Regulating uranium mining in the Grand Canyon Watershed: The science-policy interface

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The Grand Canyon Watershed (GCW) – the area including the National Park, Grand Canyon Parashant and Vermillion Cliffs National Monuments, multiple Native American Reservations and over one million acres of public federal land – is home to rich deposits of uranium. Breccia pipe uranium mining in this area has gone through two major periods: one during the Atomic Era of 1950s-80s, and a second boom between 2004-08 due to spiking global prices. Mining the GCW has been a politically contentious endeavor, whereby science and policy meet on the stage of national decision-making. This paper investigates the science-policy interface when it comes to regulating uranium mining in the Grand Canyon Watershed. Specifically, it first reviews the technical, regulatory, and political history of uranium mining between the 1950s and 2012, providing background to the industrial and political landscape. Second, it reviews the scientific literature that investigates the environmental and social impacts of uranium mining in the area. Last, it contextualizes this research in the science-policy interface by reviewing the politics of 2012 to present day through the lens of the multiple streams policy framework.

I. Background: Grand Canyon uranium mining & regulatory oversight

<u>Uranium mining methods and industry development in the Grand Canyon</u>

Uranium is a chemical element, most commonly used for fueling atomic power sources or weaponry, which naturally occurs across 14 western states in America. Uranium has three isotopic forms, U-238 (most common), U-235 and U-233, and it is the heaviest naturally occurring element with a half-life of ~4.5 billion years. Since uranium mining's inception in the 1940s there have been more than 15,000 mining claims made across the country, though in recent years uranium is only being mined from six locations in Wyoming and Nebraska (EIA 2019a).

The Grand Canyon watershed is home to considerable uranium deposits with an estimated 1.3 million tons of uranium. These levels are three times more than deposits in the rest of the country, making it an attractive location to mine (Alpine et al. 2010). Uranium ore in the Grand Canyon area is mined from breccia pipes, which are underground formations created by rock collapses, composed of mixed mineral and rock. Breccia pipes were created when groundwater dissolved, leaving cavernous pipes up to hundreds of feet in diameter, which were later filled with water carrying minerals such as uranium, and again dissolved over time (Bills et al. 2011).

The first period of uranium ore mining began after World War II and continued into the 1980s, in what was dubbed the Atomic Era. In the Grand Canyon, the Orphan Mine was the first area to have been identified for uranium exploration in 1951. Orphan Mine was an old copper mine dating back to 1893, and though it was located within the National Park borders, it was able to call upon mining claims that predate the 1919 establishment of the Park.[1]

During the Atomic Era, conventional mining methods included open-pit or below-ground (tunnel mining), which involved digging up uranium ore. Uranium ore contains some economically viable amount of uranium, usually 0.05 percent to 0.2 percent uranium oxide, and so gathering rocks by these mining methods for eventual milling was the traditional way of processing uranium. A common byproduct of conventional mining practices is waste rock, which is a pile of ore that sits on mining property. Ore with valuable amounts of uranium in them are mined and then milled (also called

[1] This site was mined up until 1969, and officially acquired by the Park in 1987.

concentrated) into "yellowcake," named after the bright yellow color of the mineral, which is also called triuranium octoxide (U_3O_8) or uranium concentrate.

The second wave of uranium mining came in response to surging global uranium prices, starting around 2004 and climbing considerably in 2006 after a flood in the Canadian Cigar Lake Mine, one of the largest producers of uranium. This period set off a rush of mining claims and proposed operations across the United States, and the Grand Canton Watershed was no exception. Prices climbed from $20 per pound in early 2004 to a peak of $148 per pound in May 2007. The mining method more popular during this era on onward has been in-situ recovery (ISR), also called solution mining, which circumvents the removal of ore. Rising in commercially popularity as early as the 1990s, ISR utilizes underground pipes to chemically dissolve the uranium minerals and pump the solution up to the surface, eliminating the waste rock (World Nuclear 2017). The uranium rich solution is then extracted and concentrated at the ISR location, as opposed to a separate milling facility as is the case with conventional milling.

In conventional or modern techniques, the concentrated uranium (U_3O_8) is then transported to refineries to enrich the concentrate into gaseous uranium hexafluoride (UF_6) and then a fuel pellet (UO_2), which then finally fuels rods for atomic energy production. This power source critical for nuclear because it is an isotope that can split easily, which is necessary for atomic power.

The Grand Canyon Watershed now has more than 10,000 mining claims, 831 of which were active as of 2018 (Reimondo 2019), spread across three different parcels. To the north, Bureau of Land Management owns two parcels, and the Kaibab National Forest manages the third in the south (Figure 1). Within these parcels is ~12% of the total uranium in northern Arizona, while another 35% is within the National Park or National Monuments, unable to be mined (Bills et al. 2011). The renewed attention on uranium mining after the global price peak in 2007 has created tension between industry, government and local stakeholders with regards to access and mining rights on this land.

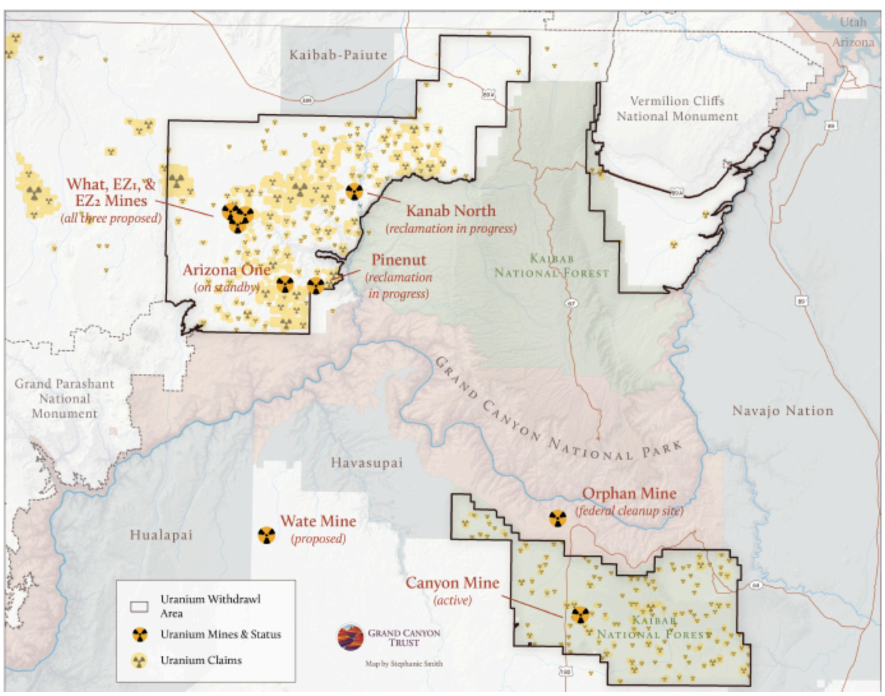

Fig. 1. Grand Canyon Watershed with mining claims and federal land partitions (Reimondo 2019)

Regulatory oversight of uranium mining

The regulatory oversight of uranium mining operations is polycentric, in that there are multiple overlapping jurisdictions with nested responsibilities (Hooghe and Marks 2003). The key actors include the governing bodies of federal lands, particularly the Bureau of Land Management and the National Forest Service, as 75% of the nation's mining claims are on federal or tribal land (USEPA 2007). These agencies were some of the original regulating bodies that worked to comply with the General Mining Act of 1872. This act, based on the mining efforts of the Gold Rush decades earlier, asserts that the government will protect private claims to public land if a mineral resource is located. In the 1970s Environmental Era, the role of the states in regulating mining became relevant due to federal legislation such as the Clean Water Act (CWA) and Clean Air Act (CAA), which set goals under the Environmental Protection Agency (EPA). This includes monitoring and permitting systems to regulate household and industrial level point-source pollution such as industrial mining waste. States are often responsible for the execution of the CWA and CAA, which includes regulating permitting alongside federal bodies, and requesting reporting material such as an Environmental Impact Statement.

Beyond the mining process, the US Nuclear Regulatory Commission (NRC) takes over the regulation of uranium from the stage of milling onward, which is outside the scope of this paper. Note that ISR is itself considered a milling rather than a mining practice, so NRC regulations apply this this form of mining, while open pit or tunnel mining are monitored by federal lands. Once the uranium is milled into a concentrate of U_3O_8, the NRC manages it possession, use and transport.

The management and remediation of the waste from conventional open pit and tunnel mines is left to either the federal lands managers, or the EPA under their monitoring of TENORM (Technologically Enhanced Naturally Occurring Radioactive Materials). This branch of regulation focuses on identifying and minimizing human and environmental harm from the uranium mining process. It dominantly deals with mining waste rock, due to the fact that the US law does not consider them to be a radioactive byproduct, and so it is not required to be disposed into specialized radioactive waste facilities (USEPA). However, the exact burden of managing the waste materials of mining is undefined, and so it is common that it goes unmonitored.

Policies and regulation pre-2012

The modern day tensions related to mining reflect the clash between the 1872 General Mining Act and the Atomic Era's unbridled exploration, with the Environmental Era's regulations, alongside highly politicized science and environmental justice movements. In order to trace the pattern of this conflict, the case of the Canyon Mine can serve as an example of mining development in the area. In 1984, Energy Fuel Inc. (EF). submitted a proposal of operations at Canyon Mine – a mining claim made six miles south of the Grand Canyon. Located in the Kaibab National Forest, this proposal was reviewed and approved by the National Forest Service in 1986 after an initial Environmental Impact Assessment. Though the local Havasupai Tribe appealed the proposal for operation throughout the latter half of the 1980s, the continued and definitive rulings were made in favor of the Forest Service's decision to support EF, which concluded in 1991. Due to falling uranium prices, however, EF stalled on its development process throughout much of the 1990s, but began revitalizing plans again in the mid-2000s based on the price increase. They were not alone, as claims within five miles of the Grand Canyon National Park went from 815 in mid-2007 to 1,130 in early 2008, many of which were excluded from environmental review (EWG 2008).

In response to the surge in mining claims, Arizona Democratic Congressman Grijalva proposed the Grand Canyon Watersheds Protection Act in 2008. This proposal would have designated the Grand Canyon Watershed as a National Monument, protecting more than one million acres from current and future mining operations. This act was supported by environmental groups, most outspokenly being the local Havasupai Tribe, the Grand Canyon Trust, and a network of local environmental NGOs and businesses who formed the Grand Canyon Watershed Coalition. Though the Watershed Protection Act was not taken up by either the House or Senate, the energy of environmental groups was among the spirit capitalized on by up-and-coming President Obama. In 2009 the Obama administration placed a two-year moratorium on uranium mining in the area in order to support a broad scale Environmental Impact Assessment (EIA) and encourage more research on the impacts. Two-years later, the administration declared another 20-year moratorium on new mining claims, set to last from 2012-2032. The following section reviews the research that has responded to these calls for more information.

II. Research on impacts of uranium mining

The demand for more research by the 2009 and 2012 moratoriums called attention to the ecological, hydrogeological, and social science that has been conducted in relation to uranium mining. The US Geological Survey (USGS) was particularly tasked with researching the topic in the Grand Canyon, which is what has been the driving most recent research in the area. However, there has also been research conducted by other stakeholders – the EPA, the Grand Canyon Trust, and environmental justice scholars – all of which have relevance to our understanding of uranium mining impacts.

<u>Soil, water quality, and biotic impacts from USGS</u>

Tasked with researching more since 2009, USGS has produced a series of research reports, conference proceedings, and academic articles over the past ten years. The first of these was a four-chapter report outlining the uranium resource availability, the impact of previous mining efforts, historical water chemistry, and pathways for uranium-induced ecotoxicity (Alpine et al. 2010). Focusing on the impact of previous mining efforts, the second chapter found that while historical levels (without mining) of uranium were found to be on average 2.4 ppm soil concentration in the region (max 5.6 ppm), soil samples around five historic mining sites had on average 9 ppm uranium. These increased levels are likely due to both leaching from rainwater, as well as weathering and dust transport. For example, at Kanab North Mine, where waste rock has been exposed for over 20 years, there is evidence of dust transport whereby soils outside the perimeter of the mining area average 28 ppm uranium (compared to 2.4 ppm average). At another site, Pigeon Mine, uranium concentrations are visualized in Figure 2. Here, concentrations of uranium were highest (171 ppm) at historical waste sites (some of which have not been remediated), as well as in rock (79.1) and soils surrounding the waste sites.

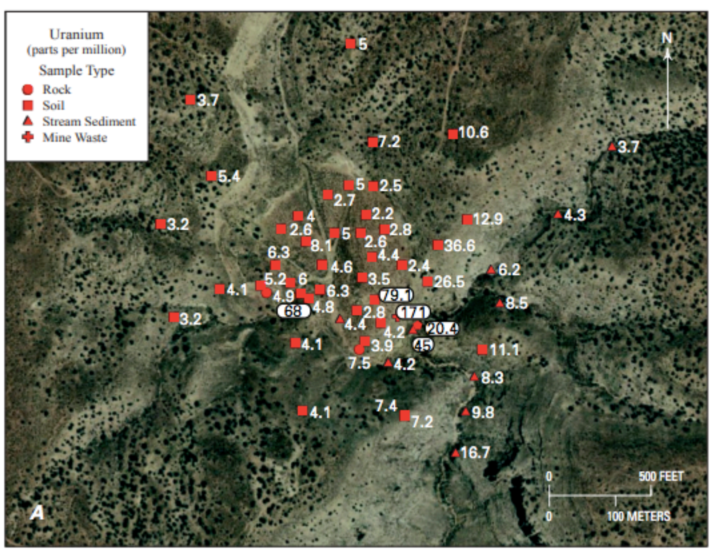

Fig. 2. Pigeon Mine uranium concentrations (Alpine et al. 2010)

At Hack Canyon Mine, where there was a flash flood that washed waste rock and ore downstream, stream sediment samples were tested for levels of elements above a baseline upstream. Uranium ranged from 2.1-10.2 ppm, compared to the 1.7 ppm baseline, and arsenic ranged from 9-17 ppm, compared to the 4.6 baseline average (Figure 3).

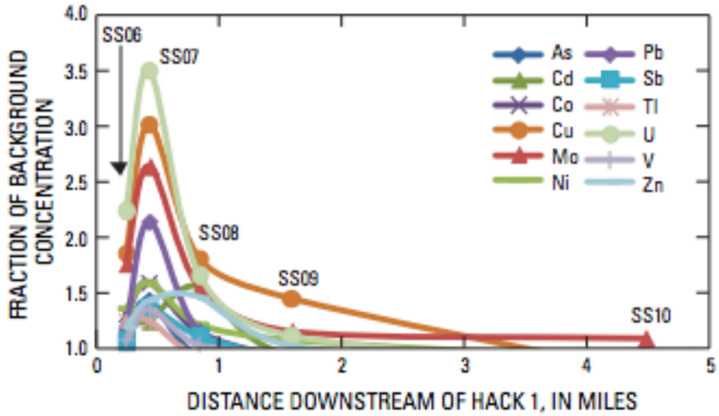

Fig. 3 Ratio of concentrations of metals in stream sediments to their concentrations in upstream sediments (control) as a function of distance downstream from Hack Canyon Mine (Alpine et al. 2010)

Though this report collected no biological data, the fourth chapter was dedicated to reviewing literature on ecological impacts. Studies reviewed generally concluded that uranium can negatively affect the survival, growth, and reproduction of plants and animals, but the effect of chronic exposure is rather limited. The authors note, however, that nearly all of the park's species of concern live within the three parcels of mining interest, and that there is reason for concern particularly for herbivores, aquatic species, and burrowing animals, all of which are likely receiving higher exposures to uranium (Alpine et al. 2010).

In total the 2010 USGS report found elevated levels of uranium in soils and water, which could translate to be above EPA concentrations (which in drinking water is 0.03 ppm), and some evidence of ecological impacts (though admitting large gaps in the data). However, USGS concludes that definitive findings are challenging to make, and calls for more research to identify how mineral concentrations differ between the natural geology of the GCW compared to mining conditions (Bills et al. 2011).

At the same time, a member of the Arizona Geological Survey, alongside a consulting geologist, published a report evaluating the effects of a hypothetical uranium ore spill on the water quality of the Colorado River (Spencer and Wenrich 2011). Noting that the River's average concentration of uranium is 0.004 ppm, they estimate this spill scenario would change the river to a concentration of 0.00402 ppm after a year, which they argue is both negligible in the context of normal variability, and still well under the EPA standard of 0.03 ppm. In contrast, a review of water quality data in streams, creeks and springs finds that uranium levels are elevated above EPA minimum standards, urging a more precautionary approach to future uranium mining efforts (Wachholtz et al. 2018).

Later studies on ecological impacts found that byproduct elements from mining, such as arsenic and selenium, where highest in biota connected to mining containment ponds, such as spadefoot toads (Hinck et al. 2017). Additionally, containment pond selenium levels increased from 0.3 µg/L in May 2013 (pre-monsoon) to 3.1 µg/L in August (which exceeds thresholds for aquatic toxicity), indicating the role that heavy rain events can have on metal leaching into ponds. For the small mammal kangaroo rat, the metal byproducts of arsenic and thallium may pose greater risk, particularly to juvenile kangaroo rats (Hinck et al. 2013). Thallium is particularly troubling for herbivores as it has a higher rate of transferring from soil to vegetation. Later studies of small mammals confirm that though mammals at mining sites do have higher concentrations of mining-related elements (Cleveland et al. 2019), they do not exceed thresholds, though they note the gap still present in aquatic animals.

Altogether, the evidence gathered by USGS and geology-adjacent researchers confirms that mining-related metals, including uranium, arsenic, selenium and thallium, are significantly higher compared to non-mining areas, particularly in soils and aquatic animals. However, the cautionary take-aways from these articles are mixed based on limiting understanding of thresholds, resulting in complicated interpretations for policy.

Environmental and health impacts from the EPA

The EPA is tasked to deal with mines ex-post, and thus has a series of reports on mining contamination that have been continuously published as mining operations develop. For instance, in 2007 the EPA published a two-part technical report on the history and environmental impact of uranium mining on human health and the environment (USEPA 2007). This reports reviews the potential for health implications, particularly cancer risk, and finds a as a log-linear relationship between the concentration of uranium (pCi/L) to risk of cancer, whereby cancer risks can increase by 3.5 units from minimal to maximum reasonable uranium exposure near mines. With regards to water contamination, it is argued that with limited precipitation, as is the case in the Colorado plateau, the chances of aboveground mining waste seeping into groundwater is considered low. However, underground mining operations that intersect an aquifer could have contamination potential. Using soil-screening guidance, the question of radionucleotides contaminating groundwater was considered. They find that uranium becomes more mobile in lower pH, which is common in mine waste areas, although migration of uranium into groundwater seems very dependent on geological conditions. For instance, there is little migration of uranium to a groundwater supply in the Yazzie-312 mine area in Arizona, with gravel and sand soils, but they note other studies that have found considerably elevated levels of uranium near Monument Valley mines in shallow groundwater (Longsworth 1994 in USEPA 2007). And because uranium plumes only travel up to 1.25 miles, this limits the spread of uranium concentration in water sources (USEPA 2007). In total, the EPA outlines risks and notes that there is variation based on soil-type, precipitation amounts, and location of groundwater resources.

Environmental NGOs & Environmental Justice Research

Reports coming from environmental non-governmental organizations stand in contrast from both the USGS and EPA research, as they assert far more definitive positions on the science by the government. For example, the Grand Canyon Trust published on the topic of uranium mining in 2019, reviewing the USGS 2010 report's findings as cause for concern – pointing to the elevated levels, the history of the Hack Mine flood, and the notable radioactive levels near mining sites (Reimondo 2019). Additionally, the troubling history of uranium mining in the Navajo Nation was a topic highlighted in many environmental NGO reports. Between 1944 and 1986, 30 million tons of uranium were mined from Navajo Land in Arizona, just 300 miles from Grand Canyon Watershed. Throughout this time, Native Americans were often employed in the mines and mills, and then in 1979 the New Mexico Church Rock Mill had a dam breach, spilling of toxic effluent into the Puerco River (Brugge et al. 2007). With 1,100 tons of uranium mining waste and 93 million gallons of radioactive water, this event is still the US's largest spill of radioactive materials. Such an example is useful for historical and academic reference, though virtually no references are made to it in the debates of the Grand Canyon watershed assessments by USGS, BLM, or associated scientists.

The effects suffered by the Navajo Nation from 30 years of mining, abandoned mines, and the dam failure resulted in the EPA designating the area as a Superfund site in 1994, and continued settlements currently totaling $1.7 billion contribute to reclamation (USEPA 2013). Despite this being the largest radioactive spill in US history, scholarship on the issue is limited, and documentation of ecological and public health effects is fairly limited to media releases and public health journals. Though it is hard to link health issues to any one acute or chronic event, health issues including cancers and kidney diseases have been statistically linked to exposure (Hund et al. 2015). And in an assessment of water sources, 12% were identified as exceeding the uranium Maximum Contaminant Level, and 15% exceeded these levels for Arsenic, whereby sources closer to abandoned mines had a greater chance of contamination (Hoover et al.

2017). This research by environmental NGOs and environmental justice scholars, however, is left out of technical reports by governmental researchers.

III. Discussion: The science-policy interface

Government action in the context of scientific research: 2009 to present day

Though much research has been conducted between 2009 to present day on the topic of uranium mining, how it has been interpreted has contributed to a series of politicized controversies. The science-policy interface became particularly pronounced between 2009 and 2011, when the Bureau of Land Management conducted an EIA (BLM 2011) in response to the 2009 uranium moratorium. This EIA outlined four options for the future of mining (no change to permitting mining claims, or limit mining development for 20 years: protect one million, 700,000 or 300,000 acres), and was a 1000+ page document reviewing mining histories in the area. During the comment period, this EIA received blowback from both environmental advocacy groups and state and local governments. Specifically, regional governing bodies including the Central Arizona Project, Metropolitan Water District of Southern California, and Southern Nevada Water Authority joined together in the Lower Colorado River Water Partnership. This Partnership submitted a review to the BLM, asserting that it did not go far enough to assess the impacts of mining on water quality, and that is strongly consider additional extensions of the moratorium to accommodate additional research (Modeer et al. 2011). Additionally, a white paper by the Environmental Working Group reviewed the EIA, asserting conflict of interest between the science used and the conclusions made by the BLM, promoting skepticism of its power to inform political decisions (EWG 2011). Despite the loud regional voices opposing uranium, Arizona's Department of Environmental Quality still issued three mining permits on the land – perpetuating the contention between local groups and industries.

In light the contentious BLM Report, the Department of Interior Secretary Ken Salazar decided to take the most conservative recommendation by the EIA, extending the moratorium by 20 years on all one million acres. This moratorium, set to last from 2012-2032, was declared alongside a call for more research to understand how mining effects aquifers (DOI 2012). Still, this policy allowed for existing operations and mining claims to stay active – it only limited new claims from being made. Additionally, the administration did not approve the Grand Canyon Watershed Protections Act, which was still being pushed by Arizona Representative Grijalva in an effort to declare the area a National Monument, permanently protecting the area.

The agenda has started shifting sine the election of Donald Trump in 2016. When a long-standing appeal to the Ninth Circuit court of appeals was upheld in support of Salazar's moratorium in November of 2017, President Trump submitted an executive order the following month to officially put uranium on the "critical minerals" list, which would increase its value by placing domestic purchasing requirements (Reimondo 2019). Additionally, it was claimed that Trump's administration was considered instituting a reversal on the moratorium to promote domestic uranium stocks (Eilperin 2017). A year later still, high courts upheld the 20-year moratorium in yet another ruling against the National Mining Association in 2018, indicating that there is still strong support for the DOI order.

Despite the current administration's clear opposition to the moratorium, Representative Grijalva was bolstered by the support from the courts, and again pushed his Grand Canyon Watershed Protections Act in 2019, now H.R. 1371. In October 2019, this bill was voted on and passed in the House, and Senator Sinema then proposed the Grand Canyon Centennial Protection Act to the Senate – a partner bill that builds on Congressman Grijalva's work (December 2019 as S.3217). Currently, the future of uranium mining is hanging in political crosshairs. While S.3217 for a permanent moratorium is in the queue of the Senate, in February 2020 Trump proposed his 2021 budget requesting $1.5 billion over 10 years to develop a uranium reserve.

Discussion: Multiple streams framework for understanding the uranium policy process

The policies related to uranium mining over the past ten years beg for a deeper understanding of how science and policy interact. The multiple streams framework (MSF) aims to explain the mechanisms behind the policy process, which can provide structure for understanding why certain policies are enacted while others are not. This framework is helpful for identifying the way that scientific research alone is not the driving force behind policy, but rather how it is instrumentalized in the context of political mood and public opinion.

MSF maintains that there are three "streams" in the policy process, all of which must align in order for policy to be actualized: the problem stream, political stream, and policy stream (Zahariadis 2014). The general idea is that these streams represents a primordial stew of sorts – each of which has a myriad of public problems, policy solutions, and political actors – and only when they align is there a "policy window" in which policy can actually be brought into effect. The problem stream means that the issue at hand is perceived as a problem by the public, which is usually brought into dialogue in response to a focusing event. Focusing events are typically acute events that bring a country's attention to a topic. The political stream is the alignment of national mood, pressure group campaigns, and administrative or legislative turnover – all of which can converge to inform the political will of the moment. As far as the policy stream is concerned, it is important that the technical know-how exists in order to address the problem perceived by the public. This is often where scientific research enters into the conversation. The concept of a policy stream is that scientists, paired with policy-makers, are developing relatively robust policy quite often. However, much of it is proposed and falls flat, only to return to the stream of ideas.

In the case of GC uranium mines, an MSF assessment is presented in Table 1. With regards to the problem stream between 2009-2012, the problems were two-fold. The first problem that prompted some response was the spike in uranium prices between 2004-2008, increasing the number of mining claims and thus regional concern for the environmental and health safety of the area. Second, on the international arena in 2011 was the earthquake resulting in the Fukushima nuclear disaster. The Fukushima disaster resulted in evacuation within 20 kilometers of the plant based on leaked radioactive material, and a clean-up process that is estimated to last 30 to 40 years – all of which garnered much media attention and public skepticism of nuclear. It is likely that the Fukushima tragedy was a focusing event in 2011, aligning the problem stream to the decision for the 20-year moratorium in 2012.

Politically, the entrance of Barack Obama and his administration was in an optimal moment to challenge uranium mining in 2009. New to the office with a relatively progressive environmental agenda, calling for a two-year moratorium for research received little pushback. Still in 2012, the administration had high support, allowing for the most conservative closure of one million acres. The fact that Obama did not opt for a permanent protection for the land, however, may have been an attempt to temper his progressive policy-making in a moment of gearing up for a second election.

The role of scientific research for informing policy played a central role in 2009 to 2012 period. One of the major reasons for the moratorium was due to limited scientific information on uranium mining, and so governmental agencies were tasked with research collection and impact assessment. Despite the upsurge in efforts to determine mining impacts, evidence by the USGS was inconclusive and tentative. Based on these uncertainties, rather than convert the land into a National Monument with permanent protections, the 20-year moratorium was declared to help policy and science catch-up. And over time, this policy has had fairly strong staying power, being upheld in federal course cases in 2017 and 2018.

Table 1. Multiple streams framework assessment for Grand Canyon uranium mining

	2009	2012	2020
Problem	Rising mining claims	Fukushima	Conservation & EJ awareness
Politics	(Early) Obama	(Re-election) Obama	Trump & Republican Senate
Policy	Sparse scientific support	Scientific support	Scientific efforts ongoing

The turnover of administrations, however, is likely to shift the country's stance on uranium. The Trump administration presents a clear shift in the political mood. Moreover, with the Fukushima disaster years past now, it is challenging to say what the nation currently problematizes. Though there have been active efforts on behalf of the environmental movement, such as protecting against Keystone XL, Bear's Ear and the like, the risk of nuclear still may not be as present. So despite the existing scientific evidence on ecological impacts from more recent USGS studies, as well as more recent environmental justice research and EPA settlements related to the Navajo Nation, it is likely that the political and problem streams do not align. This being the case, the political and problem streams are likely to have turned against the chances of Grand Canyon Watershed protection from uranium mining through the recent Senate Bill, despite better science and policy supporting it.

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