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Yellowstone Super-Volcano: Evalutaion, Potential Threats, and Possible effects on Nebraska Citizens Health and Prosperity

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YELLOWSTONE SUPER-VOLCANO: *EVALUATION, POTENTIAL THREATS, AND POSSIBLE EFFECTS ON NEBRASKA CITIZENS HEALTH AND PROSPERITY*

by

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"The sleeping subterranean fires again awake and shake the mountains, and every leaf trembles. The old craters, with perhaps new ones, are opened, and immense quantities of ashes, pumice, and cinders are again thrown into the sky. The sun, shorn of his beams, glows like a dull red ball, until hidden in sulphurous clouds. Volcanic snow, hail, and floods fall on the new forest, burying it alive, like the one beneath its roots."

~John Muir

YELLOESTONE SUPER-VOLCANO: EVALUATION, POTENTIAL THREATS, AND POSSIBLE EFFECTS ON NEBRASKA CITIZENS HEALTH AND PROSPERITY

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Abstract

Yellowstone National Park is located over a hot spot under the North American tectonic plate and holds a potentially explosive super-volcano that has the ability to cause deadly consequences on the North American continent. After an eruption the surrounding region would see the greatest devastation, covered by pyroclastic deposits and thick ash fall exterminating most all life and destroying all structures in its path. In landscapes of greater distance from the event the consequences will be less dramatic yet still substantial. Records of previous eruption data from the Yellowstone super-volcano show that the ash fall out from the eruption can cover areas as large as one million square kilometers and could leave Nebraska covered in ash up to 10 centimeters thick. This would cause destruction of agriculture, extensive damage to structures, decreased

temperatures, and potential respiratory hazards. The effects of volcanic ash on the human respiratory system have been shown to cause acute symptoms from heavy exposure. Symptoms include nasal irritation, throat irritation, coughing, and if preexisting conditions are present some can develop bronchial symptoms, which can last for a few days. People with bronchitis and asthma are shown to experience airway irritation and uncomfortable breathing. In most occurrences, exposure of volcanic ash is too short to cause long-term health hazards. Wearing facial protection can alleviate much of the symptoms. Most of the long-term ramifications of the eruption will be from the atmospheric changes caused from disruption of solar radiation, which will affect much of the global population. The most pertinent concerns for Nebraska citizens are from the accumulation of ash deposits over the landscape and the climatic perturbations. Potential mitigation procedures are essential to prepare our essentially unaware population of the threat that they may soon face if the volcano continues on its eruption cycle.

Introduction

Life for mankind on this mysterious green and blue planet has never been without dilemma. All through humankind's complicated life history we have had to battle against threats of many forms. Disease, war, starvation, and many others, but none of these compare to the threats we have had to endure from our maternal steward, nature. She has provided us with perils that have left mankind in ruins, yet has given us rewards that allowed us to thrive. The severe temperatures, torrential rains, extreme droughts, and other obstacles that nature has placed in our paths have forced us to our knees and made survival on this planet a continuous challenge. Yet, time and time again we have adapted our lifestyles to make success out of natures' distress. We have been left struggling to survive yet we have managed to prevail. Through all of this trial and error with nature we have come accustomed to the inevitability and uncertainty of life on this planet. Yet there is still one trick up natures' sleeve, one that humans have not yet been forced to endure. A force of nature that is so powerful that it has the capability to leave the entire globe in ruins. This unruly beast is the super-volcanic eruption, a natural phenomenon of which humans have never experienced.

The volcanic eruption itself is not a new threat to mankind. Humans have been placed in the path of this menacing process of crust formation many times over history. But no eruption on recorded has been at the level of a super eruption. According to the Volcanic Exposivity Index (VEI), a logarithmic scale used to assess the magnitude of volcanic eruptions, a super-eruption is an event expelling a mass of 450 or more cubic kilometers of material (Newhall, 1982).). In comparison Mount St. Helens, which produced 1 to 2 cubic kilometers of volcanic rock (Fritz, 1985), was a minuscule event yet had many unfortunate ramifications on the population in the vicinity of the blast. The repercussions of an eruption of the super volcanic size are incomprehensible.

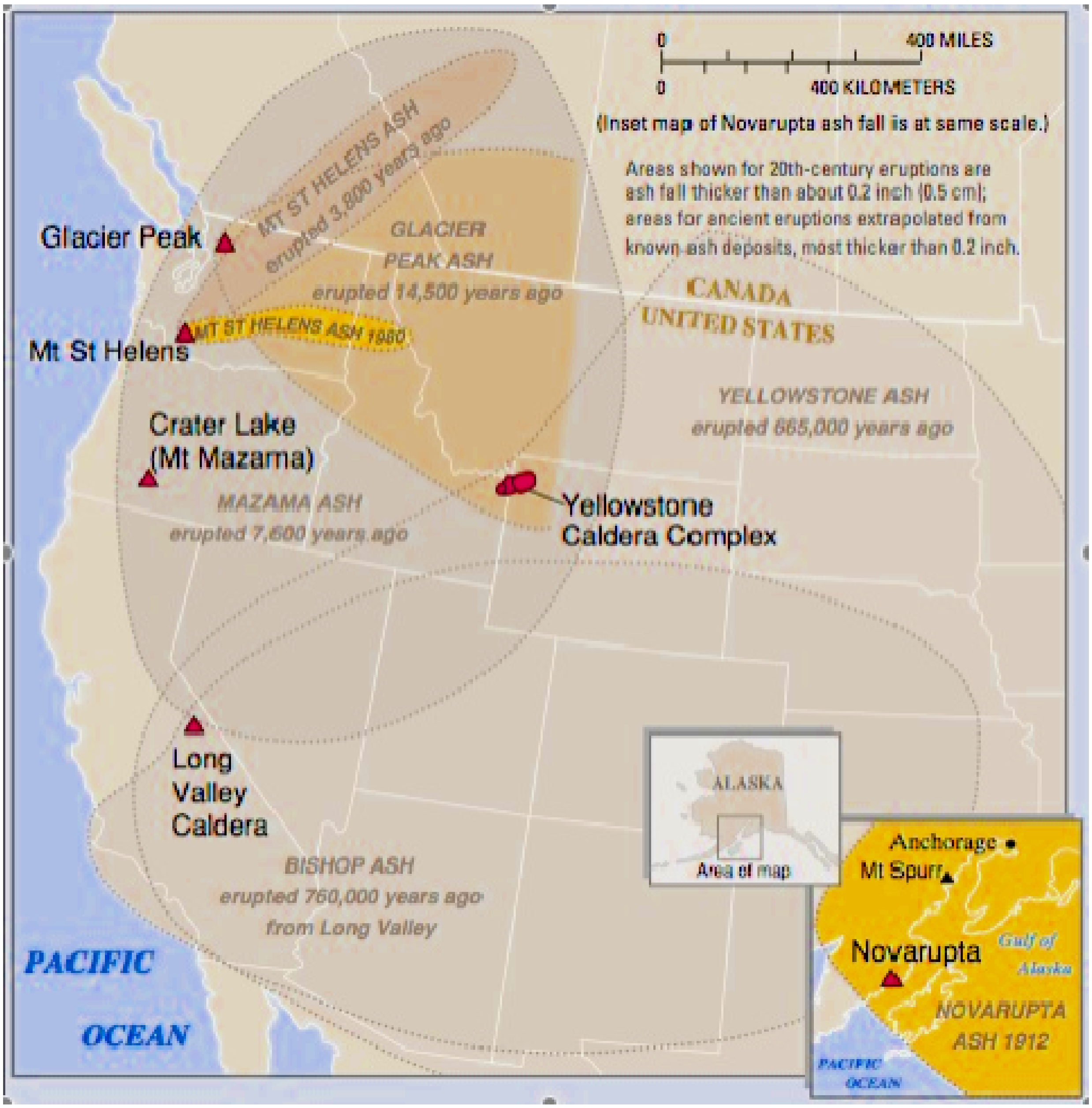
This type of eruption, as rare as it might be, is an absolute certainty in the future of this planet. It is not a matter of if an eruption will occur, but when it will occur. Currently the largest threat of super-volcanic size for Americans is a volcano largely unrecognized as such and has played a major role in the geologic development of one of our most famous National Parks.

Yellowstone National Park is the location of one of North America's most dangerous super-volcanoes. The caldera located at the center of the park formed approximately 640,000 years ago when the most recent eruption of the underlying magma chamber occurred (Wicks, 2006). Many of us have visited this extraordinary place and taken in its aesthetic beauty. However one rarely considers the extreme consequences that would result in the event of an eruption of the underlying magma chamber. Many citizens of the United States would fall victim to the destructive consequences of its eruption.

After its exploration in 1869, the Yellowstone area was described as a 'Temple of the Living God' (Langford, 1905). It was previously only accounted for in the supposed 'tall tales' of mountain men and fur traders, but later after the Washburn-Langford party undertook official exploration in 1870, the first true accounts of the area were made (Langford, 1905). After many years of extensive research it is now understood that this location was the site of a very powerful geologic event. Underneath the surface lies a hot spot, a super heated core of magma underneath the North American Plate (Lowenstern, 2006). Analysis of previous eruptions has shown that the Yellowstone super-volcano could have the potential to produce from 300 to 2500 cubic kilometers of ejected volcanic rock (Fritz, 1985).

The question at the forefront of the concerns of a possible super volcanic eruption is; what affect will it have on humanity? There have been a considerable number of sizable volcanic eruptions that have allowed humans to gather knowledge of these unstoppable events, their predictors, and their effects on the public, such as Mount St. Helens in Washington and Mount Pinatubo in the Philippines. However, an eruption of super-volcanic size is a little understood event. Mankind's only knowledge of these potentially cataclysmic events comes from research of past eruption sites and up-scaled projections from the effects of smaller eruptions (Self, 2008). In the event of an eruption of Yellowstone's super-volcano, citizens of Nebraska could potentially face detrimental consequences.

One consequence that may have the most damaging affect on the population of Nebraska is ash fallout. Review of the ash deposits of Yellowstone's previous eruptions indicate that the entire state of Nebraska has the potential of being affected, (Figure 1) (Kenedi, 2000). Ash fall can cause a wide range of damage to agriculture, structures, and power infrastructure, as well as to human health (Sparks, 2005). The health affects would likely have the most destructive consequences. The long-term ramifications of exposure to volcanic ash have only been studied over the last 40 years, especially after concern arose following the eruption of Mount St. Helens (Horwell, 2006). How the ash affects human health is dependent on its particle size, mineralogical composition, and physico-chemical properties, however these properties vary widely in eruptions, even in eruptions from the same site (Horwell, 2006). Exposure to these particles may cause silicosis, non-specific pneumoconiosis, chronic obstructive pulmonary disease, and acute respiratory symptoms (Horwell, 2006).



(Figure 1.)
A visualization of the ash fall extent of the past three events from Yellowstone as well as other significant ash fall events.
(Kenedi, 2000)

There are also many other possible consequences of heavy ash fall that can have a detrimental effect on Nebraskans' and should be examined. Damage to infrastructure from the weight of ash, disruption of communication and travel, and crop failure from thick layers of acid ash deposits are all possible outcomes (IVHHN). These consequences will cause severe disruption to citizens' life styles and future prosperity.

This paper is an extensive literature review collecting secondary data to assess the potential ramifications of an eruption of the Yellowstone super-volcano on the citizens of Nebraska. This paper covers data collected from secondary research on super-eruptions that scientists have determined from up scaling of smaller events and research on the deposits left from past super-volcanic eruptions. Next, an examination of Yellowstone National Park and the underlying magma chamber will assess the potential for an eruption. The geological structure of Nebraska's subsurface will be examined to assess trends for fallout across the state as result of past volcanic eruptions. Last to be reviewed are the health effects that may result from ash fall. This has been extensively studied since the eruptions of Mount St. Helens in Washington and Mount Sakurajima in Japan and many conclusions have been drawn. Finally, an analysis of the potential consequences of ash fall on Nebraska including the ecological and economical effects will be conducted.

Many citizens are unaware of the potential harms that Nebraska could face and are unprepared to respond to the consequences. We are in need of a preparedness plan and education on possible mitigation techniques to prepare for the future eruption.

Literature, Materials, and Methods

This paper examines the consequences to Nebraska and surrounding areas when an eruption of the Yellowstone super-volcano occurs in our future. To examine the consequences a broad analysis of previous research was conducted. The research was conducted in three phases. First an analysis of research done on super-volcanoes is conducted with emphasis on Yellowstone and its previous eruptions. Second up to date statistics on the health concerns involved with ash fallout are examined. Lastly, an analysis of consequences of ash fallout on structures, crops, and other factors that would impede daily lives of citizens is conducted. This evaluation of information will lead to a better understanding of the consequences that Nebraska will face in the event of a super-eruption and will help to determine the possible mitigation procedures we could perform to prepare ourselves.

For phase one, information collected from Harris (2008) was reviewed to aide in understanding the effects the eruption would have with an emphasis on meteorological aspects. This information was also well documented in the variety of publications that outlined the many outcomes of super eruptions such as the 2008 article by Stephen Self and Stephen Blake, the 2005 paper by The Geological Society of London including Stephen Self and Stephen Sparks, 2007 publication by Julien Louys, and 2006 article by Stephen Self. These articles provide a detailed outline of what scientists expect might occur in the event of a super-volcanic eruption including details of many of the recorded large-scale eruptions in human history.

Information on the Yellowstone magma chamber and its characteristics was gathered from Jacob Lowenstern, Robert Smith, and David Hill's article in 2006; Charles

Wicks, Wayne Thatcher, Daniel Dzurisin, and Jerry Svarc in 2006; and Robert L. Christiansen from 1984. For the evaluation park history, the historical accounts of John Muir and the journal of Nathanial P. Langford were assessed. These sources provide the information specifically relevant to the Yellowstone caldera and its underlying magma chamber as well as details on the discovery and first encounters with the Yellowstone system.

In completing phase two, research of the composition of volcanic ash of known eruptions and the potential health effects it has had on the human body was reviewed. The affects of dust and silica particles on human health are known to cause many respiratory diseases. It is probable that the volcanic ash may have similar effects on human health depending on composition and may lead to detrimental effects on the health of Nebraska citizens. Research done on smaller scale eruptions has been well documented over the past few decades as eruptions have occurred in densely populated areas. Several sources were researched on recorded eruptions and provide information on the health effects of the airborne release of ash particles including a report by Eiji Yano (1990); Claire Horwell and Peter Baxter from 2006; International Volcanic Health Hazard Network (IVHHN); the 1986 article written by Donald Dollberg, Michele Bolyard, and David Smith; information from Peter Baxter, Roy Ing, Henry Falk, Jean French, Gary Stein, Robert Bernstein, James Merchant, and Jack Allard (1981); the 1986 paper by Kris Olsen and Jonathan Fruchter; and the 1986 paper by Sonia Buist and Robert Bernstein. These resources provide information on recent eruptions where the public was exposed to ash fall for extended periods or sporadically over several years. In these cases the health effects of the ash were recorded as well as the chemical and physical composition of the ash.

To complete phase three, an evaluation of other socio-economic effects the ash fall on the public was conducted to gain further understanding of the potential consequences. Data collected from previous eruptions show that ash can have varying effects on modern life. Communication, transportation, and infrastructure will be impacted causing extensive disruption to communities. There may also be varying affects on the crops and vegetation causing disturbance to food supplies, which could lead to malnutrition or starvation in addition to the economic impact it would have on the American farmer. For this phase the 1980 report by Robert Bernstein, Peter Baxter, Henry Falk, Roy Ing, Lawrence Foster and Floyd Front was evaluated. Also many of the previously mentioned reports on the consequences of super-volcanic eruptions provided information on the damage to infrastructure and vegetation that may occur.

Results

Super Eruptions

Super-volcanic eruptions are rare extreme geologic events that lead to the formation of a caldera, pyroclastic flows over large regions, and ash fall that can cover continent-sized areas (Self, 2008). These events are rare in a human life scale but fairly common over geologic time (Sparks, 2005). Some say these events can reoccur from the same magma chamber every 100,000 to 200,000 years (Self, 2008), while others project their reoccurrence to be longer, up to 500,000 years (Sparks, 2005). In either case they are unlike any natural disaster that mankind is familiar with, and considering their severity and longevity they may be our greatest natural threat (Self, 2008). It is suggested that the longer the dormancy period between eruptions from a magma chamber the larger the next eruption will be (Sparks, 2005). We must consider these events not as a matter of if one may occur, but instead as when one will occur next. There is a probability of 1 in 10,000 that another super-eruption will occur in the 21st century, if it does in this densely populated society, tens of millions are threatened (Sparks, 2005).

There are two types of volcanic eruptions and both have ejection volumes that range from one cubic kilometer to a few thousand cubic kilometers (Self, 2006). First is an effusive eruption, such as the type that exists on the archipelago of Hawaii, which produce less volatile eruptions and emit large lava flows (Self, 2006). The second type is what this paper is concentrating on, explosive eruptions. These eruptions are violent and expel large amounts of fragmented material in the form of ash and pyroclastic deposits (Self, 2006). During an explosive eruption the magma from the underlying chamber expands and rapidly cools forming the fragmented ash particles that are violently expelled (Christiansen, 1984). A complex relationship exists between the mass of expelled magma and the volume of erupted material as these measurements are usually different is size (Self, 2006). Our current understanding of super-volcanic eruptions is based on studies of observed explosive eruptions and on the ash deposits from known past eruptions (Christiansen, 1984)

By definition a super-volcano is one that produces an eruption with an excess of 450 cubic kilometers, or greater than 1×10^{15} kilograms, of material (Self, 2006). The last super-volcanic eruption to occur on Earth took place in New Zealand approximately 26,000 years ago from the Taupo Volcano. It released 530 cubic kilometers of material (Self, 2008). Another more extreme super-volcanic eruption occurred from the Toba

Volcano, approximately 75,000 years ago (Self, 2008). This volcano, located in Sumatra, Indonesia, expelled approximately 2,800 cubic kilometers of material (Self, 2006). Some researchers propose that the Toba eruption could have led to a bottleneck in the human population, however there is very little evidence to support this hypothesis (Gathorne-Hardy, 2003). If a decline in the human population was a result of the eruption there would be similar effects on other species including many extinctions and none are recorded to have occurred from Toba (Gathorne-Hardy, 2003).

Eruption intensities are assessed from a scale created in 1982 by Christopher Newhall and Stephen Self called the Volcanic Explosivity Index (VEI), similar in concept to that of the Richter scale used for evaluating earthquakes (Newhall, 1982). Eruption intensity is determined based on three criteria: volume of ejected material, height of the ejected column, and duration of the blast. The VEI illustrated in Table 1, a representation of the table found in Newhall and Self's original paper, ranks anything above a 4 as cataclysmic with definite stratospheric injection (Newhall, 1982). Super-eruptions are usually considered any eruption of VEI 6 or greater. In the last 36 million years there have been 42 super volcanic eruption ranked VEI7-8, and 5 in the last one million years (Lowenstern, 2006). It should be noted that magnitude values of all past eruptions are approximate and based upon scientific research and assumptions related to what is known of smaller scale eruption episodes (Self, 2006).

VEI	0	1	2	3	4	5	6	7	8
Description	Non-explosive	Small	Moderate	Moderate-Large	Large		Very Large		
Ejected Volume (km^3)	0.0001	0.0001-0.01	0.01-0.1	0.1-1.0	1.0-10	10-100	100-1000	1000-10k	> 10k
Height of Column (km)	< 0.1	0.1-1	1-5	3-15	10-25		> 25		
Qualitative Description	Gentle, Effusive		Explosive		Cataclysmic, Paroxysmal, Colossal				
Duration (hrs)	< 1		1-6	1-12	1-12 or more	6-12 or more		> 12	
Tropospheric Injection	Negligible	Minor	Moderate	Substantial					
Stratospheric Injection		None		Possible	Definite		Significant		

(Table 1)

Another classification scale used bases intensity on the mass of ejecta and was developed by H. Tsuya in 1955 (Self, 2006). His scale defines intensity with an M for magnitude, where M = $\log_{10}$ (mass erupted in kg) – 7.0 (Self, 2006). In this classification scale super-eruptions are M7-8 and above (Self, 2006). Only one eruption rating an M9 exists according to scientific research and is the largest known super eruption to have occurred on Earth (Self, 2006). It is termed the 'Fish Canyon Tuff Event' and occurred over 28 million years ago in what is now the state of Colorado. This monstrous eruption released approximately 5,000 cubic kilometers of material (Sparks, 2005).

Only a few threatening super-volcanoes are being closely monitored at this time, Yellowstone, Long Valley in California, and Phlegrean Fields in Italy (Sparks, 2005). Seismic unrest, ground heating and swelling, changes in groundwater temperature, and increased concentrations and fluxes of volatile gases may indicate an impeding eruption (Sparks, 2005). However, at this time, we poorly understand the length of build up to an eruption, if the size or course of events can be predicted with monitoring, what precursory activity is, or if initial activity will lead to an eruption (Self, 2006). Studies of source vents indicate that super-eruptions occur only from very complex and evolved magma chambers (Christiansen, 1984).

In order for a super-eruption to occur a silica-rich magma is required, in addition, the magma must be near the surface and contain a high amount of silica with at least 40% suspended crystals, and contain a large amount of dissolved gases (Lowenstern, 2006). These characteristics lead to a magma that is viscous having a high surface tension, which allows for quick degassing and fragmentation of the magma (Lowenstern, 2006). This fragmentation is a result of the magma expanding and immediately cooling as pressure is released from the system (Christiansen, 1984). This type of pyroclastic magma system is driven by the high volatile gas content, which is released as the magma rises to the surface (Lowenstern, 2006). If the heat and gases fail to leak out in small eruption forms, the system will eventually lead to a super-eruption (Lowenstern, 2006).

When one of these super-eruptions occurs, it would most definitely be a global catastrophe (Self, 2008). However studies of these monstrous events suggest that they alone are not capable of causing mass extinction of a species (Louys, 2007). Depending on timing, magnitude, and intensity of the eruption, many animals are able to survive these events (Louys, 2007). Most animal populations can recover quickly as long as the flora populations are able to recover (Louys, 2007). For human concern, an eruption such as this could affect agriculture over millions of square kilometers and could alter the global climate for decades (Lowenstern, 2006). Considering 90% of the world's population lives in the Northern Hemisphere and most of the food production takes place here as well, a super-eruption can, and most likely will, cause devastation to many populations (Self, 2008). It is a natural disaster that we are unable to prevent and the next eruption could occur tomorrow or 10,000 years from now (Sparks, 2005).

Yellowstone Super-Volcano

Yellowstone National Park is one of America's most adored natural landscapes. It was once termed a 'Wonderland' by John Muir and a 'Temple of the Living God' by the men who worked diligently to set it aside as a national park. Reports were heard in the early 1800's about a place out west where mud boiled and water shot out of the ground as high as the tree tops (Langford, 1905). However few would believe the tall tails of the mountain men who told them. A report made to the War Department in 1863 by Captain John Mullan confirmed the rumors to be true (Langford, 1905), and very soon after it was discovered it was dedicated and set aside for the people (Muir, 1901). It was not desirable for agriculture, mining, or settlement because of the thick layer of volcanic rock covering the surface of the land (Muir, 1901). Muir once described the violence of Yellowstone, "*…this destruction was creation, progress in the march of beauty through death*" (Muir, 1901).

The Yellowstone volcanic system covers a region of 6500km^3 including parts of Wyoming, Montana, and Idaho (Christiansen, 1984). This hot spot, now located at Yellowstone, began producing explosive eruptions 16.5 millions years ago but has decreased in activity over the past 10 million years (Lowenstern, 2006). This is most likely due to the cooler and thicker crust layer that has developed over top (Lowenstern, 2006). Yellowstone's volcano was once thought to be an extinct, dormant system until Jagger recognized activity in 1922 (Lowenstern, 2006). In the 1960's R. Christiansen discovered and described the calderas and the corresponding eruption history of the system (Lowenstern, 2006). In 1970 researchers noticed that the caldera floor had risen 80 centimeters since the first measurements were taken in the 1920's (Lowenstern, 2006). Since then more ground deformation has been noted. Subsidence began in 1985 and continued until uplift began in 1995 (Wicks, 2006). By 1997 the entire caldera floor was rising (Wicks, 2006). The activity from 1997 until 2002 revealed evidence of the inner workings of the system and the two resurgent domes were discovered, Sour Creek and Mallard Lake (Wicks, 2006). These changes were proof that this was indeed not a dormant system but instead an active magmatic chamber of which we need a much better understanding.

Changes in the two resurgent domes are the result of two underground processes, the pressure flux in the hydrothermal reservoir and movement, formation, and crystallization of the underlying magma (Wicks, 2006). The hydrothermal reservoir is an active water system located between the magma chamber and the surface (Lowenstern, 2006). The rising heat and gases of the magma chamber meet the hydrothermal system and react with the water, which contacts the rock and transports minerals as it flows (Lowenstern, 2006). The intensely hot temperatures of the water in this system the concept that molten volcanic rock is a few kilometers below the surface (Fritz, 1985). The system has a convective thermal-energy flux of 1800mW/m^2, which indicates a magma body is cooling only a few kilometers below (Christiansen, 1984). This hydrothermal system is extremely important and helps control the effects of the magmatic system (Lowenstern, 2006). This thermal energy flux is also the driving force behind the steaming attractions of the park. There are over 1000 geysers and hot springs, fumaroles, and mud pots, (Fritz, 1985).

Study of past volcanism in the United States has led to a general model, which indicates that rising magma and associated melts may amount to 10 times the mass of the erupted material (Christiansen, 1984). These studies have also indicated that the Yellowstone system may have a magma production rate of $0.03 km^3/yr$, which is comparable to the most active volcanic regions on Earth such as the mid-ocean ridges, Hawaiian Archipelago, and Iceland (Christiansen, 1984). Using approximations for the amount of material ejected from the last two eruptions and the corresponding time that elapsed before these eruptions suggests Yellowstone has a magma build up of approximately 1 cubic kilometer every 1196 years, or $0.00084 km^3/yr$.

Calculations

Mesa Falls: $400{,}000 yrs \div 280 km^3 = 1430 yrs/km^3$

Lava Creek: $960{,}000 yrs \div 1000 km^3 = 960 yrs/km^3$

Average production: $1430 yrs/km^3 + 960 yrs/km^3 = 2390 yrs/km^3 \div 2 = 1195 yrs/km^3$

$1 km^3 \div 1195 yrs$ **= *$0.00084 km^3/yr$*** $\times$ 640,000yrs = ***$535.56 km^3$***

Literature research: ***$0.03 km^3/yr$*** $\times$ 640,000yrs = 19,200yrs $\div$ 10 = ***$1920\ km^3$***

(Table 2)

If this build up rate is realistic the forthcoming eruption could eject 540 cubic kilometers of material, however if the former assumption (0.03km3/yr) holds true, Yellowstone could potentially eject 1,920 cubic kilometers. These calculations are rough approximations that only show the wide range of ejection possible and the outcome of the eruption is unpredictable and deserves more detailed analysis.

Yellowstone is one of the largest rhyolitic magma systems on Earth and has produced three explosive pyroclastic eruptions in its lifetime (Christiansen, 1984). The youngest caldera of Yellowstone was formed approximately 640,000 years ago by an eruption that ejected 1000 cubic kilometers of material (Wicks, 2006). This eruption created what is termed the Lava Creek Tuff (Fritz, 1985). Previous to this a smaller event occurred 1.6 million years ago and expelled 280 cubic kilometers, its deposit is termed the Mesa Falls Tuff (Fritz, 1985). The largest of the three events occurred 2 million years ago and expelled 2,500 cubic kilometers of material, this deposit is termed the Huckleberry Ridge Tuff (Fritz, 1985). Only a trace remains of the caldera formed from this eruption (Fritz, 1985). It has been covered from the lava flows and deposits of the two more recent explosive eruptions (Fritz, 1985).

The present caldera has also been buried by lava flows from eruptions that occurred 150,000 years ago and 70,000 years ago (Christiansen, 1984). Since then the magma chamber has been restless with increased seismic activity, ground deformation, and hydrothermal activity (Wicks, 2006). All three eruption events show similarities and each cycle began and ended with an extended period of sporadic lava expulsions that eventually climaxed in an explosive event (Christiansen, 1984). Evidence of the ejected ash fallout from the events extends as far as Mississippi, Saskatchewan, and California (Christiansen, 1984). All three events also laid a single cooling ash sheet across the landscape, absent of erosion or accumulation of external sediments, indicating the processes took place in a matter of hours to days (Christiansen, 1984).

The current Yellowstone caldera occupies 70 square kilometers of the Park and has been dormant since the last lava flow 70,000 years ago (Lowenstern, 2006).

However, recent activity indicates the system's unrest. In addition to ground deformation the system also experiences earthquake swarms and gas and heat emissions (Lowenstern, 2006). It releases approximately 45,000 tons of carbon dioxide per day (Lowenstern, 2006). Scientists are unsure if this activity is constant with the cooling of a large magma system or if it is maintaining its output. The system is clearly still active (Christiansen, 1984).

Possible precursors to an eruption include intense unrest, possibly followed by a smaller eruption or a lava flow, or a small eruption that produces a lava flow and induces an explosive eruption (Lowenstern, 2006). Scientists believe that the last eruption of Yellowstone 640,000 years ago was preceded by periodic lava flows that occurred for a half a million years until ending with the violent eruption (Fritz, 1985). Since the last lava flow there have been no new flows out of the system (Fritz, 1985). However if the pressure of the overlying solid crust was to be reduced, either by an earthquake or the continued swelling of the two resurgent domes, the gases could be released and trigger another violent eruption (Fritz, 1985).

The deposits from the last Yellowstone eruption have provided researchers with enough scientific data to determine that the system has a cyclic pattern to its eruptive events (Christiansen, 1984). Each catastrophic eruption is prefaced by a span of 200,000 to 600,000 years of sporadic basaltic and rhyolitic lava flows (Christiansen, 1984). This results from the magma chamber evolving near the surface and producing a ring-fracture system, which allows for intermittent lava extrusions (Christiansen, 1984). The creation of the ring-fracture system is eventually followed by a cataclysmic eruption of the magma chamber. After the eruption a period of surface cooling and magma reformation takes place (Christiansen, 1984). This is indicated by more sporadic lava flows that refill the caldera floor (Christiansen, 1984). If this cycle proves to repeat itself in the future, the basaltic eruptions from 150,000 to 70,000 years ago could be an indication of an impending eruption (Christiansen, 1984). However, they could also be an indication that the system is cooling off since its last explosive event (Christiansen, 1984). All geologic, petrologic and geophysical data of Yellowstone seem to point toward a system with the ability to produce future eruptive episodes (Christiansen, 1984). In either instance it seems obvious that the magmatic chamber is still active and evolving.

Geological History of Nebraska's Subsurface

Nebraska's geologic subsurface is laden with volcanic deposits and ash accumulations from millions of years of activity from Earth's tectonic system. The landscape in the western part of the state is filled deposits with volcanic ash from past eruptions in the western United States (Swinehart, 1985). This indicates a tendency for ash clouds to spread over the continent to the east from western source vents. Many of the significant volcanic ash deposits in Nebraska's subsurface are from volcanic episodes occurring over 5 million years ago (Swinehart, 1985). Research on the Pearlette Volcanic Ash beds in eastern Nebraska, which were deposited during the Pleistocene era, are assessed as possible remnants of the ash falls from Yellowstone's past eruptions. However, the origin of this deposit is thought to be from a source southwest of Nebraska, possibly in New Mexico or California (Walker, 1967). The grain-size in this deposit has no definite geographic-trend and so the origin is unclear (Walker, 1967).

Health Effects of Atmospheric Volcanic Ash

Research of the health effects of volcanic ash on the human respiratory system has only been conducted extensively over the last 40 years (Horwell, 2006). This is due to the lack of major volcanic episodes in densely populated modern settings. Since the eruption of Mount St. Helens many researchers have been concerned with the long-term health consequences that the publics can incur from volcanic ash exposure. Many people experienced intense anxiety because of their concern about the effects of exposure to ash because little information existed at the time (Buist, 1986). Of all the hazards associated with an eruption, ash fall can affect the largest range of people because of the wide area covered by the fallout (Horwell, 2006). Ash can often remain in the atmosphere for years depending on the volume released and is often remobilized by wind and human activity (Horwell, 2006).

Volcanic ash is composed of particles of fragmented volcanic rock usually less then 2 millimeters in diameter that form during volcanic explosions (IVHHN). Studies show that the health effects of the particles are dependant on their morphology, mineralogical composition and physio-chemical properties (Horwell, 2006). The composition of the ash particles varies depending on the characteristics of the magma from which it is derived from (IVHHN). Particles must also be in the breathable size range, less than 10 micrometers, to cause any lung damage (Baxter, 1981). In the eruption of Mount St. Helens 90% of the ash particles were in this range (Olsen, 1986). One of the larger concerns for human health is the concentration of free crystalline silica, which can cause silicosis if exposure is prolonged and in excess of 50 micrograms per cubic meter (Baxter, 1986). The concern about free crystalline silica in volcanic ash stems from the known effects incurred from prolonged exposure to airborne silica in industrial settings. Many cases of silicosis, non-specific pneumoconiosis, and chronic obstructive pulmonary disease have been reported after exposure (Horwell, 2006).

The properties of the respired ash have a significantly contribute to the symptoms that may be incurred after exposure. Morphology, or the size and shape of the ash particles, is important because of the possible presence of respirable size fibrous minerals (Olsen, 1986). Concern for fibrous minerals stems from the possible carcinogenic effects to humans due to the size, shape, and biological persistence of the particle not necessarily to the type of mineral (Olsen, 1986). The mineralogical or elemental composition of the ash is still of concern however and determined by the parent material it was derived from, basalt, andesite, dacite, or rhyolite (Olsen, 1986). Basalt and andesite types have very small amounts of free crystalline but the dacite and rhyolite types carry more of the substance, so exposure to these types leads to a larger concern (Olsen, 1986). The physio-chemical properties of the surfaces of the ash particles are of concern because fallen ash may have acid coatings which can cause eye and lung irritation (IVHHN). These properties combined in specific ratios can leave exposed publics in need of serious medical attention.

The National Environmental Quality Standard for total suspended particulates (TSP) in the atmosphere is 100 micrograms per cubic meter (Yano, 1990). Significant harm can occur if exposure at this level occurs for longer than 24 hours (Baxter, 1981). Studies show that levels this high can provoke respiratory illness in exposed persons (Baxter, 1981). The peak levels of TSP after the Mount St. Helens eruption were over 30,000 micrograms per cubic meter (Baxter, 1981). This ash was determined to be high in silica and was a large health concern if exposure was prolonged (Baxter, 1981). After surveillance of hospital visits before and after the eruption of Mount St. Helens it was determined that no excessive respiratory illnesses occurred due to exposure to the ash (Bernstein, 1986). A similar study in Japan concerning the exposure to ash from Mount Sakurajima, which has frequent small-scale eruptions, showed the exposure of TSP to often be above the National Environmental Quality Standards (Yano, 1990). A questionnaire of residents living in the area for over three years determined that non-specific respiratory disease was in low occurrence, less than 10%, in two separate study locations (Yano, 1990). This study confirmed the findings at Mount St. Helens, that the health effects to persons exposed to volcanic ash are minimal (Yano, 1990).

These studies do indicate that exposure to the ash may be a cause of health concern for people with bronchitis, asthma, emphysema and severe heart problems (Bernstein, 1986). However the general public, exposed for short periods of time, are not severely affected by the ash particles (Bernstein, 1986; Yano, 1990). Volcanic ash is generally biologically inert and symptoms from volcanic ash mainly result from the irritating effect they have on mucus membranes and not from fibrous content for the crystalline silica (Yano, 1990). Other potential effects of minimal concern include eye irritation and skin irritation from contact with the body surface (IVHHN).

In the event of an eruption of the Yellowstone super-volcano the potential for atmospheric ash will be on a much larger scale than these two examples of smaller ejection eruptions. It is difficult to determine if the effects of the Yellowstone ash particles will be the similar to the examples provided above, however the evidence shows that volcanic ash may pose less of a health concern than previously thought. The greatest concern will not be the health effects of ash inhalation. Consideration of the other potential ramifications of the ash fall such as agricultural and structural damage may be of larger concern to the prosperity of the population. It is important to also keep in mind that the atmospheric opacity will be of greatest concern.

Other Consequences of Super-Volcanic Eruptions

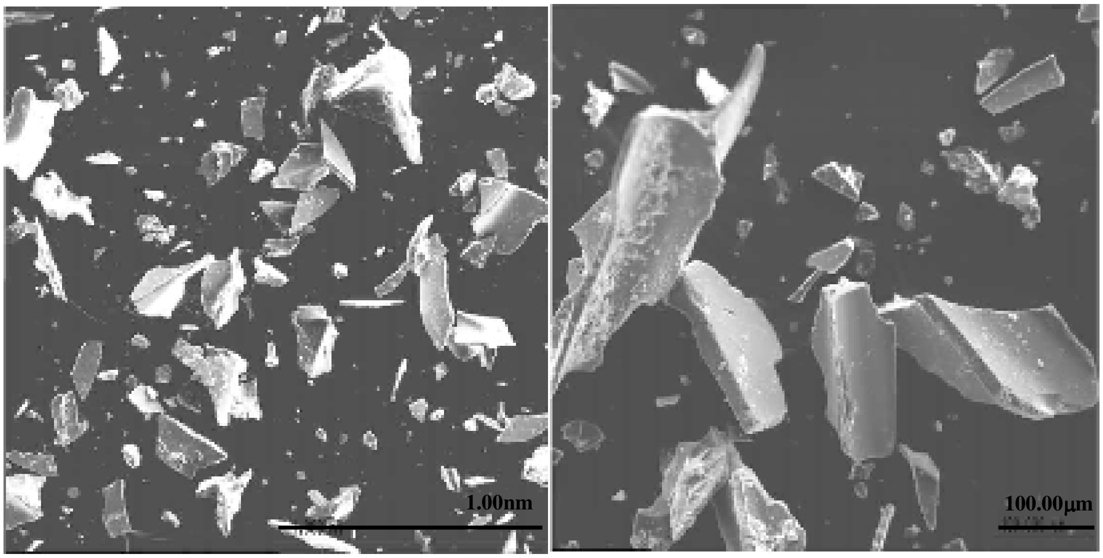
It is clear at this point that a super-volcanic eruption would present consequences to society of a scope that have not been experienced in human history. The effects from an eruption of the Yellowstone volcano will be incurred by most of the population in the United States and depending on the size and scale, possibly by the entire population on the Earth. Models of the climatic effect of this type of eruption show potential global devastation for periods of decades (Louys, 2007). Pyroclastic clouds, caldera collapse, volatile gas release, and atmospheric ash clouds will disrupt modern life and disable many of the systems on which we depend on.

In the immediate vicinity of the eruption the entire landscape will be leveled and any human-made structures will be completely demolished by the collapse of the caldera floor (Self, 2008). The subsiding crater may be 15 to 100 kilometers in diameter but will cause structural damage for hundreds to thousands of square kilometers (Self, 2006). The ash flows, also called pyroclastic clouds, hug the ground with a thick, extremely hot, fast flowing mixture of volcanic ash and volatile gases (Self, 2008). This can cover 20,000 square kilometers from the source vent and can leave a deposit of ash and pumice 10 to 100 meters thick (Self, 2008). Temperatures of these flows can reach 100's of degrees Celsius and will leave nothing alive in their path (Self, 2006). The release of volatile gases, mostly carbon dioxide and water vapor, is of less concern in this type of event because of the vast amount of gases already present in our atmosphere (Self, 2008). It is thought that their release would cause little change.

The most concerning impact of the eruption will likely be the atmospheric ash clouds that have the potential to affect the entire planet. The ash cloud can cause two different consequences after a super-volcanic eruption. Injection into the upper atmosphere can cause the formation of sulfuric acid aerosols leading to potential global cooling and in the lower atmosphere and the eventual fallout of the ash can cause damage with the collection of thick layers of ash and disruption of physical health of animals. The ash cloud from the Toba eruption, that released $2500km^3$ of material, injected 10^{15} grams of fine ash into the Stratosphere (Louys, 2007). According to ice core data the fall out of this ash from the stratosphere after Toba took approximately 6 years (Sparks, 2005).

The concern of this gas-laden ash entering the stratosphere is the chemical reactions that occur with the stratospheric gases (Self, 2008). The sulfuric gases that are emitted from the eruption have the potential to reach to tropopause 15-20 kilometers above the surface (Self, 2006). These gases, especially sulfuric acid, react with the water vapor in the lower stratosphere to form a sulfuric aerosol (Sparks, 2005). This aerosol backscatters and absorbs the solar radiation entering the Earth's atmosphere (Sparks, 2005). This causes a cooling effect in the lower atmosphere and could lead to a global climate changes (Sparks, 2005). The aerosols can quickly encircle an entire hemisphere and it can encircle the entire globe depending on the season of the eruption (Self, 2006). This could lead to a global temperature change of 3-5 degrees Celsius for an extended period of time (Sparks, 2005). Atmospheric modeling of an eruption event at the same latitude as the Yellowstone volcano indicated severe short-term cooling globally of less than 10 degrees Celsius with recovery period lasting up to 10 years (Self, 2006). The total effects of this climatic change is uncertain considering the complexity of our climatic system, however it is sure to have severe consequences to modern society.

The other potential effect of the atmospheric ash cloud is the fall out of the material as it stretches across the landscape. The accumulating ash near the volcano could be 10 meters thick and at father distances would thin out to few centimeters, possibly 1 million square kilometers down wind (Self, 2006). These deposits would most likely be up to 10 centimeters at greater distances (Self, 2008). Fall out of the ash cloud usually occurs up to 24 hours after atmospheric injection at distances greater than 150 kilometers (Rose, 2003). The larger ash particles will fall out closer to the source vent and smaller particles, less than 500 micrometers, can remain in the atmosphere and move downwind (Rose, 2003). Research done on the shape of the particles shows that atmospheric drag affects the distance traveled because of the non-spherical shape of volcanic ash (Rose, 2003). Figure 2 shows the general shape of volcanic ash particles.



(Figure 2) Scanning electron microscopy images of volcanic ash particles showing the platy structure. (Rose, 2003)

This ash can contaminate water supplies, disrupt transportation, cause failure of electronic equipment, disrupt aviation (Sparks, 2005) and can cause structural collapse (Self, 2008). The potential coverage over a continent sized area would increase the albedo of the Earth's surface, which could lead to even great heat loss to the lower atmosphere (Self, 2008). It may also kill much of the vegetation and if deposited on the ocean surface, could cause carbon dioxide draw down from the atmosphere and changes to ocean's carbon dioxide cycle (Self, 2008, 2006). These consequences have the potential to devastate the global economy and leave many incapacitated after the event (Sparks, 2005). Not to mention the potential health affects caused by inhalation of the silicic laden ash.

Potential Mitigation Procedures

In the event of a super-volcanic eruption of the Yellowstone volcano the citizens of Nebraska, as well as the rest of the United States, need to have preparedness and mitigation procedures in place to reduce chaos and increase awareness of the dangers involved. After investigation of the consequences of super-volcanic eruptions the Geologic Society of London Working Group determined actions that need to be taken to create such a plan. They suggest investment in better research of the known source vents and of possible sites of unknown vents, collaboration of volcanologists and climatologists in preparing data, increased research of the composition of gases and particles that may be released, increased research of past eruption events, initiatives to improve understanding of the nature of the hazards, and development of a multidisciplinary task force to determine the environmental, economic, social, and political consequences of the fall out (Sparks, 2005).

These actions are logical and necessary to our understanding of the consequences that we may incur. They will give our population the most applicable knowledge and understanding in order to prepare ourselves for the event. To make this knowledge useful we also need methods in place to disburse the information gained to the general public to ensure everyone can understand how to react and what actions need to be taken.

A threat of this type is not something that human communities have been preparing for throughout human history. Some type of preparedness is necessary because in the event of an eruption people will need to know how to react. It is very likely that there will little time to prepare in locations such as Nebraska, only a matter of hours. This may allow for some organization and preparation, but it is necessary that people know what to do with that time.

In addition to utilizing the suggestions of the Working Group one of the first steps that need to be taken is education of the public. Increasing awareness of the geologic potential of Yellowstone through some type of education program is a necessity. This would allow for a common working knowledge amongst our communities of the possible consequences. It would also be helpful to provide specific information to specific publics, for example preparing farming communities for the agricultural effects. These types of small steps can go a long way. If more people are prepared the chaos and disruption to our lives can be minimized in the long term and recovery to a functioning system may be more attainable in the aftermath.

Citizens in Nebraska could reduce the threat on their families by having a type of disaster preparation system in their homes. Many will face long periods trapped in doors without the ability to go outside or travel and will need supplies to ensure safety and survival. Items to have on hand include facial masks for protection of respiratory threats, a battery operated radio, a non-perishable food supply, flashlights, water jugs, and so forth. Many of these items are already available in most homes and simple organization is the key to safely. If people know what to expect then they will have a better understanding of how to keep themselves and their families safe and secure.

Discussion

In the event of a super-volcanic eruption from the Yellowstone magma chamber, Nebraska citizens would endure many consequences that would cause disruption to modern lifestyles. The eruption would be larger than any explosive volcanic episode that man has experienced in recorded history. It would inject significant amounts of hot, gas laden ash particles into the atmosphere. The volume could be up to thousands of cubic kilometers, as indicated from the previous eruptions of the site, and could spread over most of the landscape of the United States (Self, 2008). Nebraska would be impacted considering its proximity to the source vent, the entire state is within 1600 kilometers of the Yellowstone caldera.

Our regional atmosphere would be saturated in thick ash fall out within 24 hours of the eruption and the material would persist in the air for weeks before fallout. Even then it will likely be redistributed into the air from wind and human activity. It will leave everything covered in an ash deposit of one to 15 centimeters (Self, 2008). This would cause disruption of many modern conveniences that we are accustomed to. It may be nearly impossible to send warning or communicate with distant communities. People therefore may be left literally in the dark with little warning and even less support or assistance.

The ash would contribute to serious long-term environmental degradation in the areas covered by thicker deposits. This includes the destruction of our agriculture systems, especially if the eruption occurred during a growing seasonNebraska's close proximity to the eruption would ensure that many of these consequences would be serious for our state.

The health effects incurred from exposure to the atmospheric ash fall is of great concern considering the heavy loads, wide range, and densely populated areas covered from the event. However exposure must be long-lived in order to lead to development of respiratory symptoms. The longevity of exposure to the ash in a Yellowstone eruption, although expected to last for days to weeks, is not long enough to cause serious threats to our health from silica inhalation.

The greatest concern for Nebraska citizens, as well as the entire planet, is the effect of the sulfuric aerosols on the Earths radiation budget. If enough aerosols are created and the effect is wide spread, the Earth could experience substantial cooling leading to many climatic and environmental concerns. It is uncertain what effect this will have on our climate system, ocean currents, and landscapes but they can be severe and problematic. On the extreme side of the spectrum, life as we are accustomed to may change to a system that may not be suitable for human habitation. On the other side, the cooling may be regional and be equalize in a decade. It depends on the scale of the event and the compilation of effects on the Earths systems.

The eruption of Toba in Sumatra 75,000 years ago injected 10^{15} grams of ash and gases into the stratosphere (Rampino, 1992). It is proposed that this eruption accelerated the climatic shift into a period of intense glaciations. Ice core data indicate that the fall out form this eruption took approximately 6 years (Sparks, 2005). From a smaller scale perspective, the Pinatubo eruption in the Philippines in 1991 released 2×10^{12} grams of sulfuric gases and formed stratospheric aerosols that encircled the earth in less than two weeks, the cloud then circled the entire planet in three months (Self, 2006). This obstructed Earths solar radiation intake for three years and cause a global temperature change of 0.5 degrees, which persisted for two years (Self, 2006). This level of event has serious consequences for the regional area but global effects may also be severe.

Yellowstone could, depending on size, have a range of effects medial to these to drastically different events.

Conclusion

The possibility of an eruption of Yellowstone is a possibility in the future of our civilization. There is no doubt that this event will cause substantial harm to the livelihoods of our communities. The potential damages are severe and are unlike any disaster that we have experienced in our history.

The most wide spread effect will be the intense ash fall out resulting from the blast. It is essential that we ensure the preparation of our people through education and awareness of the potential consequences. It is unlikely that the risk to our health will be detrimental in the long-term after exposure. Studies show that in similar, small-scale events, the ash was not a serious threat. However, considering the potential scale of the eruption, these finding are hard to project onto a Yellowstone eruption. Health safety can be increased with use of respiratory protective gear. Without the necessary preparation, many may inadvertently put themselves or their families in harms way.

The consequences could be incurred by our entire globe and cause changes to our weather patterns that would seriously disrupt our civilized lifestyles. It is hard to predict how serious these changes may be, however it is certain that they will have a detrimental impact our society considering our heavy reliance on modern technologies.

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