hardrock Mines in the United States: Escape From a Regulatory Impasse?*, 1 WM. & MARY POL'Y REV. 25, 27–28 (2010).
22. *See id.* at 27 (one million square kilometers is roughly equal to 240 million acres).
23. *See id.* at 27–28.
24. *Id.* at 26.
25. Lounsbury, *supra* note 12, at 150.
26. *Extent of the Problem,* ABANDONEDMINES.GOV, http://www.abandonedmines.gov/extent_of_the_problem (last visited Oct. 22, 2017).
27. *Abandoned Mines–Information on the Number of Hardrock Mines, Cost of Cleanup, and Value of Financial Assurances: Testimony Before the Subcomm. on Energy & Mineral Res. of the H. Comm. On Nat. Res.*, 112th Cong. 1 (2011) (statement of Anu K. Mittal, GAO Natural Res. & Env't Team).

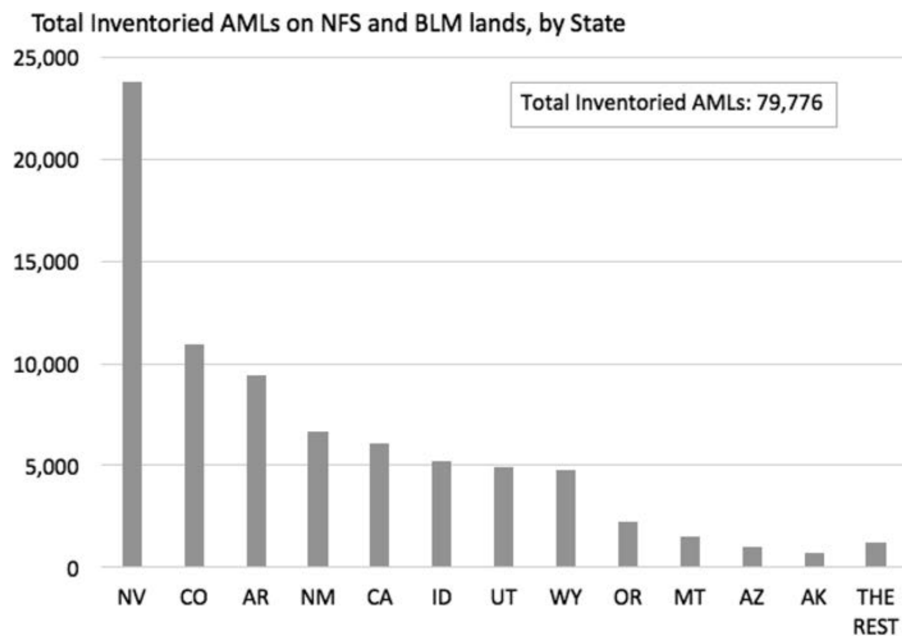

FIGURE 1. Total inventoried AMLs on NFS and BLM lands by State. Data include both open mines (74% of total) and closed mines (26% of total). These data do not include mines on private lands.

environment" by leaching arsenic into ground and surface waters.[28] As of 2009, the U.S. Forest Service ("NFS") and BLM did not even have a method in place to inventory the number of AMLs on their lands.[29] By 2016, those agencies, in partnership with relevant State agencies, inventoried nearly 80,000 known AMLs on NFS and BLM lands.[30] See Figure 1.[31]

The bulk of the abandoned mines exist in eleven western states, and Arkansas.[32] It is important to note that these totals do not represent all AMLs. For instance, although Colorado has nearly 11,000 AMLs on public lands, the State estimates a total AML inventory of approximately 23,000.[33] The State of Colorado has identified 293 draining mines impacting water quality.[34] Of those,

28. *Id.*
29. *See id.*
30. ABANDONEDMINES.GOV, http://www.abandonedmines.gov (last visited Oct. 22, 2017).
31. Original chart, data from Bureau of Land Management & National Park Service data sets. *Id.*
32. *Id.*
33. COLO. DIV. OF RECLAMATION MINING & SAFETY, DEP'T OF NAT. RES., http://mining.state.co.us/Programs/Abandoned/Pages/impwelcomepage.aspx (last visited Oct. 22, 2017).
34. *GIS Data to Accompany Colorado Mining Stream Impacts and Restoration Efforts Map*, COLO. DIVISION OF RECLAMATION MINING & SAFETY, DEP'T OF NAT. RES., http://mining.state.co.us/Programs/Abandoned/Documents/Draining_Mines_GISData-DRMS_08-18-15.pdf (last updated Aug. 13, 2015) [hereinafter *GIS Data*].

only forty-seven have active water treatment, and thirty-five are under investigation or are being remediated. However, the bulk of Colorado's draining AMLs directly impacting water quality either have no active water treatment, or are non-point sources (e.g., tailings piles) that do not lend themselves to water treatment facilities due to their dispersed nature.[35] Likewise, California, has just over 6,000 AMLs on NFS and BLM lands,[36] but estimates a total throughout the State of 47,084.[37]

B. THE NUMBER OF AFFECTED WATERSHEDS

Abandoned mines may leak a toxic brew of acidic water, laden with heavy metals such as lead, cadmium, arsenic, zinc, and copper.[38] This runoff can, and has been known to kill all biological life downstream for many miles. For example, after the Canadian owners of the Summitville gold mine in Southwestern Colorado abandoned it in 1992, spring floods caused its cyanide-laced open pits to overflow, resulting in nearly thirty miles of "dead" river. All aquatic life was wiped out downstream of the mine.[39]

The 2015 Gold King Mine disaster in Colorado is another notable abandoned mine disaster. Gold King evidences the impact of environmental harms that surround abandoned mines, even when officials are actively attempting to clean up the site.[40] In the Gold King accident, EPA contractors accidentally released an estimated 3-million gallons of toxic mine water into the Animas River in southwest Colorado, turning it bright orange for hundreds of miles. The consequence of this release is that the ecology of the Animas River has changed, perhaps permanently. EPA crews conducting Superfund cleanup investigations believe that acid mine drainage from Gold King, and other century-old mine sites, have produced metals concentrations 100-times greater than acceptable danger thresholds for wildlife.[41]

Disasters like Gold King and Summitville are among the most publicized and visible manifestations of the insidious and chronic AML problem. Tens of

35. *Id.*

36. ABANDONEDMINES.GOV, *supra* note 30.

37. Lillie et al., *supra* note 12, at 15-8.

38. LIMERICK ET AL., *supra* note 3, at 16.

39. Robert C. Bigelow & Geoffrey S. Plumlee, *The Summitville Mine and its Downstream Effects: An On-Line Open File Report 95-23,* U.S. GEOLOGICAL SURV., https://pubs.usgs.gov/of/1995/ofr-95-0023/summit.htm (last updated July 11, 1995); *Acid Mine Drainage*, EARTHWORKS, https://www.earthworksaction.org/issues/detail/acid_mine_drainage#.Vkoe20szJg0 (last visited Feb. 20, 2016). For a helpful visual of what acid mine drainage looks like at one extremely contaminated "Superfund" site, *see Diagram of Acid Mine Drainage at Iron Mountain Mine*, USGS: CAL. WATER SCI. CTR., http://ca.water.usgs.gov/projects/iron_mountain/images/acid_mine_drainage.png (last visited Feb. 10, 2016).

40. Casey Leins, *Photos: Mine Waste Spill Pollutes Animas River*, U.S. NEWS & WORLD REP. (Aug. 11, 2015), http://www.usnews.com/news/photos/2015/08/11/photos-mine-waste-spill-pollutes-animas-river.

41. Bruce Finley, *Lead Pollution Spreading*, DENVER POST, Oct. 20, 2017, at 1A [hereinafter Finley, *Lead Pollution*].

thousands of abandoned mines leak acid-metals into creeks and streams and rivers and related watersheds throughout the West. Pollution that is equivalent to the acute Gold King spill leaches out of AMLs across the country every couple of weeks.[42] Current estimates for the mileage of waterways impacted by acid mine drainage nationally are not precise, because it is so difficult to accurately count the total number of neglected, orphan mines that populate the many mountains in the West. The EPA at one time believed that almost 10,000 miles of rivers in the United States had been impacted by acid mine drainage.[43] Colorado, for instance, has inventoried 1,645 miles of streams directly affected by untreated mine runoff.[44] Ohio's inventory of rivers shows that AMLs on NFS and BLM lands have had an effect on 1,300 miles of in-state rivers.[45]

C. PROBABILITY THEORY AND ECOLOGICAL RISK ASSESSMENT TO MEASURE DAMAGE CAUSED BY AMLS

Probability theory, in conjunction with "ecological risk assessment," permits one to estimate the probable impacts of acid mine drainage on people and the environment.[46] Ecological risk assessment involves defining probability distributions of *exposures*, identifying probable *effects* from those exposures, and arriving at a *risk* level, using a composite of the two probabilities.[47]

Exposure Distributions - An exposure distribution is measured in terms of the distribution or dose of a contaminant, such as lead or cadmium from an AML. The distribution accounts for the place and time of the exposure.[48] Such a distribution in exposure over the land area of an AML may be defined by a number of sampling points, or wells in proximity thereto.[49] These sampling points may be queried over time to develop a time-based distribution as well, in order to establish seasonality of contaminant releases (e.g., releases may be lower in the winter when streams are frozen).[50] Time-based distributions may be used to determine the amount of exposure over a period of time, and to assess the effectiveness of remedial measures.[51]

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42. Bruce Finley, *EPA Crews Working on Gold King Cleanup Find Elevated Lead Threatening Birds, Animals and, Potentially, People*, DENVER POST, Jan. 5, 2018 [hereinafter Finley, *EPA Crews*].

43. U.S. EPA, TECHNICAL DOCUMENT: ACID MINE DRAINAGE PREDICTION 1 (1994) [hereinafter DRAINAGE PREDICTION REPORT].

44. *GIS Data*, *supra* note 34.

45. *Acid Mine Drainage Abatement Program*, OHIO DIVISION OF MIN. RESOURCES, http://minerals.ohiodnr.gov/abandoned-mine-land-reclamation/acid-mine-drainage (last visited Oct. 22, 2017).

46. *See, e.g.*, GLENN W. SUTER II ET AL., ECOLOGICAL RISK ASSESSMENT § 5.2 (2d ed. 2006).

47. *Id.* §§ 5.6.1–5.6.3. (A probability distribution is the likelihood of a certain event happening, or a certain concentration of a contaminant, based on samples of the actual environment. One example is the classic bell curve, or normal distribution).

48. *Id.* § 5.6.1.

49. *See id.*

50. *Id.*

51. *See id.*

Effects Distributions - Effects distributions measure the likelihood of adverse impacts on affected populations of plants, animals, or people, in response to exposure to a contaminant from an AML.[52] Effects from environmental exposures could include adverse growth rates, reproductive impairment, cancer, or even death.[53] Effects may be determined through laboratory study, field observations, or mathematical extrapolation.[54]

Risk Distributions - Risk is a function of exposure and effects.[55] Risk estimates the probability that an exposed individual in a population of plants, animals, or people will suffer an effect from the exposure.[56] To measure risk, both exposure and effects distributions must be related to the same populations, and for the same chemicals discharged into the environment from an AML.[57]

While probability theory and ecological risk assessment can estimate the likelihood and gravity of the harms to ecosystems and humans, basic chemistry and biology reveals why leaking abandoned mines produce this harm. The chemistry behind the formation of acid mine drainage is well understood.[58] Mining activity exposes vast quantities of rock to the atmosphere, which accelerates natural weathering processes.[59] The difference between natural weathering and AML leaching has been likened to the difference between brewing coffee with whole beans and with grounds.[60] The rock at many hard rock mining sites includes sulfide minerals, such as pyrite (FeS_2), galena (PbS), millerite (NiS), arsenopyrite (FeAsS), cinnabar (HgS), and others.[61] When that rock is exposed to air and water, it oxidizes, forming solutions of sulfuric acid and heavy metal ions. Equation 1, below, showing the oxidation of pyrite, is typical of the dissolution processes present at many hard rock AMLs.[62] Once in acid solution, further reactions are possible, depending on the pH.[63]

52. *See id.* § 5.6.2.
53. *See id.* §§ 4.3.3, 5.6.2, 9.1.1.
54. *Id.* § 5.6.2.
55. *Id.* § 5.6.3.
56. *See id.*
57. *Id.*
58. *See* DRAINAGE PREDICTION REPORT, *supra* note 43, at 4.
59. *Id.*
60. Roberts, *supra* note 12, at 366 n.29. "Coffee brewing is a simple illustration that comes to mind to help explain the difference between naturally-occurring water acidity on mineral-laden lands and toxic acid mine drainage. If boiling water is poured over whole, unground beans of coffee, the result is, at best, a yellowish-brown cup of hot water with a little bit of caffeine in it. However, if the same coffee beans are finely ground and *then* the hot water is poured over them, the result is a delicious cup of morning jet-fuel. Similarly, rocks left to themselves are like whole-bean coffee: when the water and air interact with the sulfide minerals, some acid and metals are released into the water. When those same rocks are ground up, these mine tailings are similar to coffee grounds. Snowmelt and precipitation 'brew'through the tailings, creating acid mine drainage—much like a freshly-brewed cup of coffee, but slightly less delicious." *Id.*
61. *See* DRAINAGE PREDICTION REPORT, *supra* note 43, at 4.
62. *Id.*
63. *Id.* at 4.

$$2FeS_2(s) + 2H_2O + 7O_2 \rightarrow 4H^+ + 4SO_4{}^{2-} + 2Fe^{2+}$$

Equation 1. The oxidation of pyrite is typical of the dissolution processes present at many hardrock AMLs.[64] *H^+, further reacts with water to form H_3O^+, or hydronium ions, which are responsible for the acidity in the resulting runoff.*

The extensive ecological damage caused by acid mine drainage is also well understood. When the water becomes acidic enough—i.e., the pH drops—the stream effectively dies and becomes nearly devoid of all aquatic life.[65] The streambed can become coated with sulfide deposits that prevent fish and insects from nesting and spawning.[66] The case of the Iron Mountain Mine in California is illustrative. The drainage from that mine is 6,300 times more acidic than battery acid. That mine alone killed approximately 20 million salmon between 1981 and 1996.[67] The damage from AMLs extends beyond an individual species; heavy metals deposited by AML runoff can spread through entire food chains. Plants absorb the heavy metals, insects eat the plants, aquatic life in the form of fish, and birds, eat the insects. Mammals eat both fish and birds, and every animal along the chain becomes contaminated.[68]

Acid mine drainage poses health risks to humans as well. Toxins such as cyanide (used in leaching gold out of low-grade ores[69]), asbestos, and mercury have polluted over 3,000 miles of rivers, which are the water supplies for downstream communities.[70] For example, the Bingham Canyon copper mine in Utah contaminates groundwater with toxic heavy metals in a plume that is spreading toward Salt Lake City's water supply.[71] An abandoned W.R. Grace vermiculite mine caused widespread asbestos contamination of Libby, Montana, leading to the deaths of two hundred people.[72]

D. THE COST OF CLEANUP

While it is difficult to know the precise cost of cleanup, all estimates suggest that the price will be extraordinarily high. One calculation by the Mineral Policy Center puts the price tag between \$32.7 and \$71.5 billion.[73] A 1996 report by the Government Accountability Office estimated that the cost to clean up mine sites

64. *Id.*

65. Roberts, *supra* note 12, at 367.

66. *Id.*

67. Lisa Sumi & Bonnie Gestring, *Polluting the Future: How Mining Companies Are Contaminating Our Nation's Waters in Perpetuity,* EARTHWORKS 12 (May 2013), https://www.earthworksaction.org/files/publications/PollutingTheFuture-FINAL.pdf.

68. Finley, *EPA Crews*, *supra* note 42.

69. Roberts, *supra* note 12, at 372.

70. WHITE HOUSE, ECONOMIC REPORT OF THE PRESIDENT 219 (1997), http://www.presidency.ucsb.edu/economic_reports/1997.pdf.

71. *See* DAVID BARKER & ROWAN SCHMIDT, EARTH ECONOMICS, ENVIRONMENTAL AND SOCIAL BENCHMARKING ANALYSIS OF NAUTILUS MINERALS, INC. SOLWARA 1 PROJECT 47–48 (2015).

72. Associated Press, *Charges Issued Over Asbestos at a Mine*, N.Y. TIMES, Feb. 8, 2005, at A16.

73. JAMES S. LYON ET AL., MINERAL POLICY CENTER, BURDEN OF GILT 3 (1993).

on federal lands alone could be as high as $35 billion.[74] In considering cleanup costs, it is important to note that many sites will need more than one-time-only remediation; they will need water treatment, with its associated operating costs, into perpetuity.[75] One remediation site in Montana, the Zortman-Landusky gold mine, costs $1.5 million per year to operate.[76] That annual cost is projected to continue into the indefinite future. When mine cleanup costs are not one-time-only costs, but costs which continue indefinitely, government decisionmakers are likely disinclined, for budgetary reasons, to initiate cleanup actions which incur such costs.

Despite such high-profile, highly-publicized events as Gold King and Summitville, the existing law in the United States governing mining and mined lands reclamation remains largely ineffective at correcting, or even deterring, the continuation of the problem of AMLs. As Part II below points out, current law surrounding the issue of abandoned mines not only does little to help the situation, it contributes to making it worse. Provisions in existing law discourage good Samaritans, as well as governmental agencies, from initiating cleanup operations. Continued reliance on existing law only ensures that the problem will persist.

II. THE CURRENT STATE OF MINING LAW

A. FEDERAL MINING LAW IS INEFFECTIVE AT CORRECTING THE PROLIFERATION OF AMLS

The law of hardrock mining on federal lands is still largely controlled by the Mining Law of 1872.[77] This law was passed just after the Civil War as a response to the California Gold Rush. Most of the mines established in the late 19th and early 20th centuries were, and remain, on federal lands.[78] The Act makes it extremely easy for any American individual or firm to stake a mining claim on federal land, and to do so for a *de minimis* cost of under $5 per acre. There is no requirement to pay the government royalties for any minerals extracted.[79] Unsurprisingly, given the law's age, it fails to include provisions requiring miners to consider the environmental consequences of hardrock mining, or to perform any environmental remediation or reclamation after the mine is closed.[80]

The focus of the 1872 Law is to encourage would-be miners to explore federal lands for valuable hardrock minerals and to facilitate the extraction of these minerals if they are discovered. The law is centered on self-initiation and free access

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74. U.S. GEN. ACCOUNTING OFFICE, REP. NO. GAO/RCED-96-30 - FEDERAL LAND MANAGEMENT: INFORMATION ON EFFORTS TO INVENTORY ABANDONED HARD ROCK MINES 10 (1996).

75. Roberts, *supra* note 12, at 371–72.

76. *Id.* at 372.

77. The Mining Law of 1872, 30 U.S.C. §§ 22–42 (2012).

78. David Gerard, *The Mining Law of 1872: Digging a Little Deeper*, PROP. AND ENV'T RESEARCH CTR. 2 (1997), https://www.perc.org/1997/12/01/the-mining-law-of-1872-digging-a-little-deeper/.

79. *Id.* at 2–3.

80. *Id.* at 12.

to federal lands; no permission is needed from a government agency to stake a claim.[81] The Law is silent about cleanup when there are no minerals remaining to remove. Mine owners can simply walk away from the mine site if they run out of money or deplete the site of its minerals. The 1872 Law applies to approximately 270-million acres of federal lands—nearly one-quarter of the total land mass in the United States. That fact alone suggests that there are a large number of potential AMLs, spread across a wide area in the West.

Wherever the 1872 Law applies, a miner is encouraged to open the earth to explore for minerals, and if minerals are eventually discovered, to extract them, without concern for the environment. After the minerals are exhausted, that mine site may then be abandoned, regardless of the environmental damage caused by its abandonment.[82] The 1872 Mining Law is concerned primarily with the front-end of the mining process and ignores the environmental backend consequences that follow when the mining operations cease. Despite this glaring gap in the 1872 Law, the law remains largely unchanged from when it was enacted.[83] The United States Congress has treated this 19th Century statute like a veritable constitution for hardrock mining, impervious to subsequent amendment.

B. CURRENT ENVIRONMENTAL LAW DISCOURAGES ACTION BY GOOD SAMARITANS

The federal statute governing most major mine cleanups is The Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA").[84] Three features of CERCLA transform it into a particularly troublesome obstacle for anyone wishing to clean up an AML. CERCLA imposes liability on anyone who is an "owner" or "operator" of a hazardous waste site (i.e., an abandoned mine). CERCLA liability is strict, joint & several, and retroactive. While the intent of Congress in adding these liability features to CERCLA was likely to give it teeth, the threat of such fierce liability has the unintended consequence of perpetuating leaking abandoned mines. Few would-be "operators" are foolhardy enough to touch an AML property; any attempts at cleanup would transform them into CERCLA "operators," subjecting them to strict, joint, several, and retroactive liability for the entire cost of the mine cleanup.

Strict liability - If an organization, agency, or well-funded environmental benefactor wishes to clean up an abandoned mine site, it is irrelevant that the person initiating or paying for the cleanup has a motive to minimize the downstream environmental damage of the mine. For CERCLA liability, intent does not

81. *Id.* at 2.
82. *General Mining Law of 1872- Polluter of Water, Provider of Pork*, EARTHWORKS, https://www.earthworksaction.org/files/publications/EWfs-1872MiningLaw-WaterPolluterPorkProvider-low.pdf (last visited Feb. 20, 2016).
83. *General Mining Law of 1872*, EARTHWORKS, https://www.earthworksaction.org/issues/detail/general_mining_law_of_1872#.VkoodUszJg0 (last visited Feb. 20, 2016).
84. Comprehensive Environmental Response, Compensation, and Liability Act, Pub. L. No. 96-510, 94 Stat. 2767 (1980).

matter.[85] The only elements needed for strict liability to attach are: (i) the site is a "facility" [a former mine site qualifies]; (ii) the defendant is a responsible person, which is defined broadly under the law; (iii) a hazardous substance has been released, or threatened to be released; and (iv) the plaintiff in the resulting CERCLA action incurred response costs—which are virtually any costs associated with mine cleanup.[86] Further, one can be strictly liable without having actually caused a release of hazardous waste.[87]

Joint and Several Liability - CERCLA liability is joint and several among all potentially responsible parties ("PRPs").[88] In other words, all the liability can be shifted to any PRP, regardless of its role in the contamination, and regardless of its insignificant contribution to the hazardous waste problem. Picture a scenario where a mine site becomes abandoned after fifty years of activity when its owner files for bankruptcy. The derelict mine is left leaking toxic waste into a local river. If an environmental non-profit organization attempted to mitigate the damage, it could be liable for the cleanup costs caused entirely by the now defunct mining company. If a wealthy good Samaritan chose to ameliorate just a small portion of the waste at the site, she could suddenly find herself responsible for the entire site cleanup.[89] Cleanup costs for an entire site can range from the tens to hundreds of millions of dollars.[90] Few individuals or organizations are bold or foolish enough to take on this potential legal burden, which can be defeated by the defendant only if it can show, typically through expensive litigation, that the environmental harm is easily divisible.[91]

Retroactive liability - CERCLA applies retroactively.[92] It can reach back in time to hold persons liable for environmental damage that occurred decades before CERCLA was even passed.[93] "CERCLA by its terms has unlimited

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85. JOHN S. APPLEGATE, JAN G. LAITOS & CELIA CAMPBELL-MOHN, THE REGULATION OF TOXIC SUBSTANCES AND HAZARDOUS WASTES 918–919 (2000).

86. Westfarm Assoc. v. Washington Suburban Sanitation Comm'n, 66 F.3d 669 (4th Cir. 1995); Akzo Coatings, Inc. v. Aigner Corp., 909 F.Supp. 1154, 1161 (N.D. Ind. 1995).

87. United States v. Hercules, Inc., 247 F.3d 706, 721 (8th Cir. 2001), *cert. denied sub nom.* (finding chemical manufacturer to be a generator who arranged for disposal—an "arranger" under CERCLA § 9607(a)(3)—and was therefore correctly held jointly and severally liable).

88. United States v. Chem–Dyne Corp., 572 F.Supp. 802, 810 (S.D. Ohio 1983).

89. *See* S. REP. NO. 109-351, at 8 (2006).

90. JONATHAN L. RAMSEUR & MARK REISCH, CONGRESSIONAL RESEARCH SERVICE, SUPERFUND: OVERVIEW AND SELECTED ISSUES 17 (2006) (CRS Report No. RL33426).

91. *See, e.g*., In re Bell Petroleum Services, Inc.*,* 3 F.3d 889, 902–03 (5th Cir. 1993) (defendant has the burden to apportion liability).

92. *See, e.g.,* United States v. Monsanto, 858 F.2d 160, 173–74 (4th Cir. 1988); United States v. Ne. Pharmaceutical & Chemical Co., 810 F.2d 726, 732–34 (8th Cir. 1986); United States v. Shell Oil Co., 605 F.Supp. 1064, 1072–73 (D. Colo. 1985).

93. *See, e.g*., Shell Oil Co. v. United States, 751 F.3d 1282, 1288–89 (Fed. Cir. 2014). Oil companies were sued for recovery cleanup costs under CERCLA for activities relating to World War II fuel production, which had occurred forty-five years prior and thirty-eight years *before* CERCLA's enactment. The companies avoided liability on other grounds, but the suit was not settled until seventy-two years after fuel production began. *Id.*

retroactivity."[94] If a good Samaritan wishing to clean up an abandoned mine discovers that it is strictly liable under CERCLA, it could be liable not just for environmental damage that took place from the time of the cleanup. The retroactive liability includes damage incurred that began once the mine originally began poisoning streams, which could be when the initial owner of the mine first opened it in the 19th century.

Yet, CERCLA is not the only federal law that stymies cleanup efforts. The Clean Water Act ("CWA") is partly to blame as well. Under the CWA, a permit is required for all discharges of wastewater from a mine; it is irrelevant that the discharge is because a good Samaritan has initiated a mine cleanup operation.[95] The CWA requires parties wishing to discharge treated abandoned mine waste to obtain a National Pollutant Discharge Elimination System ("NPDES") permit. The permitted party then assumes the responsibility to meet the permit's discharge water quality standard, in perpetuity, and faces the potential for unlimited liability should it fail.[96] The CWA sends a message to anyone who might be thinking about becoming involved with abandoned mine remediation: if you attempt to help, you will be held vicariously liable, and held responsible both for the cost of cleanup and for the ongoing cost of water treatment.

In short, existing federal law actually conspires to perpetuate the problem of abandoned mines: the still-applicable 1872 Mining Law has no provision preventing the abandonment of hardrock mining operations, while CERCLA and the CWA actively discourage abandoned mine cleanup. It is no wonder, therefore, that there are so many AMLs throughout the West. But why have policymakers been unable, or unwilling, either to correct obvious deficiencies in the laws, or to devise some realistic way to begin to remediate the equally obvious abandoned mine problem? One explanation may lie in what may be called a "paralysis paradox," to which we now turn.

III. UNDERSTANDING THE PARALYSIS PARADOX

When policymakers confront a big, needing-to-be-solved, environmental or natural resources problem, one should not necessarily expect a swift, effective, and directed response. However, too often, what follows is a combination of denial, delay, and defeat. Some policymakers will deny the existence of the problem. Some will indefinitely delay action while undertaking endless studies and

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94. Commonwealth Edison Co. v. United States, 271 F.3d 1327, 1351 (Fed. Cir. 2001).

95. David Gerard, *Why it's so Hard to Clean up Abandoned Mines,* PROP. & ENVTL. RES. CTR. (Aug. 13, 2015), https://www.perc.org/blog/why-its-so-hard-clean-abandoned-mines.

96. *See* Comm. to Save the Mokelumne River v. E. Bay Mun. Util. Dist., 13 F. 3d 305 (9th Cir. 1993); *see also Opportunities for Good Samaritan Cleanup of Hard Rock Abandoned Mine Lands: Oversight Hearing Before the Subcomm. on Energy and Mineral Res. of the H. Comm. on Res.*, 109th Cong. 50 (2006) (statement of Timothy Brown, Ph.D., Research Associate, Center of the American West, University of Colorado, Boulder) ("A good Samaritan has the choice of achieving the highest water quality standards or of not undertaking the project at all.").

investigations pertaining to the problem. Some will take steps to defeat proposals that address the problem, especially if the proposals are expensive or if they adversely affect important constituents. The end result is policy paralysis and the emergence of a paradox. Despite the presence of a well-documented environmental problem that should not be permitted to continue unabated, such as the problem of AMLs, policymakers become unable to implement effective and meaningful remedial action.[97]

This paralysis paradox often manifests itself in three ways. The first is triggered by the problem itself, which may seem so overwhelming that policy initiatives are deterred. This is called Problem Paralysis. The second describes how policymakers often approach a complex problem—with much planning, investigation, and contemplation, but no action. This is called Analysis Paralysis. The third concerns the proposals advanced to address the problem, particularly by academics. Their proposed solutions tend to be either politically unrealistic, or based on outdated assumptions. Neither approach yields effective policy. This is called Proposal Paralysis. Each type of paralysis can prevent the implementation of policy addressing big environmental problems, and all of them are in play in the case of AMLs.

A. PROBLEM PARALYSIS

When policymakers confront a big, complex, difficult problem, their initial (and often only) response may be to balk at attempting to design a response. The reason for this inaction is the scope of problem, which may be so intimidating as to appear either unmanageable or altogether unsolvable. The idiomatic phrase for this kind of paralysis is "boiling the ocean." To "boil the ocean" refers to an unfeasible task, so complicated that it is difficult to know where to begin.[98] Or, it

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97. Although this article is using AMLs as an example of the paralysis paradox that arises in the case of the persistent problem of abandoned mines, the phenomenon of policy inaction in face of emergencies involving natural systems is evidenced with other "big" environmental problems, such as the three referenced in note 6, *supra*. No sweeping law and policy responses have been advanced to slow climate change, species extinction, or the draw-down of water from underground aquifers. *See, e.g.,* Brady Dennis, Juliet Eilperin & Christopher Mooney, *Trump Administration Releases Report Finding 'No Convincing Alternative Explanation for Climate Change*, WASH. POST (Nov. 3, 2017), https://www.washingtonpost.com/news/energy-environment/wp/2017/11/03/trump-administration-releases-report-finds-no-convincing-alternative-explanation-for-climate-change/?noredirect=on&utm_term=.58c156608b75 (the report is at odds with the White House decision to withdraw from the Paris Climate Accord, the decision to champion fossil fuel use, and the decision to reverse President Obama's climate policies); Robin McKie, *Biologists Think 50% of Species Will Be Facing Extinction by the End of the Century*, GUARDIAN (Feb. 25, 2017), https://www.theguardian.com/environment/2017/feb/25/half-all-species-extinct-end-century-vatican-conference (one in five species on Earth face extinction, "without our showing much sign of caring"); *Groundwater Depletion*, U.S. GEOLOGICAL SURV., https://water.usgs.gov/edu/gwdepletion.html (last updated Dec. 9, 2016) (increased demands on American groundwater resources have overstressed aquifers in many areas of the Nation).

98. *What is "Boiling the Ocean"?*, WISEGEEK, http://www.wisegeek.org/what-is-boiling-the-ocean.htm (last visited Apr. 5, 2018).

is a task which is "too large,"[99] or simply, an "impossible task."[100] The phenomenon of Problem Paralysis seems to occur when the problem just overwhelms the would-be problem-solvers.

Problem Paralysis is not limited to big environmental problems, such as the AML problem in the American West. It has been observed in a myriad of situations when decision makers, tasked with addressing a project or issue, discover that the task is too complex or large in scope. For example, it is well documented that complicated but needed transportation projects can fail to be built or are delayed indefinitely, when the task appears too difficult.[101] A too-difficult project may experience so many bureaucratic and decisional hold-ups that the project is out of date by the time it is finally started. Similarly, the problem of health care inequities among a population has stymied policymakers, due to the "complexities of the problem."[102] Bankers seeking to reduce risk have found that many risk system initiatives are so ambitious and complex that they are never completed.[103] The reality of Problem Paralysis extends even to the issue of managing elephants in Kenya's National Parks—the so-called "elephant problem" became so complicated that it resulted in "a paralysis of policymakers."[104]

A textbook example of Problem Paralysis is the problem of AMLs in the West. Commentators have noted that the sheer scope of the AML problem has engendered a kind of "resignation" and "fatalism" which follows from an environmental problem that appears to be "overwhelming."[105] This depressing reaction is due in part to the perceived magnitude of the problem. The sheer number of abandoned mines and AMLs in the West is incredibly large—ranging from tens of thousands to hundreds of thousands of sites.[106] These mines are adversely affecting countless streams, rivers, and watersheds.[107] The cleanup cost for some of the most difficult abandoned mines can be as high as $200 million for just one site, plus millions annually for ongoing maintenance.[108] The total cost of cleanup

99. Patrick Marren, *The Devil's Dictionary of Business Strategy*, 33 J. OF BUS. STRATEGY 58 (2012).

100. *Boil the Ocean*, OXFORD DICTIONARY OF THE INTERNET (3d ed. 2013).

101. Jean-Louis Denis et al., *Escalating Indecision: Between Reification and Strategic Ambiguity*, 22 ORG. SCI. 225 (2011) (discussing how transportation planners become gridlocked to the point where they are unable to move forward to actual implementation).

102. Wayne Kondro, *The Fiendish Puzzle of Health Inequities*, 184 CAN. MED. ASS'N J. 1456, 1457 (2012).

103. James Lam & Michael Litwin, *Where's Risk? EWRM Knows*, 85 RISK MGMT. ASS'N J. 64, 68 (2002) (discussing proposed risk system initiatives proposed to minimize the risk of bank loans).

104. Jeff Schauer, *The Elephant Problem: Science, Bureaucracy, and Kenya's National Parks*, 1955 to 1975, 58 AFR. STUD. REV. 177 (2015).

105. *Limerick, supra* note 3, at 11. *See also* Diep*, supra* note 8 (Abandoned Uranium Mines: An Overwhelming Problem in the Navajo Nation).

106. *See supra* notes 1, 3, 8.

107. *EPA Survey Finds More Than Half of the Nation's River and Steam Miles in Poor Condition,* EPA (March 26, 2013), www.epa.gov/aquaticsurveys.

108. LIMERICK*, supra* note 3, at 31.

could be over $35 billion.[109] Two well-publicized abandoned mines in Colorado —Summitville and Gold King—have already cost the EPA hundreds of millions of dollars.[110] Paralysis is an understandable reaction among legislators and policymakers when a problem is caused by so many sources, and when the cost of remediating the problem seems fiscally exorbitant.

There is yet another reason for policy paralysis when the problem's extent, scope, and cost is as great as the problem of AMLs. Social scientists have commented that when the "numbers" associated with a particular problem become too large, another collateral issue arises, which is termed "The Problem of Excess."[111] If a problem is so complex, and its scope is "massive," there are then too many possible actions that might be taken, causing an overload of alternatives. When the sheer volume of policy choices becomes overwhelming, the result is "paralysis."[112] Policymakers may be simultaneously overcome by the problem's scope, and overloaded with alternatives. Both lead to paralysis which make action impossible.

Moreover, normal economics is also not helpful, because orthodox economics requires prices, which cannot emerge without scarcity. When there is a condition of scarcity, such as with land, valuable commodity resources, or human skill-sets, neoclassical economics predicts that markets will arise where the product in demand becomes priced, rewarding those willing to bid or pay the highest amount. Demand and supply curves determine that price, and scarce but in-demand goods and services wind up where they should—with those willing to pay that price. In a context of excess, however, such as when there are thousands of AMLs, there is no scarcity. And without scarcity there is no price or price-setting, and no free-market basis for making choices among alternative actions.[113]

B. ANALYSIS PARALYSIS

Another form of paralysis occurs when remedial or corrective action is prevented by policymakers substituting action with excessive analysis of a problem. This tendency is called "Analysis Paralysis," or "paralysis by analysis."[114] The

109. See, *supra* notes 73–76.

110. Bruce Finley, *EPA Stabilizes Gold King, Faces Rising Colorado Desire for Fish-Friendly Clean Water*, DENVER POST (Sept. 4, 2016), https://www.denverpost.com/2016/09/04/epa-stabilizes-gold-king-faces-rising-colorado-desire-for-fish-friendly-clean-water/; Bruce Finley, *EPA Granting Colorado $1 Million for Summitville Toxic Mine Cleanup, One of Many Still Not Complete*, DENVER POST (Feb. 28, 2017), https://www.denverpost.com/2017/02/28/summitville-mine-cleanup-superfund-epa-grant/. Much of this cost stems from pre-remediation investigations, studies, fact-finding inquiries, meetings, planning sessions, and scoping events, often conducted and prepared by expensive outside consultants; but little to none, so far, on cleanup.

111. *See* Andrew Abbott, *The Problem of Excess*, 32 SOC. THEORY 1 (2014).

112. *Id.* at 14.

113. *Id.* at 12.

114. *Paralysis by Analysis*, THE OXFORD DICTIONARY OF SPORTS AND MEDICINE (3rd ed. 2006) (thinking too much about an activity's execution can disrupt or prevent performance).

Analysis Paralysis problem occurs if decisions are postponed, and action deferred, because policymakers are either overcome with an unhealthy obsession with numbers, analyses, studies, or investigations, or they become preoccupied with attending meetings, collecting data, and organizing statistics.[115] Commentators have acknowledged that the phenomenon of Analysis Paralysis is a surprisingly common, albeit unintended, outcome of otherwise well-meaning policy initiatives.

Consider, for example, the policies of risk assessment and cost-benefit analysis. It is an article of faith among regulators of toxic substances and hazardous waste that prior to standard-setting, one should first seek to measure the risks from potentially dangerous chemicals, and then decide whether a risk is worth regulating in light of the attendant costs and benefits.[116] Unfortunately, commentators have pointed out that the process of attempting to assess risk significantly slows down or even prevents government interventions. Instead of taking action, policymakers try to decide (1) whether to regulate at all, (2) what method of regulation makes the most economic sense, and (3) how to regulate potentially dangerous activities or products.[117] Similarly, environmental law professors have warned that requiring a cost-benefit analysis is a "recipe for 'paralysis by analysis.'"[118]

Sometimes the Analysis Paralysis phenomenon is a deliberate strategy, designed to permit questionable scientific critiques (paid for by industry) to challenge legitimate science urging regulatory action.[119] Although the alternative contrary scientific "evidence" may be specious, its introduction, debate, and ultimate refutation can delay needed regulation for decades.[120] Sometimes mandated

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115. Ann Langley, *Between "Paralysis by Analysis" and "Extinction by Instinct,"* 36 SLOAN MGMT. REV. 3 (1995); JONATHAN LAW, BUSINESS: THE ULTIMATE RESOURCE (A&C Black, 3rd ed. 2011).

116. *See* JOSEPH V. RODRICKS, CALCULATED RISKS: THE TOXICITY AND HUMAN HEALTH RISKS OF CHEMICALS IN OUR ENVIRONMENT 151–153, 160–161 (2d ed. 2007); RICHARD A. REVESZ & MICHAEL LIVERMORE, RETAKING RATIONALITY: HOW COST-BENEFIT ANALYSIS CAN BETTER PROTECT THE ENVIRONMENT AND OUR HEALTH 10–13 (Oxford University Press, 2011); *see generally* APPLEGATE ET AL., *supra* note 85, at 2–46.

117. Stephen M. Johnson, *Competition: The Next Generation of Environmental Regulation*, 18 SOUTHEASTERN ENVTL. L.J. 27–31 (2009); Franklin Mirer, *Distortions of the "Mis-Read" Book: Adding Procedural Botox to Paralysis by Analysis*, 9 HUM. AND ECOLOGICAL RISK ASSESSMENT 1129 (2003).

118. Daniel A. Farber, *Rethinking Regulatory Reform After American Trucking*, 23 PACE L. REV. 43, 51 (2002). *See also* Cary Coglianese, *The Rhetoric and Reality of Regulatory Reform*, 25 YALE J. ON REG. 85, 89–90 (2008); Alexander N. Hecht, *Administrative Process in an Information Age: The Transformation of Agency Action Under the Data Quality Act*, 31 J. OF LEGIS. 233, 240 (2005) ("Critics of economic analysis argue that tools like cost-benefit analysis (CBA) may contribute to a 'paralysis by analysis' of government agencies, in that excessive CBA may drain agency resources and slow down the rulemaking process").

119. Chris Mooney, *Paralysis by Analysis*, THE ENVTL. F., Sept./Oct. 2004, at 42.

120. Naomi Oreskes & Erik Conway, *Merchants of Doubt: How a Handful of Scientists Obscure the Truth on Issues from Tobacco Smoke to Global Warming*, AM. ORNITHOLOGICAL MAG. 436 (2010) (recounting how specious evidence slowed scientific and policy acceptance of the harms generated by cigarettes and pollution).

hyper-analysis prior to action produces unintended consequences, such as when excessive analytical quantification and rationality induces rigidity of thought while stifling creative innovation.[121] But the most common consequence of excessive pre-action analysis is paralysis, which either slows down the regulatory process or grinds it to a halt.[122]

Certain federal environmental statutes reflect extreme analysis pathologies associated with agency delays, inaction, and overall institutional paralysis. The leading statute, which induces delays of actual action, is the National Environmental Policy Act ("NEPA").[123] It has been well and long documented that NEPA requires resource managers to spend enormous amounts of time and energy engaged in formulating hyper-detailed analyses while "little or no activity occurs on the ground."[124] When NEPA is combined with other federal laws requiring comprehensive analyses prior to decision-making, the effect can range from federal program slowdowns to *de facto* moratoria on government decisions.[125] Yet another example of federal agency Analysis Paralysis is the process followed by the U.S. Fish and Wildlife Department prior to a species being listed for protection under the Endangered Species Act.[126]

Abandoned mines and AMLs in the West trigger Analysis Paralysis in large part because of the first class of paralysis—"Problem Paralysis," discussed above. When good faith policymakers seek to "tackle remediation of the thousands of abandoned mines scattered across the West, it is, similar to the problem of climate change, 'almost overwhelming.'"[127] Because the problem itself seems so

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121. R.T. Lenz & Marjorie Lyles, *Paralysis by Analysis: Is Your Planning Becoming Too Rational?*, 18 LONG RANGE PLANNING 64 (1985).

122. *Coglianese*, *supra* note 118, at 88. The antithesis of Analysis Paralysis is when an agency simply makes a lightning-like decision about a complex problem, without undertaking any analysis. *See, e.g.,* Michael Biesecker, *EPA Says Superfund Task Force Created by Pruitt Kept No Records of Meetings*, CHICAGO TRIBUNE (Dec. 20, 2017), http://www.chicagotribune.com/news/nationworld/politics/ct-epa-pruitt-superfund-task-force-records-20171220-story.html (EPA Administrator Scott Pruitt created a Superfund Task Force to prioritize how to clean up 1300 Superfund sites – instead of Analysis Paralysis, this Task Force wrote an "intricate plan in 30 days," where there was no agenda for its meetings, no reference tools, no decision-making records, and no rationale for its recommendations).

123. National Environmental Policy Act, 42 U.S.C. §§ 4321–4370 (1970).

124. Paul J. Culhane, *NEPA's Impacts on Federal Agencies, Anticipated and Unanticipated*, 20 ENVTL. L. 681, 698–99 (1990). *See also* Michael Francis, *Opinion: The NEPA and Major Water Resource Planning for the Future. What's the Problem? Analysis Paralysis*, 18 ENVTL. PRAC. 69 (March 2016); Bradley C. Karkkainen, *Toward a Smarter NEPA: Monitoring and Managing Government's Environmental Performance*, 102 COLUM. L. REV. 903, 929–30 (2002).

125. *See, e.g.,* Jan G. Laitos, *Paralysis by Analysis in the Forest Service Oil and Gas Leasing Program*, 26 LAND & WATER L. REV. 105 (1991).

126. *See* Joanna Wymyslo, *Legitimizing Peer Review in ESA Listing Decisions*, 33 ENVIRONS: ENVTL. L. AND POL'Y J. 135, 136, 154–56 (2009) (discussing how the "listing" process under the ESA is characterized by time-consuming peer-reviews, endless scientific debate, exhaustive and expensive habitat investigations, and unpredictable political logrolling that often prevents a list/no-list decision on many species).

127. Westney*, supra* note 11 (quoting in part a CERCLA lawyer involved in the cleanup of the Gold King mine.)

huge, action to clean up the mine is deferred, replaced by the appearance of action in the form of endless meetings, studies, and investigations.[128] The Analysis Paralysis phenomenon becomes the norm, while the big environmental problem of AMLs persists.

C. PROPOSAL PARALYSIS

The third type of paralysis involves the nature of the proposed solutions that are advanced by commentators. These proposals tend to urge traditional "first generation" responses that either command a particular action or forbid a particular behavior. Alternatively, the proposals (especially by academics) rely on another class of first generation response, which relies on neoclassical economic theory. Pursuant to neoclassical economics orthodoxy, solutions to big environmental problems are inevitably based on market-driven models, which are assumed to reduce transaction costs and externalities, while maximizing private, individual ownership interests. Unfortunately, these first-generation proposals perpetuate policy paralysis. They are either politically unrealistic or practically unworkable.

1. Proposals that Command or Prohibit

Commentators proposing solutions to the abandoned mine problem inevitably call on lawmakers (i.e., the United States Congress or federal agencies) to enact or amend legislation or engage in rulemaking. Such new laws would command two actions: (1) the removal of obstacles in old laws discouraging voluntary "good Samaritan" remediation; and (2) the spending of money to pay for the colossal costs of mine cleanup. The first of these actions requires that both the CWA and CERCLA be amended, so that good Samaritan remediation efforts are not discouraged by the threat of liability. Removal of these liability provisions would in theory encourage good Samaritans, knowing that new statutory exceptions will protect them from the risk of being financially responsible for all phases of the cleanup.[129] The second proposal requires either the creation of a bond to

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128. *See, e.g.,* Bruce Finley, *EPA Orders Sunnyside to Begin Groundwater Probe*, DENVER POST Mar. 16, 2018, at 4A ("Local officials have raised concerns that EPA officials are studying the [abandoned mine] problem to death without getting the actual clean up done."); Finley, *Lead Pollution*, *supra* note 41 (EPA Superfund project chief Rebecca Thomas has "acknowledged concerns about drawn-out EPA processes. 'It is a valid criticism of the EPA—taking far too long in the studies before we start to take response actions.'"); Finley*, One Year Later*, *supra* note 11 ("Federal steps toward a superfund cleanup [of Gold King mine] still consist mostly of meetings."); PENDLEY*, supra* note 10, at 21 (instead of "positive action," officials addressing the Gold King mine disaster engage in endless risk/benefit and cost/benefit analyses).

129. *See* Lillie et al., *supra* note 12 at 15-3 to 15-17; Roberts*, supra* note 12, at 392, 405; Lounsbury, *supra* note 12, at 153, 164, 1703–80; Rhett B. Larson, *Orphaned Pollution*, 45 ARIZ. ST. L J. 991, 1011–14 (2013); Seymour, *supra* note 12, at 945–46 (new good Samaritan protections would incentivize "remining" at abandoned mine sites); Lynn M. Kornfeld, *Reclamation of Inactive and Abandoned Hardrock Mine Sites: Remining and Liability Under CERCLA and the CWA*, 69 U. COLO. L. REV. 597,

pay for abandoned mine remediation, paid for by all new mines, or the imposition of a tax (e.g., the re-initiation of the Superfund tax, or a tax on the extraction of hardrock minerals) to be used for AML cleanup.[130]

While both proposals would be incredibly helpful, there is little chance that either would be implemented. Lawmakers have known for decades that good Samaritans need to be encouraged, not punished, for cleanup initiatives, but lawmakers have for decades adamantly refused to alter existing law.[131] Similarly, calls for new taxes and new appropriations to pay for AML remediation will almost surely fall on congressional deaf ears.

Another class of proposal calls for new laws that prohibit or heavily condition private commercial decisions to open new mines or "remine" existing mines. Like the proposals that command action, these negative proposals are equally unlikely as a matter of political reality. Many commentators have for decades proposed that the 1872 Mining Law be "reformed" and "updated" or "replaced" so miners can no longer simply abandon mines with impunity.[132] Yet, even though commentators have urged that the 1872 Mining Law be changed to reflect modern conditions, this 1872 Law remains stubbornly in place, largely unchanged for well over a hundred years.

A similarly futile recommendation is that adequate financial assurance, and realistic bonds, be posted as a condition to hardrock mining.[133] There is no question that upfront guarantees of cleanup will help ensure that mines will be remediated

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624–26 (1998) (protections from liability under the Clean Water Act would incentivize remining); *see also* David Gerard, *Why It's So Hard to Clean Up Abandoned Mines*, PROP. & ENV'T RES. CTR. (Aug. 13, 2015), www.perc.org/blog/why-its-so-hard; *Mining Industry Exploits Clean Water Act Loopholes*, EARTHWORKS (Sept. 8, 2015), https://earthworks.org/publications/mining_industry_exploits_clean_water_act_loopholes/; Doug Young, *How to Solve the West's Abandoned Mine Problem*, REALCLEAR ENERGY (Nov. 30, 2015), http://savethewater.org/2015/12/08/solve-wests-abandoned.

130. Roberts, *supra* note 12, at 402; Lounsbury, *supra* note 12, at 190–203; Seymour, *supra* note 12, at 940; Jane Kloeckner, *Developing a Sustainable Hardrock Mining and Mineral Processing Industry: Environmental and Natural Resource Law for Twenty-First Century People, Prosperity, and the Planet*, 25 J. ENVTL L. & LITIG. 123, 156–60 (2010); Jeffrey Kodish, *Restoring Inactive and Abandoned Mine Sites: A Guide to Managing Environmental Liabilities*, 17 J. ENVTL. L. & LITIG. 257 (2002) (discussing how the Brownfields Revitalization of Environmental Restoration Act of 2001 expanded the brownfields program and could help fund abandoned mine cleanup).

131. Ironically, environmental lobbyists have been wary of relaxing liability consequences for anyone involved with abandoned mines. These lobbyists fear that mining companies would use exceptions in order to re-mine without legal consequence, if the mine were to "blow out" and contaminate downstream waters, which is what happened in Colorado with the Summitville and Gold King mines.

132. Lillie et al., *supra* note 12, at 15-29 to 15-31; Roberts, *supra* note 12, at 384–92; Kloeckner, *supra* note 130, at 169–71; Young, *supra* note 129.

133. *See* Leonard & Regenold, *supra* note 12; Lillie et al., *supra* note 12, at 15-30 to 15-31; Roberts, *supra* note 12, at 402; Wernstedt & Hersh, *supra* note 21, at 31–34, 39–42; Gerard, *supra* note 129; *see, e.g.,* Bruce Finley, *State Lawmakers Look to Prevent Mining Disasters*, DENVER POST 6A (March 22, 2018) (although Colorado lawmakers have proposed new laws that would require mining companies to make reclamation plans and post financial assurances to cover the costs of mine cleanup, the Colorado Mining Association has announced that the organization will "fight the bill").

when they are no longer operating. However, any proposals requiring mining companies to post expensive surety or reclamation bonds prior to mining have been, and will be met with, fierce opposition from the mining community. Such proposals will likely be politically unrealistic.

2. Proposals Based on Neoclassical Economics

Among many academic commentators, it has been a given that public policy should be influenced by neoclassical economic theory. The neoclassical theoretical structure is premised on certain beliefs. First, all economic and social interactions, including interactions involving AMLs, are interactions among individuals, where all individuals are both selfish and rational. As rational beings, they think marginally, and can always estimate the additional benefit gained from an action, and the additional cost this action incurs. Such rational individuals have been termed "*homo economicus,*" who act only if the benefits derived from an action are larger than its risk and costs.[134]

A second neoclassical economic belief is that such individuals best choose by optimizing self-welfare in competitive markets. These markets respond to demands for commodities and valuable services. In neoclassical markets, these market items will wind up where they should, because transaction costs are low, and market items have a price which fluctuate freely in such a way that supply equals demand, yielding a natural equilibrium.[135] A third belief is that this goal of economic efficiency, sometimes known as a "Pareto efficient outcome," encounters various obstacles, such as poorly defined property rights, negative externalities, and high transaction costs.[136] Academic commentators often seek to establish policy, which reflects these goals and assumptions when there is a resource problem to solve, such as the AML problem.

Commentators have suggested, for example, incentivizing AML remediation through the implementation of water quality credit trading markets.[137] In such a "market," beloved by neoclassical economists,[138] mining companies engaging in AML remediation, which increase the assimilative capacity of the receiving watercourse, could "sell" or "auction off" that capacity to other potential dischargers. Markets have also been proposed for financially capable abandoned mine owners, who could trade cleanup and remediation funding with regulatory agencies in exchange for easier permitting or promises not to sue regarding reopened mines.[139] Other proposals consistent with neoclassical economic orthodoxy

134. YANNIS PAPADOGIANNIS, THE RISE AND FALL OF HOMO ECONOMICUS: THE MYTH OF THE RATIONAL HUMAN AND CHAOTIC REALITY 49 (2014).

135. THALER, *supra* note 13, at 5.

136. *See* R.H. Coase, *The Problem of Social Cost*, 3 J.L & ECON. 1 (1960).

137. *See, e.g.,* Larson, *supra* note 129, at 1014–17.

138. *See, e.g.*, Bruce A. Ackerman & Richard B. Stewart, *Reforming Environmental Law: The Democratic Case for Market Incentives*, 13 COLUM. J. ENVTL. L. 171 (1988).

139. Lillie et al., *supra* note 12, at 15-31.

would (1) impose a tax on products that contain minerals from hardrock mines to internalize the external costs of AML cleanup,[140] (2) prioritize mine cleanups on a cost and risk basis,[141] and (3) monetize and quantify the "natural capital" values that are threatened by AMLs.[142]

These proposals suffer from the same defect as the first-generation proposals that command or prohibit—they are politically unrealistic. One cannot envision either the United States Congress or a federal agency adopting laws creating cap-and-trade markets for cleaned up abandoned mine water quality credits. It would be even less likely that lawmakers would impose new taxes to internalize the negative externalities of discharging abandoned mines. Even if lawmakers could summon the political will to implement such proposals, there is considerable growing skepticism about the assumptions underlying neoclassical economics and public policies grounded in that theory.[143] Behavioral economics provides a countervailing view of how humans in fact make choices, which is contrary to the welfare optimizing neoclassical model embraced by academic commentators.[144]

For AMLs and other big environmental problems, it might be time to consider second-generation policies. This next generation of policy response to big, complex, seemingly overwhelming problems would be based not on commanding or prohibiting behavior, or neoclassical economics, but on science. Reliance on science-based policies removes each of the three forms of policy paralysis and permits a more effective response to big, complex environmental problems.

IV. SECOND-GENERATION SOLUTIONS: BRINGING SCIENCE TO BEAR ON THE SEEMINGLY INTRACTABLE

When big problems arise that call for remedial policy, Problem Paralysis deters policy; Analysis Paralysis avoids policy; and Proposal Paralysis prevents policy. In order to cut through this policy gridlock, science should be considered as a methodology equipped to address big, complex problems, like AMLs. Science-based methodologies are preferred because they simplify complexity and uncertainty, and make problems of enormous scope more manageable. Rather than rely on regulation or neoclassical economics, policy based on science becomes a second-generation policy solution, which is equal to the task of addressing big, complicated environmental problems. The second-generation policies borrow from the world of systems methodology, game theory, and chaos theory.

140. Lounsbury, *supra* note 12, at 201.

141. *See* Paul Stokstad, *Structuring a Reclamation Program for Abandoned Noncoal Mines*, 25 ECOLOGY L.Q. 121, 156–58 (1998).

142. Kloeckner, *supra* note 130, at 167–68.

143. THALER, *supra* note 13, at 6 ("the premises on which the [neoclassical] economic theory rests are flawed"); PAPADOGIANNIS, *supra* note 134, at 191–239.

144. *See, e.g.,* DANIEL KAHNEMAN, THINKING, FAST AND SLOW (2011); RICHARD THALER & CASS SUNSTEIN, NUDGE: IMPROVING DECISIONS ABOUT HEALTH, WEALTH, AND HAPPINESS (2009).

These particular scientific tools all have a common theme that makes them particularly well-adapted to big environmental problems: they help mere mortals craft solutions in complex situations, where common sense action typically fails. Systems Methodology provides a rational, logical basis to allow people to choose optimal solutions from a seemingly amorphous cloud of possible options. Game theory helps people find optimal solutions when they have an adversary, as in the case of landowners and the EPA. Chaos theory helps people find islands of stability in situations that otherwise seem unpredictable.

A. SYSTEMS METHODOLOGY—THE ANALYTICAL HIERARCHY PROCESS

Humans often struggle when making decisions. This is particularly the case when we are faced with many choices, and many criteria against which to weigh those choices. This situation can give rise to Problem Paralysis—the scope of the problem appears too large and complex for humans to grasp, resulting in policy decisions that are postponed, delayed, or indefinitely tabled.

The Analytical Hierarchy Process[145] ("AHP") is a systems methodology designed to put science to work in helping to make decisions in such an environment and avoid Problem Paralysis. AHP is based on the premise that humans *can* effectively make choices when given only two alternatives. Anyone who has been to an eye doctor has been on the receiving end of a form of AHP. Rather than throw all the possible combinations of diopter, spherical error, axis, and prism at the patient all at once, the doctor will go through the familiar, repetitious interrogatory, "Number one, or number two?", as she switches lenses. As the patient makes pairwise choices, the doctor is able to home in on the correct prescription. Similarly, AHP breaks down a problem with multiple choices, and multiple criteria with which to weigh those choices, into a series of pairwise comparisons that humans can handle.

An illustrative example of such a decision problem is buying a new house. Assume there are three house options—A, B, and C. Further assume that three house-related criteria are important: (1) lot size, (2) cost, and (3) whether the house is haunted. The immediate difficulty is that each house meets some, but not all, the decisional criteria. House A may be set on a five-acre plot, cost $50k, but is miserably haunted. House B may have a quarter acre plot, cost $500k, and is not haunted. House C is on a medium size lot, costs $1 million, and may be haunted.

To add to the complexity, the buyer cares more about some criteria than others. For instance, cost and haunting may be the priority, with the lot size not as important. But a buyer may place radically different relative value on the importance of these criteria. For example, for one buyer, haunting may be a good thing (if the buyer is a paranormal psychologist), or a bad thing (the buyer has a family with

145. For an introduction to the Analytic Hierarchy Process, *see* Thomas L. Saaty, *Decision Making with the Analytic Hierarchy Process*, 1 INT'L J. SERVS. SCI. 83 (2008).

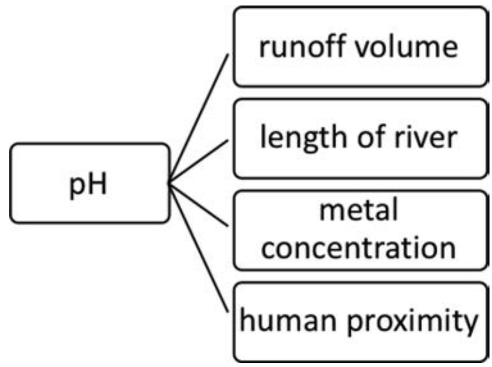

FIGURE 2. In an example AHP pairwise criteria comparison, mine runoff acidity (pH) is compared to the rest of the criteria one at a time to determine their relative importance.

small children). Considering the complexity of this house-buying problem, if the buyer has no "system" or methodology for making a decision, any decision risks becoming a bad decision.[146] Or worse, the decision may appear to be so complex that Problem Paralysis sets in and no house is ever bought.

The AHP approach to this problem is to first assess the relative importance of the criteria, (1) lot size, (2) cost, and (3) hauntedness, by asking the buyer to make pairwise comparisons between each of them. In essence asking, "which do you value more highly: lot size, or cost?" then "lot size or hauntedness?" then "hauntedness or cost?" In this way, AHP develops a priority ranking for the criteria. Then AHP asks, "for house A vs. house B, which has a bigger lot?" then "which costs less?" then "which will result in your life becoming the subject of both of a lawsuit and a Halloween movie?" The same questions are asked for house A v. house C, and house B v. house C. Finally, with AHP, mathematics is used to put it all together to arrive at an optimum choice.

AMLs and other big environmental problems are analogous, but larger in scope. There appear to be too many abandoned mines, affecting too many watersheds in too many different ways, where the cost of cleanup is too high. If one were to devise a policy which attempts to address a problem of this scope and complexity, normal linear policy paths would fail, because (1) it is unrealistic to try to remediate all the abandoned mines, and (2) it seems impossible to try to decide which mines to address first. The AHP process can help to *prioritize* which mines to address, in which order, given limited resources. With AHP, a seemingly infinite number of choices can be broken down to a set of pairwise comparisons, see Figure 2. Such a comparison calls for the decisionmaker to choose the best, or most important, among two options.[147] Humans are good at this. Then math

146. *See, e.g.*, *id.* at 83–84.
147. *Id.* at 85.

TABLE 1.

EXAMPLE PRIORITY MATRIX FOR ABANDONED MINE LAND CRITERIA. THESE NUMBERS ARE JUST AN EXAMPLE

Criteria comparison	Runoff volume	Miles of river	Metals concentration	pH	Proximity to humans	Eigenvalue estimates	Priority Vector
Runoff volume	1.0	0.33	0.20	0.20	0.11	0.3	4%
Miles of river	3.0	1.0	0.33	0.33	0.14	0.5	8%
Metals concentration	5.0	3.0	1.0	1.0	0.33	1.4	19%
pH	5.0	3.0	1.0	1.0	0.33	1.4	19%
Proximity to humans	9.0	7.0	3.0	3.0	1.0	3.6	50%
	23.0	14.3	5.5	5.5	1.9	7.1	
					Lambda max	5.1	
					Consistency Index	0.017	
					Consistency Ratio	0.016	

does the rest of the hard work: the decision maker arranges the options in an exhaustive set of comparisons, and simply picks the most important of each pair.

The AHP process can be applied to the environmental problem of AMLs. Assume, for example, that as a matter of policy we need to select three mines that are worthy candidates for remediation because they all directly drain into one watershed—Mines A, B, and C. For each mine, there is a fixed set of relevant criteria (e.g., volume of runoff, miles of river affected, concentrations of heavy metals, pH levels, proximities to wildlife and humans).

AHP is powerfully flexible in that, it can reflect either empirical data, or the values and policy priorities of the party doing the analysis—be it a state, mine owner, or EPA—or a mix of policy priorities and data. For instance, the importance of many of these criteria may themselves be the subjects of scientific findings, as to the impacts on environment and health. Further, users can plug empirical data from field water samples, reflecting which mines most strongly meet which criteria into AHP, to help determine priorities. Users could likewise incorporate data from public surveys or rulemaking comments.

Table 1 shows an example, albeit with made-up numbers, of how AHP addresses such a problem. In Table 1, the number "1" indicates that the criteria are of equal importance. Numbers higher than 1 indicate higher relative importance, and numbers less than 1 indicate that a criterion is of lesser importance. Consistent with this approach, if the intersection of criterion A in a row, and B in a column is X, then the corresponding intersection of criterion A in a column and B in a row is the reciprocal, 1/X. For example, miles of river in the row compared to runoff volume in a column is 3. The corresponding intersection of runoff volume in a row, and miles of river in a column is 1/3 or 0.33.[148]

To demonstrate, in Table 1, *pH* and *metals concentration* are of equal importance, having a *1* at their intersection. The intersection of *proximity to humans* to *miles of river* yields a *7*. The AHP method then calculates a priority vector of importance among all the criteria. This priority vector indicates that the *proximity to humans* is the most important criterion, followed by *pH* and *metals concentration*. AHP also incorporates a consistency ratio to check for situations where a ranking is not consistent. For instance, A is more important than B, and B more important than C, but C is more important than A.

AHP proceeds by comparing the importance of each pair of criteria against one another. For instance: pH vs. runoff volume; pH v. length of river; pH v. metal concentration; pH v. human proximity. Then the comparison is between another pair of criteria, such as runoff v. length of river. Comparisons continue until there are pair-wise comparisons of all criteria. AHP calculates a Priority Vector (using math beyond the scope of this paper to explain) indicating which criterion is the most important, as shown in Table 1, indicating that "Proximity to Humans" is the most important criterion.[149]

The next step in AHP is to rank how well each option meets the criteria.[150] Table 2 presents an example matrix showing the priority among three hypothetical abandoned mines, A, B, and C, each having discharge waters with different average metals concentrations. For the purposes of this exercise, assume that we have data from field water sample monitoring showing the average metals concentration in mine A's discharge waters is 100 milligrams of heavy metals per liter of water, or 100 mg/L. Mine B's metals concentration is 14 mg/L, and mine C's is 33 mg/L. Because we have quantitative data, the ranking process is simply the process of taking a ratio of each pair of mines' metals concentrations. Comparing mines A and B, the ranking is Mine A's concentration divided by

148. For a more detailed discussion of the mechanics of AHP, the reader is referred to Professor Saaty's paper, *supra* note 145.

149. *See, e.g.*, *id.* at 88. We will leave the discussion of the mathematics involved to Professor Saaty.

150. *See, e.g.*, *id.*

TABLE 2.
EXAMPLE MATRIX SHOWING THE PRIORITY AMONG THREE AMLS, A, B, AND C, RANKING THE RELATIVE METALS CONCENTRATION OF THEIR DISCHARGE WATERS

Avg. Metals Concentration (mg/L)	Mine	A	B	C	Eigen value Estimates	Priority Vector
100.0	A	1.0	7.1	3.0	2.8	68%
14.0	B	0.1	1.0	0.4	0.4	10%
33.0	C	0.3	2.4	1.0	0.9	23%
					4.1	
		1.5	10.5	4.4		

mine B's (100/14 = 7.1). Likewise, comparing mines A and C, the ranking is mine A's concentration divided by mine B's (100/33=3.0). The ranking continues for each mine, and for each criterion, again using the pair-wise comparison of B v. C. This ranking indicates that the metals' concentration emanating from mine A is considerably higher than mine B, and fairly higher than mine C. This exercise generates a Priority Vector that we use later for determining the global priority for mine clean up. Unsurprisingly, given mine A's high metals concentration, AHP arrives at a strong priority for mine A (68%), compared to the other two mines.

The final step is to combine all the criteria and option rankings to determine which mine best meets the highest priority criteria.[151] Table 3 shows the calculation of a global priority between the mines. Mine A is the highest cleanup priority, partially because it best meets the high priority criteria of proximity to humans.

All of these examples point out the obvious: policy-making becomes particularly difficult when there are complex environmental problems, requiring multi-criteria, multi-option decision-making. It is not surprising that Problem Paralysis can set in when policymakers contemplate hundreds of thousands of abandoned mines, each polluting with varying degrees of severity. But by employing scientific theory, such as systems methodology in the form of AHP, it is possible to make empirically-based, rational decisions about which abandoned mines to prioritize for cleanup.

151. *See, e.g.*, *id.* at 89.

TABLE 3.

EXAMPLE CALCULATION OF GLOBAL PRIORITY BETWEEN THREE AMLS. MINE A HAS THE HIGHEST RANKING, AND IS THEREFORE THE HIGHEST PRIORITY TO ADDRESS

Option Priority Vector →	Runoff volume	Miles of river	Metals concentration	pH	Proximity to humans	
Criteria Priority Vector v	4%	8%	19%	19%	50%	
A	43%	19%	62%	37%	73%	
B	43%	8%	6%	25%	22%	
C	14%	73%	32%	39%	5%	
A	2%	1%	12%	7%	36%	59%
B	2%	1%	1%	5%	11%	19%
C	1%	6%	6%	8%	3%	22%

B. GAME THEORY—TWO PLAYER, CONSTANT-SUM GAMES

Another manifestation of the Paralysis Paradox—Proposal Paralysis—occurs when commentators offer up solutions to big problems which reflect the same tired, derivative, but ultimately, politically unrealistic remedies. Instead of relying on standard regulation or law-and-economics approaches, policymakers should consider alternative, science-and-math based methodologies for addressing big problems. Game theory is a science-and-math based tool, which may help to simplify the task of remediating big complex environmental problems, like the problem of AMLs.

Game Theory offers a path to optimum solutions where there are adversaries jockeying for the best position, say the United States Environmental Protection Agency ("EPA") and a past mine owner. Here "optimum" is defined as a policy that results in the best outcome for both players of the game.

Assume that for AMLs, the two players in the overly-simplified AML cleanup game are a regulator, such as the EPA and a good Samaritan ("GS") organization wanting to perform some, but not all, cleanup of an AML. In such a game, there is no competition between the two players.[152] Rather, the game involves the players making choices, not unlike a common board game, like chess.[153] The game

152. *See* MENDELSON, *supra* note 16, at 1–7.
153. *Id.* at 1.

could be played at a single mine site, or a larger region like a watershed or county.

In a simple two-player game, such as the AML game between the EPA and the GS, the rules of the game dictate how the two players may make choices, what initial positions they start at, and the terminal positions they occupy at the end of the game.[154] Once players reach a terminal position, they may no longer make choices to better their situation, and the game ends.[155] The rules define a payoff for each player at the end of the game.[156] In a constant-sum game, there is a fixed amount of payoff to split between the players; in other words, there is a fixed market to split.[157] The "optimum" solution to a game is when neither player, even knowing the other player's strategy, has anything to gain by changing the player's position. If each player has chosen a strategy, and no player can benefit by changing strategies concurrent with other players leaving their strategies unchanged, then those strategy choices and corresponding payoffs are optimal to all the players in the game. Such an optimum point is called a "Nash equilibrium," after John Forbes Nash, who helped to identify one of the foundational concepts in game theory.

For a simple example of a two player, constant sum game, consider two siblings, A and his sister, B, who have one hundred pieces of Halloween candy to split between themselves. The children may "move" by employing various bargaining strategies (*e.g.*, hair pulling, teasing, threats, or empty promises). An example of the outcomes for child A for such a game are shown in Table 4. In this game, the goal is to get the most pieces of candy possible. We will measure success as the difference between the number of pieces Child A actually gets and an equitable distribution of 50/50. For instance, if the table shows –40, this number indicates child A is a loser in the game. He has −40, which means he has 40 pieces less than an equitable split, or 50 – 40 = 10 pieces of candy. Likewise, if the table shows +20, Child A has 20 pieces more than the equitable split, or 50 + 20 = 70. He wins.

The columns in Table 4 represent the possible bargaining strategies Child B may employ to get the most candy. Likewise, the rows represent the strategies for Child A. Strategies 1 and 2 need not be the same for each player. Assume that strategy 1 is making threats, while strategy 2 is pulling hair. The numbers in the table represent the difference from an equitable 50/50 distribution of candy for Child A. So, if both children employ strategy 1, Child A loses 40 pieces of candy and will end up with 10 pieces of candy (50 − 40). Child B will wind up with 90 pieces (50 + 40). However, if Child A stays with strategy 1 and Child B

154. *Id.* Game theory can be extended to a higher number of players, and non-zero or fixed sum games, but such a discussion is beyond the scope of this article. *See id.* at 143 for a more in-depth treatment of more complex games.

155. *Id.* at 1.

156. *Id.* at 2.

157. *Id.* at 58.

TABLE 4.

SAMPLE CONSTANT-SUM GAME MATRIX. VALUES INDICATE THE PAYOFF FOR CHILD A CALCULATED AS A DIFFERENCE BETWEEN THE EQUITABLE SPLIT OF 50/50, AND A'S ACTUAL TAKE. SO, −35 REPRESENTS 50 − 35 = 15 PIECES OF CANDY. CHILD B GETS THE REMAINDER OF 100 − 15 (A'S SHARE) = 85. A IS A LOSER IN THIS GAME. THE NASH EQUILIBRIUM FOR THE GAME IS SHOWN AT − 35. NEITHER PLAYER BENEFITS BY DEVIATING FROM THIS COMBINATION OF STRATEGIES

	Child B_1	Child B_2
Child A_1	−40	0
Child A_2	−35	+20

switches to strategy 2, the pile is evenly split (no child "loses" any of their original 50 pieces).

The game in Table 4 has a Nash Equilibrium point at A_2, B_1 (–35). Nash Equilibrium is the point of a game in which it is stable, in the sense that if either player deviates from that point, they are worse off.[158] Turning back to Table 4, at Nash Equilibrium, Child A chooses strategy 2, and has lost 35 pieces of candy, leaving A with 15 pieces of candy (50 − 35), while Child B chooses strategy 1 and now has 85 pieces (50 + 35). If Child A changes to strategy 1, while child B sticks with strategy 1, then Child A loses 40 pieces of candy, and ends up with even less candy, 10 pieces. Likewise, if from Nash Equilibrium, Child B switches to strategy 2, and A stays at his strategy 2, then A's payoff is 50 + 20 = 70 pieces, and B is left with 100 – 70 = 30. Child B has no rational reason to change strategies. One can see from Table 4 that there is an optimum strategy for each party —it is for Child A to deploy strategy 2, say pulling hair, and for Child B to deploy strategy 1, say making threats. Neither are made better off if either veers from that strategy.

Table 5 applies game theory to AMLs. Instead of two children, assume the two players are the EPA and a GS who wants to clean up an abandoned mine. Instead of candy, there is an AML site that costs $100 million to remediate. The payoff for GS is the amount of the cleanup that EPA pays or recoups from others; these values are shown in Table 5. Suppose that EPA has two strategies. First, EPA could sue all past owners/operators of the mine to attempt to recoup the highest amount of cleanup cost.[159] As a second strategy, EPA could sue only the deepest-pocket potentially responsible parties ("PRPs"). Likewise, GS could have two strategies. First, it could operate only on a small portion of the AML site. Second, it could operate on a majority portion (or all) of the AML site. The Nash

158. *Id.* at 56–59.

159. Note that this simple game ignores the element of time. EPA's first strategy could be extremely lengthy.

TABLE 5.

SAMPLE CONSTANT-SUM GAME MATRIX FOR AN AML CLEANUP. VALUES IN THE TABLE REPRESENT THE AMOUNT OF THE CLEANUP PAID BY EPA (OR THAT EPA RECOUPS FROM OTHER PRPS). THE POINT AT (EPA1, GS2) REPRESENTS THE GS BEARING THE TOTAL COST. THIS SITUATION COULD HAPPEN UNDER CERCLA'S STRICT, JOINT-AND-SEVERAL LIABILITY. THE CELL (EPA2, GS2) REPRESENTS A NASH EQUILIBRIUM WHERE EPA PAYS $60- MILLION AND GS PAYS $40-MILLION

	EPA_1	EPA_2
Good $Samaritan_1$	90	60
Good $Samaritan_2$	0	40

Equilibrium point in Table 5[160] is at (EPA_2, Good $Samaritan_1$), in which GS decides to clean up a small portion of the site, and EPA decides to sue just the biggest PRPs, letting GS off the hook, as a *de minimis* PRP. In this scenario, EPA pays for $60 million of the cleanup, and GS $40 million (100 – 60 = 40).

If GS deviates from its first strategy and cleans up a larger portion of the site under its second strategy, while EPA is steadfast at its strategy 2, EPA pays $40 million, and GS pays $60 million (100 – 40 = 60). This would be a losing strategy for GS. Meanwhile, if EPA deviates from its second strategy of suing just the big PRPs, while GS remains steadfast, then EPA pays $90 million and GS pays the remaining $10 million. This makes no sense for EPA. If GS follows its second strategy (larger portion of the site), while EPA sues everyone (its first strategy), GS could end up paying the entire cost of the cleanup, akin to what EPA does when it applies CERCLA joint and several liability on responsible parties.[161] Knowing EPA's strategy, GS would be unwise to take on a majority or all of the site.

Applying game theory beyond an individual mine site, we are likely to find that no two AMLs are identical, potentially prompting the use of a new game and new strategies, and even new players at each. Players could also enlarge the game board to encompass an entire watershed or region, employing more general strategies. In such a game, once the players arrive at a Nash Equilibrium in the form of a memorandum of understanding, they can agree to tailor solutions to individual mine sites.

Of course, the real world involves more than just two players and a finite pot of money. In application, using game theory to address AMLs would likely go one of two ways. First, more advanced game theory may be applied to encompass that complexity. This is the realm of Ph.D. economists. More likely, game theory

160. You can identify a Nash equilibrium point by identifying a point that is simultaneously the minimum in its row, and the maximum in its column.

161. *See* Joint and Several Liability for CERCLA, *supra* notes 88–91 and accompanying text.

would be employed less literally than presented here, to arrive at a general understanding between the players and how they will engage with one another.

Applying game theory to the problem of AMLs may be a methodology to avoid the unrealistic proposed solutions from commentators that produce Proposal Paralysis. Game theory can show how the players EPA and GS can reach an equilibrium point that allows each to achieve its own optimum result and make progress toward cleaning up AMLs.

C. MODERN NON-LINEAR DYNAMICS—CHAOS THEORY AND STRANGE ATTRACTORS

Traditional mathematical and analytical tools for understanding or describing complex systems of the Natural World, such as algebra and calculus, are ill-suited to the task because such systems are not static, but subject to constant, dynamic change, and are highly sensitive to their initial condition or state.

Take, for example, some of the dynamics and initial conditions at play with AMLs. The attention and solutions employed at AMLs are highly dynamic, and can include at least: the vagaries of political gyrations from left to right, at national, state, and local levels; changes in climate affecting precipitation and temperatures; human population growth and encroachment on AMLs and the commensurate increases in water consumption; erosion of hillsides denuded by wildfires—themselves caused by millions of acres of standing dead beetle kill pines; re-opened or hastily closed mines motivated by fluctuations in global metals prices; and urgency brought on by unforeseen disasters like Gold King and Summitville. The initial condition of AMLs, namely the 1872 Mining Law, continues to influence the state of AMLs today.[162]

Thus, what we need is a model which can start with a description of the initial state of a system as well as an understanding of the system when the system is subject to instantaneous change at any time.[163] When classical methods for describing complex systems fail, a new technique is necessary which permits ever-changing systems to be understood and "captured" analytically, so that the system can be studied while it is changing.[164] Otherwise, attempts at understanding such dynamic systems leads to Analysis Paralysis.

One can see an example of the futility in applying classical analytical tools to dynamic systems in the overly simplistic model of the Earth's atmosphere developed by Edward Lorenz. See Figure 3.[165] The behavior of the "state variables," inherent in climate, when plotted over time, seem to have no order, and instead appear to be completely chaotic. These data lead to no predictable models or

162. *See, e.g.*, § II *supra*.

163. *See* SALLY J. GOERNER, CHAOS AND THE EVOLVING ECOLOGICAL UNIVERSE 205 (1994).

164. *Id.*

165. Cleve Moler, *Periodic Solutions to the Lorenz Equations*, CLEVE'S CORNER: CLEVE MOLER ON MATHEMATICS & COMPUTING (Apr. 28, 2014), https://blogs.mathworks.com/cleve/2014/04/28/periodic-solutions-to-the-lorenz-equations/#27bd412e-a4d6-42aa-a407-9847b8731f86. Figure created by the author using Moler's lorenzgui.m MATLAB program.

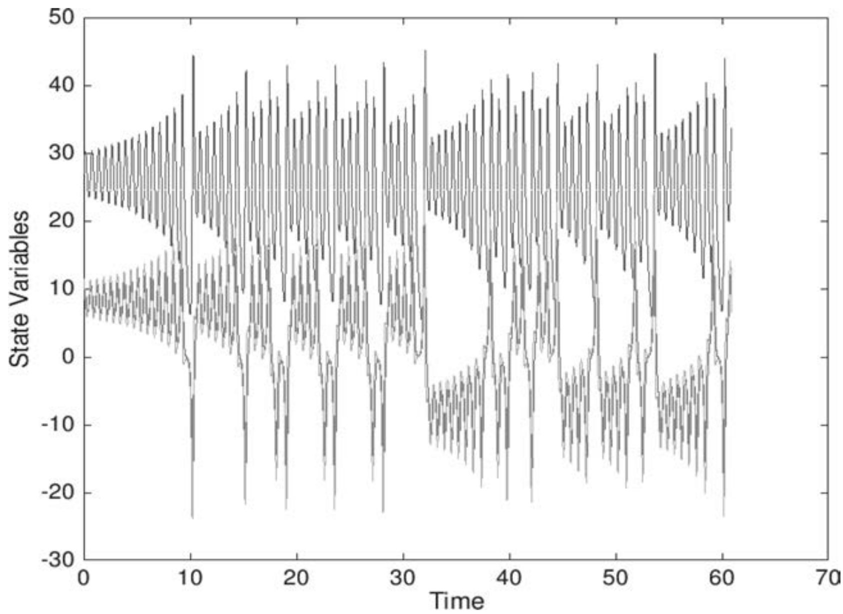

FIGURE 3. State variables of the Lorenz equations plotted over time, exhibiting chaotic behavior.

conclusions. Interpreting non-linear dynamic, or chaotic, systems, such as climate, ecosystems, or even abandoned mines, requires looking at data in a different way so as to avoid Analysis Paralysis.[166]

The French mathematician and theoretical physicist Henri Poincaré was the first person to describe dynamic systems using a graphical representation called a phase space diagram that shows the state of a system plotted against the system's key variables.[167] A phase space diagram is one tool used to describe "chaos theory;" in that a seemingly unpredictable, non-linear, changing chaotic system can in fact be understood in terms of its different variables. Figure 4 shows the same data as Figure 3, but in a phase space diagram.[168] The stars represent points in the system called Strange Attractors.[169] Such systems are characterized by two fundamental features: 1) a sensitivity to small changes in initial conditions, and 2) the system itself is constrained by the attractors.[170] The attractors do not define what the system can do; they help to determine what it cannot do. The attractors

166. Wayne Woodhams, *A Nonlinear Dynamic Method for Supporting Large-scale Decision Making in Uncertain Environments* 21 (Dec. 1995) (unpublished Ph.D. dissertation, Old Dominion University) (on file with UMI Company).

167. GOERNER, *supra* note 163, at 212.

168. Moler, *supra* note 165. Figure created by the authors using Moler's lorenzgui.m MATLAB program.

169. GOERNER, *supra* note 163, at 212.

170. Woodhams, *supra* note 166, at 25.

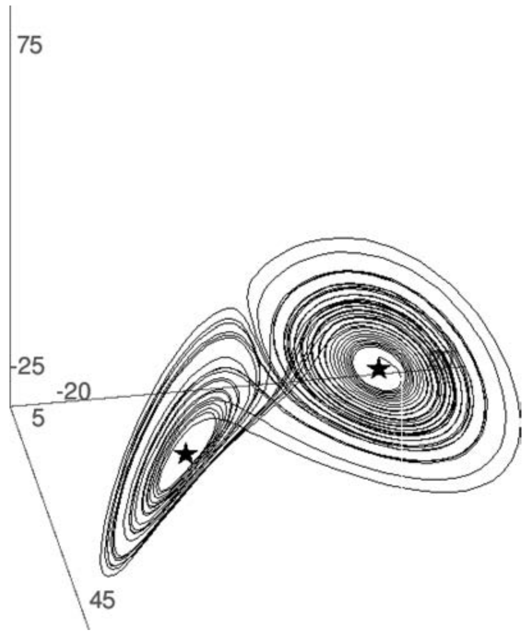

FIGURE 4. An example of a phase diagram showing two basins of attraction (the stars), or Lorenz Strange Attractors. Although chaotic, the state of the system is bounded by the attractors.

give bounds to an otherwise chaotic system and provide some sense of predictability.[171] Because of the presence of attractors, a seemingly chaotic system is not a random system, but always tends to move toward the attractors.[172]

The science of chaos theory may be applied to a system which is both complex and chaotic—i.e., the problem of tens of thousands of AMLs which appear to discharge heavy metals into watersheds with no apparent predictability or pattern in quantity or impact on health and environment. Chaos theory—non-linear dynamics theory—may be applied to such big problems requiring "large-scale" decision-making.[173] These kinds of large-scale problems (1) cannot be remediated without the commitment of large amounts of money, (2) occur in an environment whose boundary extends beyond the decision-maker's influence, and (3) have outcomes that take a significant amount of time to resolve, and (4) are influenced by initial conditions creating the system.[174] AMLs have each of these characteristics: There are billions of dollars at risk; no single decision-maker is in control;

171. *Id.*
172. Woodhams, *supra* note 166, at 21–22.
173. *See generally*, Woodhams, *supra* note 166.
174. *Id.* at 1.

the timescale for resolution stretches out over decades; and these mines are all heavily influenced by an initial condition—the 1872 Mining Law.

The problems of the AMLs system exist in an environment which is "dynamic." The relationships between the variables influencing the system's outcome are always in flux, and may not even be fully known.[175] Policy that attempts to influence the system of AMLs does not necessarily have a set of known outcomes.[176] The environmental harm produced by the abandoned mines does not occur in a systematized way; rather, the long-term chronic pollution and the short-term abandoned mine blow-outs (e.g., the Gold King incident) appear to be chaotic.

Chaos theory presumes that no matter how complex a system may be, such as the earth's weather, migratory patterns of birds, or the spread of vegetation across a continent, those systems rely upon an underlying order. Complex systems most often work in patterns, caused by the sum of many pulses. They often seem to run through some kind of cycle, where the system tries to achieve an equilibrium of some sort. That equilibrium is a dynamic, non-static state, represented by attractors.

The problem of AMLs is one such complex system. This system seeks to settle in a dynamic situation, where there are attractors. For chaos theory to apply to AMLs, five broad steps must be taken. Policymakers should: (1) identify and define all stakeholders, (2) determine as many of the variables as possible that influence cleanup decisions, (3) track changes in those variables over time, (4) create phase space diagrams of all pairs of the variables in part to identify attractors, and (5) factor in "uncertainty," to account for variables which are not foreseeable, but which can affect the success of policy.[177] We will next examine all five of those criteria relative to the AML problem, and then illustrate a simple example of Chaos Theory as it applies to AMLs.

Identify Stakeholders - The first step to applying Chaos Theory to the AML problem is to identify the relevant stakeholders. Relevant stakeholders for the AML problem include: the EPA, other state and federal regulators, private landowners, water users and utilities, the public (both downstream and in surrounding communities), good Samaritans, hunters and fishers, mining companies, the mines, and the downstream natural environment, including relevant ecosystems.

Variables of Influence - Next, in order to plot a phase diagram for the AML problem, like Figure 4, we need to identify the important variables that affect the state of the AML system. For simplicity, we begin with the criteria we previously considered when deploying systems methodology and the analytical hierarchy process (AHP).[178] These criteria could encompass runoff volume, miles of river

175. *Id.*
176. *Id.* at 3.
177. Method adapted from Woodhams, *supra* note 166, which applied this methodology to the question of investment in commercial space activities.
178. *See supra* notes 145–151 and accompanying text.

affected by AMLs, number of humans at risk, the degree of metals concentrations, and river pH. In addition, relevant variables would include emerging and known mine cleanup technologies, government regulations, public sentiment, the amount of money that Congress might authorize pursuant to a CERCLA Superfund cleanup or pursuant to a direct appropriation addressing AMLs, water quality, fish populations, and human health impacts.[179]

Change in System Variables of Influence Over Time - Having identified the variables of influence, we need to measure how they change over time. The collection of data on these variables may utilize both quantitative methods (performing quality sampling on stream water), and qualitative methods (surveying public opinion on the designation of their region as a superfund site).[180] Data needs to be collected either retroactively by reviewing existing data, or prospectively, by gathering new information.

Preparation of Phase Space Diagrams - Having collected the values of the variables of influence, we can chart the changes to them over time. See Table 6. The first row of data, for instance, shows changes in the annual runoff volume, likely influenced by normal year-to-year variations in precipitation. If one only looks at the raw data in Table 6 over time, it is difficult to see any pattern or predictability. However, if we plot the same data in a phase space diagram in Figure 5, a possible attractor (shown by the inset circle), and therefore some constraint on the system's behavior, becomes apparent.[181] Figure 5 shows a correlation between the runoff volume and the human population at risk. Because of the presence of an attractor, there is not pure randomness or chaos when measuring runoff volume and humans at risk. There is a correlation in quadrant I, which permits the formulation of policy which is not a blind guess.

Uncertainty - Figure 5 also shows an arrow indicating a System Uncertainty Index. This is the distance of any coordinate from the origin and can be tracked over time as shown in Figure 6. Spikes in the uncertainty index can show the influence of outside forces, such as unexpected abandoned mine cataclysms like Gold King or a change in administration with different environmental priorities.

Both the phase space diagram and the uncertainty index can be used to determine which variables most influence the state of the system defined by the AML problem. Energy and effort can be placed on those few variables most likely to have a positive influence on the outcome. Instead of Analysis

179. Any of these factors could potentially be used in an AHP analysis as well.

180. *See e.g.*, Bruce Finley, *Superfund Cleanup Sought for Gold King, Other Mines*, DENVER POST (Feb. 26, 2016), https://www.denverpost.com/2016/02/28/superfund-cleanup-sought-for-gold-king-other-mines/ (reporting that local residents affected by the Gold King disaster have resisted Superfund designation due to the stigma associated).

181. Woodhams, *supra* note 166, at 61–63.

TABLE 6.
HYPOTHETICAL CHANGE IN SYSTEM VARIABLES OVER TIME

System Variable	Annual Change (%)				
Year	1	2	3	4	5
Runoff volume	15%	25%	20%	7%	−34%
Miles of river	10%	9%	−20%	11%	4%
Humans at risk	20%	8%	−25%	10%	−26%
pH	34%	300%	5%	−4%	−50%
Metals concentration	−8%	4%	3%	9%	7%

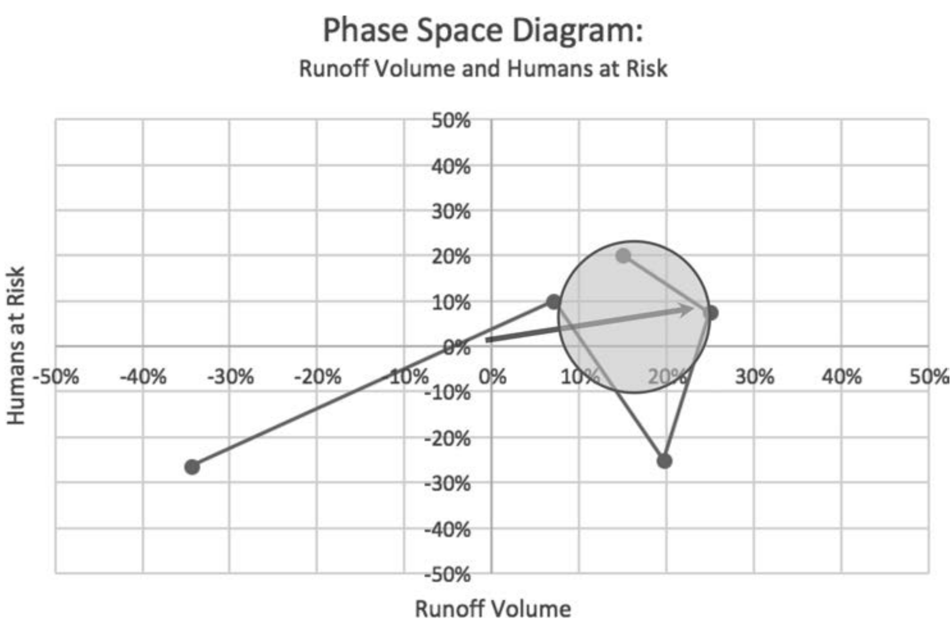

FIGURE 5. A hypothetical phase space diagram for changes in human populations at risk and runoff volume over time. The distance from the origin to any point may be used to calculate a system uncertainty index, as indicated by the arrow. The circle shows the location of a possible attractor.

Paralysis, policy can concentrate on those variables that are capable of being understood, where some degree of predictability is possible. Instead of being overwhelmed with uncertainty in a sea of chaos, policy can track the patterns that emerge in complex systems.

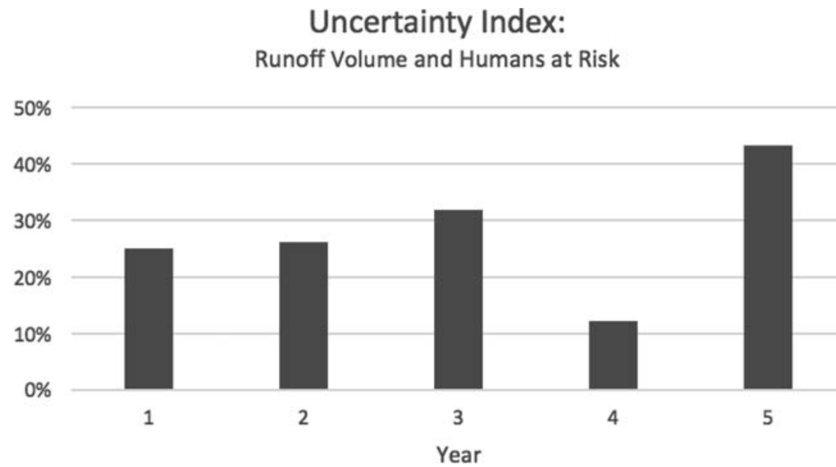

FIGURE 6. A hypothetical uncertainty index over time. This generally shows the uncertainty of the system increasing over time.

D. PUTTING IT ALL TOGETHER

The true power of applying these approaches to AMLs is to use them all together. This could be accomplished by starting with Chaos Theory. The first two process steps in applying Chaos Theory, i.e. identifying stakeholders, and determining variables that influence cleanup decisions, can feed directly into Systems Methodology and Game Theory. When we identify stakeholders, we identify the players of the Game. When we identify variables affecting cleanup—variables of any kind including data, policy priorities or public sentiment—we can feed those into AHP to make priority calls about which mines to tackle first or how to address them.[182]

Chaos Theory elucidates changes in variables over time identifies stable solutions, and can inform strategy decisions in the Game. We might even find that the Lorenz Attractors are coincident with the Nash Equilibria. This would be the case if the goals of the game are structured such that they incentivize an approach toward a stable solution. Thus, Chaos Theory can help structure the Game.

There are nearly an infinite number of ways these tools can be combined to address the problem of big problems.

182. Our discussion of AHP did not touch on this, but the H is for "Hierarchy." The reason for this is that AHP can be applied in a hierarchical fashion all up and down the levels of a problem. For instance, players in a Game could use it to evaluate the likely priorities of the other players, and their possible moves given those priorities. Or, we could use it to evaluate the acceptance of potential solutions among the public.

V. AVOIDING PARALYSIS BY RELYING ON SIMPLICITY

A. THE PROBLEM OF EXCESS

Big problems, such as big environmental problems, are usually problems of excess. They typically include huge anthropogenic threats to the environment, such as species extinction, climate change, or resource depletion.[183] Or the problem can encompass massive, endless pollution of watersheds from abandoned mines. While the signature problems of the Earth seem to involve excess, social theories and normative arguments tend to focus on scarcity. When there is scarcity, markets emerge and prices can be established, and neoclassical economics can provide a social theory for setting policy. But in the context of excess, there is no scarcity; there are no prices, and no basis for choice. It is too difficult for policy to be established because there are too many things to know, too many possible actions, and an overload of alternatives. As we have seen in this article, when there is an excess of options, Policy Paralysis often follows.[184]

Abandoned mines and AMLs appear to be a near-textbook example of the problem of excess leading to psychological overload and then one-policy paralysis. The problem of cleaning up so many abandoned mines and remediating chronic acid mine drainage has been likened to a "certain acidity of the soul," producing "resignation, fatalism, or a sense that [the problem is] overwhelming."[185] Even the EPA's Superfund project chief responsible for addressing the 2015 Gold King Mine spill has concurred, that the scope and extent of the AML problem "is pretty overwhelming."[186] The EPA acknowledges that its "processes" for addressing abandoned mines are "drawn out," where the agency "takes far too long in the studies before start[ing] to take response action."[187]

If problems of excess create problems of policy, succumbing to delay and paralysis, then strategies should be fashioned for dealing with excess. One such central strategy is to adopt "reduction strategies" that cut the amount of excess. A reduction strategy can make more manageable the problem of excess. Therefore, a more realistic policy strategy would be one that *simplifies* the problem and reduces it to tractable terms.[188] An example of such a reduction strategy is the Occam's Razor principle.[189]

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183. *See* Ceballos et al., *supra* note 6.

184. *See generally*, Abbot, *supra* note 111.

185. LIMERICK, *supra* note 3, at 11.

186. Bruce Finley, *EPA Crews Working on Gold King Cleanup Find Elevated Lead Threatening Birds, Animals and, Potentially, People*, DENVER POST (Oct. 20, 2017), https://www.denverpost.com/2017/10/19/gold-king-mine-cleanup-epa-lead-spreading-to-animals-people/.

187. *Id.* EPA always conducts lengthy "remedial investigations" before contemplating action involving AMLs.

188. Abbott, *supra* note 111.

189. Hauke Riesch, *Simple or Simplistic? Scientists' Views on Occam's Razor*, 67 THEORIA 75 (2010).

B. SIMPLIFYING THE COMPLEX

Much of this article has tried to exemplify the success of science in making predictable and more manageable that which appears to be overly complex. The problem of AMLs is a classic "big" problem. The tens, if not hundreds, of thousands of abandoned mines are a textbook example of a complex system, characterized by excess. The extent of this excess has stymied the implementation of effective policy. However, when one turns to science-based tools, such as probability theory,[190] systems theory,[191] game theory,[192] and chaos theory,[193] it is possible to find patterns and predictability within the complexity of the abandoned mine problem. That calm within chaos, in turn, permits the development of policy, instead of Problem Paralysis.

The Occam's Razor principle is a science-based tool that urges the same approach to complex problems and seemingly intractable issues. Occam's Razor urges methodological reductionism. The principle holds that the best policy to address a complicated set of facts caused by excess (e.g., an excess of AMLs) is often the *simplest* policy, or the simplest approach to correct the problem.[194] In other words, the best reduction strategy when confronting a problem of excess is a strategy that simplifies it and reduces it to manageable terms.

Consistent with Occam's Razor and similar reduction strategies, any policy addressing a big problem like AMLs should *not* aspire to a comprehensive "perfect" cleanup of the hundreds of thousands of abandoned mines dotting the American West. To attempt that goal is to bring on the Paralysis Paradox. What is more effective than endless studies or hand-wringing about the enormous scope of the problem is the need to take some action—action where at least something gets done. In other words, it is more important that the problem be addressed than for the problem to be solved.

When policymakers consider how to treat acid mine drainage, they should realize that there are two distinct methodological approaches. One approach—"active" mine cleanup—is cumbersome and expensive, requiring much time and commitment of resources. The other approach—"passive" mine cleanup—is simpler, quicker, less expensive, and yet effective at minimizing the environmental damage of abandoned mines. Active treatment is comprehensive and reliable. But it involves the construction, and operation, and maintenance, of large treatment facilities which have high upfront costs and even higher long-term maintenance expenses. By contrast, passive treatment is faster, cheaper, and—consistent with Occam's Razor—*simpler*. One prevalent passive method involves constructing treatment ponds and

190. *See supra* notes 46–72 and accompanying text.
191. *See supra* Part IV.A.
192. *See supra* notes 152–161 and accompanying text.
193. *See supra* notes 163–181 and accompanying text.
194. *See* BATCHELOR, *supra* note 19; *see also* FRANK WILCZEK, A BEAUTIFUL QUESTION: FINDING NATURE'S DEEP DESIGN 15 (2015) (Nature employs, in her basic workings, an economy of means).

wetlands downstream of abandoned mines that naturally purify the acid mine drainage. Another simply diverts mine water away from acidic waste rock.[195]

To its credit, the EPA is beginning to embrace the simpler, cheaper, and speedier approach to AML cleanup. This approach has been likened to a "quick-fix approach," because the remedial action can be accomplished in a short time period.[196] EPA crews in southwestern Colorado used the Occam's Razor principle to swiftly stop an acidic, fifteen gallons-a-minute flow from the abandoned Brooklyn Mine. "It took half a day. All we did was redirect the acid flow so that it didn't cross waste rock," explained EPA Superfund project manager Rebecca Thomas.[197] EPA decided to "begin with baby steps" to clean up toxic abandoned mines because EPA officials are "fighting to prevent paralysis."[198]

Instead of relying on a full CERCLA Superfund cleanup for the hundreds of mines still leaking around the infamous Gold King Mine, both the EPA and local officials instead are more realistic. They recognize that there is, and there will continue to be, a lack of federal CERCLA funding for a large-scale mine cleanup. Rather than rely on Congress to step up and either fund Superfund or reauthorize the industry tax which funded the cleanup money, those interested in actually doing something about abandoned mines in the West have conceded that such hopes are delusional. To wait on federal financial fixes will inevitably lead to Proposal Paralysis. Innovative acid mine remediators have been more practical in tapping sources of mine cleanup money. For example, the Brownfields Revitalization Act of 2002 permits grants to acid mine remediation projects where restoration of the natural landscape is the primary concern.[199] The U.S. Forest Service also receives $20 million annually for the assessment and cleanup of abandoned mines in National Forest watersheds.[200]

In addition to realism about cleanup funding, policymakers should be equally realistic about forms of legislative activism and fixes that work. One of the essences of "Proposal Paralysis," especially by academic commentators, is to propose statutory changes which seem self-evident, but which in fact have no chance of becoming law. For example, it seems obvious that the 1872 Mining Law should be amended so that hard rock miners have a tax imposed on mineral extraction to

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195. LIMERICK, *supra* note 3, at 39.

196. Bruce Finely, *Embattled EPA Pitches 40 "Quick Fixes" to Slow Poisoning of Water at Inactive Colorado Mines*, DENVER POST (Apr. 23, 2017), https://www.denverpost.com/2017/04/23/embattled-epa-pitches-40-quick-fixes-to-slow-poisoning-of-water-at-inactive-colorado-mines/.

197. *Id.*

198. *Id.*

199. 42 U.S.C. § 9628; Pub. L. No. 107-118 (2002); Kevin Fixler, *Summit County Already Worrying About Proposed Cuts to EPA "Brownfields" Budget*, DENVER POST (Mar. 10, 2017), https://www.denverpost.com/2017/03/10/summit-county-brownfields-environmental-protection-agency/ (the EPA's Brownfield's Program, which provides funding to sustainable reuse of contaminated property, has contributed funds for the cleanup of the Peru Creek Basin area between Keystone and Montezuma, Colorado).

200. *Abandoned Mine Lands*, U.S. FOREST SERV., https://www.fs.fed.us/science-technology/geology/aml (last visited Apr. 22, 2018).

remediate abandoned mine cleanup—or be required to post a reclamation bond as a condition to mining.[201] However, hard-rock mining companies fear that such up-front economic burdens will have the effect of pricing their commodities out of the international market, and will vigorously resist such statutory amendments. Such resistance has successfully beaten back all attempts to add tax or bond provisions to the iconic 1872 Mining Law.[202] A better way to raise revenue for abandoned acid mine remediation may be a tax not on mining production, but on the processing of metals into consumer products. This tax would fall directly on the consumers who benefit from mineral commodities. Another source of revenue could be a state tourism tax, because abandoned mine remediation restores aquatic habitat, which has become a major attraction for visitors in most western states.[203]

Occam's Razor would similarly urge that legislation to protect good Samaritans against Clean Water Act liability be both simple and politically realistic. There is broad consensus on the need for good Samaritan legislation, but when such legislation was proposed in the past, it had a double objective—providing an exemption for Clean Water Act liability *and* setting up a funding mechanism for AMLs.[204] A simpler solution to the good Samaritan problem would not attempt to address the question of who will pay for the cleanup, but only ensure protection from liability for those who do cleanup.[205] There are private entities ready to step in and take over cleanup of abandoned mines, so long as liability will not attach.[206]

When liability is not an issue, local governments are then free to come up with innovative ways of addressing the problem of abandoned mines. For example, in Colorado, a state burdened with tens of thousands of inactive mines, many downstream localities experience a double-pronged evil: their surface water is contaminated acid mine water, and their high population growth rates mean there are diminished supplies of fresh water. Some of these communities are seeking to address this issue by purchasing the underground water that is the source of the water being discharged from the abandoned mine. Their plan is to pump the water from the reservoir feeding the mine discharge and route the uncontaminated water directly to population needing freshwater. If successful, the underground water would be prevented from reaching exposed rock in the mine tunnels, and instead be made available as a "new" and clean freshwater source.[207]

201. *See supra* note 130 and accompanying text.
202. JOHN LESHY, THE MINING LAW: A STUDY IN PERPETUAL MOTION (2014).
203. LIMERICK, *supra* note 3, at 36–37.
204. *See supra* note 130 and accompanying text.
205. LIMERICK, *supra* note 3, at 37.
206. Kara Mason, *Legacy Eyeing Cotter Sites: The Denver Clean-Up Firm Wants to Take Over a Mill and a Mine*, DENVER POST, July 22, 2017, at 9A (so long as the liability issue is settled, the Legacy Land Company is in the business to do "really good, complicated [mine] cleanups").
207. Bruce Finley, *Mining for Water*, DENVER POST, Jan. 19, 2018, at 1A.

The lesson for policymakers, again, appears to be to "Keep it Simple."[208] If one simplifies policy approaches and possible solutions to big problems, then at least something gets done. It may not be perfect, or comprehensive, but it avoids paralysis.

CONCLUSION

Science is useful to environmental law and policy for more than just informing decision-making or quantifying risk or identifying harms. Science can also be a useful tool when lawmakers are seeking to develop policy addressing complex environmental problems that seem to have enormous scope, such as the problem of abandoned mines in the West. Such "big" environmental problems are too often met with policy paralysis. This paralysis both prevents the implementation of remedial or corrective action and results in the continuation of the problem. Scientific theories, ranging from Systems Theory to Game Theory to the Occam's Razor Principle, can help to avoid this paralysis. When these scientific theories are applied to big environmental problems, an environmental issue which might otherwise seem complicated and complex becomes manageable. Whether the big problem is abandoned mines, the subject of this article, or other big environmental problems, such as climate change or mass extinctions, science can help in the development of effective policy.

208. *See* CASS SUNSTEIN, SIMPLER: THE FUTURE OF GOVERNMENT (2013).