Amphibian responses to the 1980 eruption of Mount St Helens—implications for Noahic Flood recovery

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Noah's Flood was the greatest ecological disturbance in Earth history, and yet Earth's biota subsequently recovered, demonstrating remarkable resilience. In similar manner, the 1980 eruption of Mount St Helens in Washington State, USA, severely disrupted a large ecosystem, the responses of which have been, and continue to be, observed and documented. General mechanisms of disturbance and principles of recovery have been delineated, which likely apply to other large disturbances, including Noah's Flood. Therefore, lessons learned at Mount St Helens should assist biblical creationists in constructing a model for post-Noahic Flood biological recovery. This article looks at one facet of the Mount St Helens eruption, the impact on amphibians, and their subsequent responses to disturbance, including the following topics: mortality, biological legacies, persistence, dispersal, soil enrichment, colonization, predation, and resilience. Implications for a post-Noahic Flood recovery model are discussed.

On May 18, 1980, Mount St Helens, a stratovolcano in Washington State, USA, erupted, producing a 570 km^2 severely disturbed landscape.[1,2] This 'blast zone' has, over the last 40 years, proven to be a world-class laboratory for the study of biological responses to catastrophic ecological disturbance. Researchers in the new discipline of Volcano Ecology[3] have suggested that lessons learned at Mount St Helens are not only applicable to other volcanic settings, but also likely apply to various types of catastrophic disturbances.[4] Such thinking encourages biblical creationists to use lessons learned at Mount St Helens as an aid in developing a model for post-Noahic Flood recovery.[5–7]

This article considers the responses of amphibians to the eruption of Mount St Helens. Attention is given to pre-disturbance amphibian species and their habitats, the impact of the disturbance on amphibians, and amphibian responses to the disturbance. Implications for understanding biological recovery following Noah's Flood are discussed.

Amphibian biology

All amphibian species (fossil and living) are included in the class Amphibia. Extant Pacific Northwest amphibians occupy two orders: Caudata (salamanders) and Anura (frogs/toads).[8] Both orders are divided into several families.[9]

'Amphibian' means 'double life', referring to life cycles which contain both aquatic and terrestrial components.[10] Amphibians in the Pacific Northwest include several species of salamanders, frogs, and toads. Typically, they lay gelatinous egg masses in aquatic settings, which produce aquatic larvae. After variable periods of time, larvae complete metamorphosis, resulting in reproductively mature terrestrial adults, which return to water to breed.[11]

Amphibian skin is unique among vertebrates.[10] It is 'naked' in that it is not covered by scales, feathers, or fur. Two types of skin glands are generally present: one which produces a thin mucous film that keeps the skin moist[12] and another which manufactures skin toxins that defend against predators. Amphibian skin is also quite porous, readily allowing passage of atmospheric gases and water. Gas exchange through the skin supplements lung function. Four species at Mount St Helens are actually lungless, relying solely on cutaneous respiration.[13] Most amphibians readily lose water through their skin, as well as absorb it. Cutaneous water loss necessitates a moist environment for most species.

Amphibians are ectothermic ('cold-blooded'), that is, their body temperature is regulated by the environmental temperature.[10] They also alter their internal temperature through behaviour. For example, in hot weather, some amphibians cool by entering underground burrows. Many amphibians survive winters beneath insulating forest debris or buried in the mud bottoms of ice-covered ponds or lakes.

Larval salamanders are carnivores, feeding on zooplankton and other minute organisms, while anuran tadpoles are largely herbivorous, consuming primarily algae.[14] As adults, all Northwest amphibians prey on insects, other invertebrates, and occasionally small vertebrate animals.

Pre-disturbance amphibian habitats and species

Prior to its 1980 eruption, Mount St Helens was a 2,950 m ASL (above sea level) stratovolcano located on the west side

Table 1. Fifteen amphibian species found at pre-eruption Mount St Helens, along with their preferred breeding habitats. Order Caudata (salamanders) contains 10 species (in 4 families), and Order Anura (frogs/toads) has 5 species (also in 4 families).

Order	Family	Organism		Habitat
Caudata	Ambystomatidae	Northwestern salamander	*(Ambystoma gracile)*	lake, pond
		Long-toed salamander	*(Ambystoma macrodactylum)*	lake, pond
		Cope's giant salamander	*(Dicamptodon copei)*	stream
		Coastal giant salamander	*(Dicamptodon tenebrosus)*	stream
	Rhyacotritonidae	Cascade torrent salamander	*(Rhyacotriton cascadae)*	seep
	Salamandridae	Rough-skinned newt	*(Taricha granulosa)*	lake, pond
	Plethodontidae	Larch Mountain salamander	*(Plethodon larselli)*	forest
		Van Dyke's salamander	*(Plethodon vandykei)*	forest
		Western Red-backed salamander	*(Plethodon vehiculum)*	forest
		Ensatina	*(Ensatina eschscholtzii)*	forest
Anura	Leiopelmatidae	Coastal tailed frog	*(Ascaphus truei)*	stream
	Bufonidae	Western toad	*(Anaxyrus boreas)*	lake, pond
	Hylidae	Pacific treefrog	*(Pseudacris regilla)*	lake, pond
	Ranidae	Red-legged frog	*(Rana aurora)*	lake, pond
		Cascades frog	*(Rana cascadae)*	lake, pond

of the Cascade Mountain Range in the state of Washington, USA.[15] Its summit and upper slopes were seasonally clad with deep snowpack and also supported a dozen glaciers. Tundra and alpine meadows occupied high and medium elevation sites. Below timberline, and extending onto the surrounding landscape, grew expansive old-growth, plantation, and recently clear-cut conifer-dominated forests. Several mountain lakes, the largest being Spirit Lake, were clustered to the north. Fast-flowing streams draining the area emptied into the Columbia River system. The climate was Pacific maritime and temperate, with a mean annual precipitation of 2,373 mm at an elevation about 1,000 m ASL. Within this setting existed numerous amphibian habitats, including forests, meadows, seeps, ponds, lakes, and streams.

The pre-eruption amphibian assemblage at Mount St Helens was determined largely from museum collections, historical records, and surveys done soon after the eruption.[16] The results include 10 salamander and 5 frog/toad species (table 1).

The disturbance and its results

The 1980 eruption of Mount St Helens consisted of diverse volcanic processes which interacted with a pre-disturbance landscape, forming a mosaic of disturbance zones (figure 1).[17] A gradient of disturbance was established, extending from areas near the mountain, where intense processes eliminated all pre-eruption organisms, to distant sites, where limited disturbance allowed survival of most organisms. Five volcanic processes formed disturbance zones:[17]

1. Debris avalanche: the initial massive landslide composed of the summit and north slope of Mount St Helens.
2. Directed (lateral) blast: a northward, ground hugging steam explosion that destroyed 570 km^2 of forest in less than 10 minutes.
3. Vertical eruption: a 9-hour upward eruption producing a continuous rain of ash and pumice (tephra) on the Mount St Helens area and beyond.
4. Pyroclastic flows: incinerating flows which formed the Pumice Plain located directly north of the mountain.
5. Mudflows (lahars): flows of melted snow and glacial ice, along with volcanic debris, that travelled down streams draining Mount St Helens.

The complex landscape produced by these processes forms the stage on which the drama of biological responses is playing.

Amphibian responses to the disturbance

1. Amphibians experienced high mortality

There are no reliable estimates of the number of amphibians which perished in the 1980 eruption of Mount St Helens,

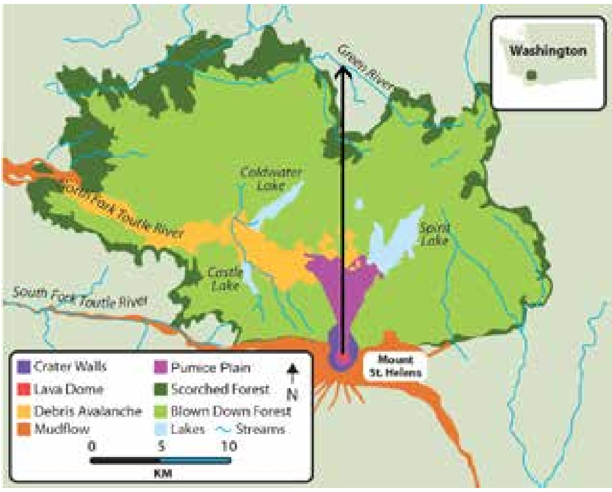

Image: Theresa Valentine, US Forest Service

Figure 1. Map of the blast zone showing disturbance zones, including: debris avalanche deposit, forest blowdown zone, scorch zone, Pumice Plain, and mudflow deposits. The arrow represents a gradient of disturbance, which depicts a progressive decline in disturbance intensity between the Pumice Plain and the intact forest.

Figure 2. Northwestern salamanders persisted in ponds and lakes by becoming reproducing adults, while retaining aquatic features, including gills. This allowed them to avoid potentially lethal conditions in the surrounding landscape.

but the toll must have been great. Amphibians in the devastated area were subjected by volcanic processes to high-impact forces, extreme heat, abrasion, deep burial, the suspension of particulates in aquatic systems, and possibly chemical toxicity.[18,19]

It is likely that three species of woodland salamanders were completely extirpated from the blast zone. These were the western red-backed salamander (*Plethodon vehiculum)* Larch Mountain salamander (*Plethodon larselli*), and ensatina (*Ensatina eschscholtzi*) – all members of the family Plethodontidae (lungless salamanders).[20] Plethodontids live on the forest floor, which provides less insulation from volcanic impacts than does an aquatic habitat, especially ice-covered lakes and ponds. In addition, no red-legged frogs were found in early surveys, suggesting there were no survivors of this species either.[21]

2. Amphibians became biological legacies

However, despite high mortality, many amphibians survived the eruption. Amphibians were first reported in the blast zone in the summer of 1980.[22] Subsequent surveys indicated that 11 of the 15 pre-disturbance species survived the eruption.[21] These became known as ‘biological legacies’, a term coined at Mount St Helens for all biological material, both living and dead, that persisted into the post-disturbance period.[18,23] It became apparent that the types, amounts, and distributions of amphibian legacies were a major determinant of the rate and pattern of post-eruption amphibian responses.

The timing of the eruption was critical to amphibian survival.[24] On May 18, winter snowpack still blanketed higher elevations around Mount St Helens and many lakes remained ice-covered. Amphibians, buried in mud at the bottom of lakes, under or within coarse woody debris, or in underground burrows, were protected. Such locations (termed ‘refugia’) allowed many adult and larval amphibians to survive the eruption. Aquatic sites, especially ice-covered ponds and lakes, produced greater amphibian survival than did terrestrial habitats.

3. Amphibians persisted in disturbed habitats

Amphibians which survived the eruption (living biological legacies) emerged into highly disturbed aquatic and terrestrial habitats. Many perished due to unfavourable conditions, but some persisted, and even thrived. One process enabling certain salamanders to accomplish this was neoteny.

Neoteny (also called ‘paedomorphism’) refers to the retention of larval features in adult organisms.[25] For example, larval salamanders normally lose their fins and gills as they metamorphose into reproductively mature terrestrial adults. However, in neoteny, larval aquatic features are permanently retained throughout adulthood, requiring neotenes to live their entire lives as obligate aquatic organisms. Neotenic behaviour was observed in three salamander species following the eruption: northwestern salamanders (*Ambystoma gracile*) (figure 2), coastal giant salamanders (*Dicamptodon tenebrosus*), and Cope’s giant salamanders (*Dicamptodon copei*).[26]

For certain salamander species, neoteny is obligatory[27, 28] but for others (including those at Mount St Helens) it is facultative, occurring only under certain environmental conditions. Sprules[29] hypothesized that facultative neoteny may be an adaptation enabling certain salamander species to survive severe terrestrial disturbances. That is, they are able to complete their entire life cycles (including reproduction) in protected aquatic sites, thus avoiding potentially lethal conditions in the surrounding disturbed terrain.

According to Crisafulli *et al.*:

> "Neoteny was an important life-history characteristic for three salamander species that appeared to allow these species to persist (or flourish) in the post-eruption landscape. Neoteny was presumably favoured because metamorphosing animals perished under harsh terrestrial conditions. As forests return to the Mount St Helens landscape, the importance of neoteny should diminish and metamorphism may become a more adaptive trait."[20]

4. Many (but not all) amphibian species dispersed great distances

Lengthy dispersal over harsh, barren volcanic surfaces seems a daunting task for amphibians, which are covered by a relatively delicate integument, require a continuously cool and moist environment, have specific food requirements, and travel rather slowly. Yet, many frog, toad, and salamander individuals managed to cover remarkable distances through some of the most disturbed terrain in the blast zone.[30] Successful dispersers colonized new ponds formed by the eruption, as well as defaunated existing habitat.

Dispersal distances for amphibians at Mount St Helens were determined between 1980 and 2000, either by tracking marked animals, or by computing travel distances from the nearest known source populations.[30] All results were based on a straight line of travel from the source population to the distant point of capture. Actual distances would have been significantly greater, however, since amphibians travel an irregular route due to obstacles and uneven microtopography.

Despite their seeming liabilities, amphibians at Mount St Helens made many impressive dispersal journeys.[30] Two western toads (*Anaxyrus boreas*) travelled at least 1.6 and 4.5 km; two Cascades frogs (*Rana cascadae*) moved 0.75 and 1.2 km; and many recently metamorphosed northwestern salamanders dispersed over 2 km. Two additional northwestern salamanders dispersed 1.9 and 3.0 km from Spirit Lake to the Pumice Plain, the most devastated part of the blast zone. Northwestern salamanders, Pacific treefrogs (*Pseudacris regilla*), red-legged frogs (*Rana aurora*), and Cascades frogs dispersed 3.7 km onto the debris avalanche deposit from their closest known source populations, while western toads and rough-skinned newts (*Taricha granulosa*) travelled 5.7 km from their nearest sources. Pacific treefrogs, observed in the volcano's crater, accomplished the longest recorded dispersal of 10 km, from their nearest known surviving population (figure 3).

How were these remarkable journeys accomplished? Several important factors were found to determine the rate and pattern of dispersal, including high reproductive capability, species vagility, landscape permeability, and linkages with fossorial animals.[30]

Amphibians produce large numbers of eggs, larvae, and dispersing newly metamorphosed individuals. For example, a mature female western toad may lay over 17,000 eggs in a single season[31] (figure 4), a Pacific treefrog produces 500–1,000 eggs per season[32], the egg mass of a northern red-legged frog is composed of 750–2,000 eggs,[33] and a northwestern salamander egg mass usually contains 50–200 eggs.[34] Following the eruption, some amphibians experienced population booms. Ponds and streams produced abundant algae and zooplankton due to removal of the forest canopy. This provided a good food source for amphibian larvae. Also, in the early post-eruption period, there were few predators. The resulting abundance of dispersing juveniles offset the high mortality associated with dispersal and helped ensure numerous successful dispersals, despite a large number of failed attempts.

Amphibian species differ in their abilities to disperse significant distances. For example, anurans generally travel more rapidly than salamanders.[35] Some salamanders, such as plethodontids, have low vagility, and are termed 'sedentary'. At Mount St Helens, these salamanders (western red-backed, Larch Mountain, ensatina) have yet to repopulate areas from which they were extirpated. Crisafulli *et al.* state:

> "We predict that ensatina and western red-backed salamanders will colonize from the margins of the scorch zone and then move inward toward the core of the Pumice Plain. The Larch Mountain salamander should colonize at a much slower rate, if at all."[20]

In contrast, western toads, Pacific treefrogs, red-legged frogs, and northwestern salamanders display greater vagility and are capable of more rapid and longer distance dispersals.

A major factor in amphibian dispersal is landscape permeability.[36] For much of the year, substrates (pumice deposits and developing soil) at Mount St Helens are impermeable to amphibians, not allowing them to cross. This includes winter, with deep snowpack, and summer, when conditions are hot and dry. However, there are two times each year when Mount St Helens' landscapes become permeable, that is, sufficiently cool and wet for amphibians to traverse. The first is an approximate 6-week period in spring, when all substrates are saturated with water from melting winter snowpack and frequent rain events. This is when most successful dispersals take place. The second time the landscape becomes permeable is after the summer drought, with the onset of autumn rains and cool weather. Permeability at this time, however, is less reliable, because the first autumn precipitation may be a limited rain event, sufficient to initiate dispersal, but not adequate to sustain dispersing animals until they reach suitable habitat. These 'false starts' often leave large numbers of stranded amphibians, such as northwestern salamanders, to die from heat and desiccation. At other times, the first autumn precipitation arrives as snow, also not conducive to successful dispersion.

Another aid to amphibian dispersal in Mount St Helens' harsh landscape is an extensive 'subway' system constructed by northern pocket gophers (*Thomomys talpoides*).[36, 37] Many of these fossorial rodents survived the 1980 eruption

Figure 3. The Pacific treefrog holds the record for the longest amphibian dispersal at Mount St Helens. Individuals travelled 10 km from their source area into the volcano's crater!

in underground burrows (living biological legacies). They flourished in the post-eruption environment and expanded their tunnel systems throughout much of the blast zone. Western toads, Pacific treefrogs, Cascades frogs, and northwestern salamanders have been observed accessing gopher burrow entrances, as well as openings where Roosevelt elk (*Cervus canadensis roosevelti*) tracks have broken into the tunnel system. In addition to being a travel route, this underground habitat provides dispersing amphibians with a respite from hot, dry surface conditions. In summer, tunnels are more humid and have temperatures 5–15°C cooler than on the surface.[36]

5. Dispersing amphibians enriched developing soil

Newly emplaced volcanic substrates at Mount St Helens served as parent material for soil development. However, these deposits contained only minimal levels of nitrogen[38] and phosphorous,[39] elements required by plants and other organisms. One supply source for these needed nutrients was the ongoing 'rain' of insects and other arthropods from the atmosphere ('arthropod fallout').[40,41] In addition, mosquitoes were found to ferry nutrients from the waters of Spirit Lake to the nutrient-deficient pumice plain.[42,43]

Unsuccessful amphibian dispersers from Spirit Lake[44] also transported nutrients onto nearby volcanic surfaces. Studies indicated that in 2014 over 100 g of nitrogen and 12 g of phosphorous were removed by amphibians from Spirit Lake.[45] An undetermined percentage of these nutrients was added to surrounding pumice deposits by decomposition of unsuccessful dispersers. A small amphibian biomass has also been removed and distributed by amphibian predators, including common garter snakes (*Thamnophis sirtalis*), river otters (*Lontra canadensis*), mink (*Neovison vison*), and various birds.[46]

The above nutrient quantities are small, in part because less than 20% of Spirit Lake's shoreline provides adequate habitat for amphibians.[47,48] However, combined with dispersal from numerous other habitats, both within and outside of the blast zone, amphibians play at least a minor role in the enrichment of volcanic soils.

6. Amphibians colonized suitable habitat

To be successful, dispersing amphibians must reach suitable habitat, such as ponds, streams, wetlands, meadows, and forests. At Mount St Helens, much pre-disturbance amphibian habitat was destroyed by the eruption, while other areas, although severely altered, were still able to support amphibian populations. In addition to eliminating existing amphibian habitat, the eruption created an even greater amount of new habitat.[49] Ground water and precipitation filled low areas between hummocks on the debris avalanche deposit, producing new ponds, 130 of which existed in 2000.[50] About half of these were ephemeral, drying by late summer, and half, perennial, containing water year-round. In addition, the debris avalanche dammed streams, forming new lakes, many of which breached their sediment dams and were short-lived.[50] Two (Coldwater Lake and Castle Lake) were stabilized by the US Army Corps of Engineers and exist today.

Post-eruption streams, ponds, lakes, and other sites, once they became geologically stable, were rapidly colonized by aquatic and terrestrial vegetation, which further stabilized substrates. These habitats provided ideal colonizing sites for dispersing amphibians. Even ephemeral ponds provided good breeding habitat for amphibians with a sufficiently short development period.[51]

Another source of new amphibian habitat was the activity of American beaver (*Castor canadensis*).[36]

None of these large rodents survived the eruption, but as riparian vegetation recovered along blast zone streams, beaver literally 'ate' their way into the devastated area. Once established, beaver dammed outlet streams of many lakes and ponds, which elevated water levels and flooded surrounding vegetation, particularly willow (*Salix* sp.) and alder (*Alnus* sp.). This greatly increased ovipositioning sites[52] available to reproducing northwestern salamanders, western toads, and Cascades frogs. Woody plants, cut by beaver, fell into ponds and provided additional ovipositioning structure.[53]

7. Predators controlled amphibian populations

Prolific reproduction, abundant larval food supplies, and limited predators, pathogens, and parasites produced some remarkable amphibian population booms in the early years following the eruption. One account describes a scientist hiking in the blast zone, about a year after the eruption, seeing a hillside that appeared to be in motion. Approaching closer, he saw that the slope was totally covered by thousands of western toads, all hopping toe-to-toe![54] Similar hordes of Pacific treefrogs, rough-skinned newts, and northwestern salamanders were seen at other sites. Such masses of amphibians were often short-lived due to inadequate terrestrial food sources. Eventually, boom – bust population dynamics diminished, especially as amphibian predators were established—three of which are especially notable.

Figure 4. Western toad larvae (tadpoles) blacken the shores of ponds and lakes within the blast zone (left), resulting in large numbers of recently metamorphosed toadlets (right).

Common ravens (*Corvus corax*) rapidly dispersed into the blast zone. These highly intelligent birds have been observed to flip toads onto their backs, strike them with their beaks, and extract the fleshy portion for food, while leaving behind the poisonous skin turned inside-out, along with the skull and eggs.[52]

Common garter snakes (*Thamnophis sirtalis*) became abundant about 10 years after the eruption.[24] These reptiles, which are semi-aquatic, have been observed feeding on adult western toads, Pacific treefrogs, and Cascades frogs, as well as larvae of western toads and coastal tailed frogs. In addition, terrestrial adult northwestern salamanders have been extracted from captured snakes.

Also found in the blast zone is the rough-skinned newt, which produces an extremely potent skin toxin.[55, 56] Its only known predator is the common garter snake, which is often resistant to the newt's toxin. It is likely that this predator-prey interaction has been re-established.

Brook trout (*Salvelinus fontinalis*), a non-native species, were introduced into high mountain lakes near Mount St Helens for recreational fishing from 1913 until 1979.[24] These lakes, formed during the Ice Age by montane glaciers, initially were fishless. They provided good habitat for amphibian species until the introduction of trout. Since brook trout feed on amphibian larvae and adults, their presence decimated amphibian populations. In May of 1980, ice cover on high mountain lakes enabled trout in many lakes to survive the eruption. Studies showed the abundance of northwestern salamanders to be about 10 times greater in lakes without fish compared to those in which fish survived.[24]

8. Amphibians displayed great resilience

'Resilience' refers to the ability of an ecosystem, or its components, to effectively recover from disturbance. Such a 'bounce-back' was clearly observed among amphibians at Mount St Helens. Although seemingly fragile creatures and subjected to massive mortality, amphibians responded remarkably to the eruption by surviving, persisting, dispersing, and colonizing both defaunated and new habitat.

Implications for post-Noahic Flood amphibian recovery

The new discipline of 'volcano ecology' focuses upon the effects of volcanic eruptions on ecosystems and the ensuing geophysical and biological responses.[3, 57] General principles derived from these studies are applicable, not only to other volcanic events, but to a wide range of catastrophic disturbances. A publication of the US Forest Service reads: "The in-depth ecological research on Mount St Helens and at other volcanoes is enabling researchers to identify universal themes in ecosystem response to disturbance" and "This means the lessons learned here can be relevant in other disturbance settings."[58] Such pronouncements encourage biblical creationists to use Mount St Helens' research as an aid in understanding ecological responses to Noah's Flood.

An important issue is whether amphibians survived the Flood as 'Ark kinds' or as biological legacies in the Flood waters (or both). The Bible states: "Everything on the dry land in whose nostrils was the breath of life died" (Genesis 7:22). This would include most adult amphibians, but not larvae or neotenic adults,[26] both of which are fully aquatic, having gills, not nostrils. In addition, several amphibian species spend over one year in their embryonic (egg) and larval stages before completing metamorphosis.[59] These could remain fully aquatic for the 371 days of the Noahic Flood. As freshwater fish survived the Flood, so possibly could have some larval and neotenic amphibian species.

Efforts are underway to delineate the 'ark kinds' (amphibian baramins) for extant amphibians.[60–62] Hennigan has tentatively[63] identified 53 extant Caudate kinds[61] and 138 extant Anuran kinds.[62] Of these, 6 Caudate kinds and 4 Anuran kinds are represented at Mount St Helens. Following Noah's Flood, amphibian kinds would have dispersed over the earth from the Ark, and diversified, forming post-Flood amphibian species. In addition, if larvae or neotenic adults[64] survived in the floodwaters, they would have dispersed from multiple sites of survival. As species, rather than kinds, their potential for further diversification would be limited. Possibly, some extant amphibian species are descendants of Flood water legacies, rather than Ark kinds.

One specialized amphibian at Mount St Helens warrants comment. The coastal tailed frog (*Ascaphus truei*) is highly adapted to cold, fast-flowing mountain streams.[65] For example, its 'tail' (in males) is actually a copulatory organ, needed for internal fertilization in turbulent stream environments. Although Hennigan tentatively postulates a "tailed frog kind", he acknowledges that the taxon may be a product of "post-Flood diversification from other terrestrial anurans."[66] Alternatively, since tailed frog larvae have a long period of development,[59] and are adapted to surviving turbulent aquatic environments, it is possible that they survived in floodwaters outside the Ark.

After the Flood, surviving amphibian species, faced daunting challenges as they dispersed into and colonized a hostile environment—a situation analogous to that encountered by amphibians in the blast zone at Mount St Helens. Lessons learned from amphibians at Mount St Helens likely apply to dispersing amphibians as they repopulated the post-Flood earth. For example, neoteny possibly provided a mechanism for certain caudates to persist in harsh post-Flood terrestrial environments.

Dispersal distances of several kilometres for individual amphibians at Mount St Helens are impressive and would enable populations of amphibian Flood water legacies, beginning at multiple sites, to gradually claim large areas. However, Ark kinds faced a much more monumental task of populating the earth from one initial location, the Mountains of Ararat. How could that happen?

Certainly, the ability to rapidly disperse is highly dependent on a species' innate vagility. Although we do not know how vagile the amphibian Ark kinds were, we can suspect that God would have preserved animals with good dispersal capability.[67] An illustration of how rapidly a highly vagile amphibian can claim a large area is that of the Cane toad (*Bufo marinus*) in Australia. In 1935, cane toads, native to Central and South America, were released in northern Queensland to control beetles attacking sugar cane crops. Within 10 years, the toads spread 2,000 km to Brisbane, which is a rate of 200 km per year![68]

Dispersing post-Flood amphibian populations were aided by numerous other factors. High reproductive capability, abundant food sources, and limited predation likely produced population booms, as witnessed at Mount St Helens. Large floating vegetation mats[69,70] (such as on Spirit Lake at Mount St Helens), driven by prevailing winds and ocean currents, likely transported amphibians. The post-Flood Ice Age,[71] due to lowering of sea levels, produced land bridges, providing global access for dispersing man and animals.[72] A cool, wet Ice Age climate likely maintained permeable landscapes for amphibian travel. Linkages with fossorial animals (such as the northern pocket gopher at Mount St Helens) perhaps provided protected passageways. Beaver, by damming streams, probably created amphibian habitat, including ovipositioning sites. And eventually, an increase in predators (along with parasites and pathogens) would have helped stabilize amphibian populations.

Conclusion

The overarching recovery theme at Mount St Helens is that of great resilience. Ecosystems appear designed to rapidly and effectively respond to catastrophic disturbances. This observation lends credibility to global recovery, within a biblical timeframe, from Earth's greatest ecological cataclysm, that of Noah's Flood. Amphibians certainly played an important role in that response.

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11. Exceptions in the Pacific Northwest include fully terrestrial salamanders in the family Plethodontidae, in which there is no larval stage or metamorphosis. Eggs, laid in moist forest sites, hatch as miniature adults. Also, 'neotenic' salamanders attain sexual maturity without undergoing metamorphosis and permanently remain fully aquatic.
12. Exceptions in the Pacific Northwest include the rough-skinned newt, which has dry, granular skin and the western toad with dry warty skin.
13. The four lungless salamander species at Mount St Helens are members of the family Plethodontidae and include: Larch Mountain salamander, Van Dyke's salamander, western red-backed salamander and ensatina.
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31. Jones, Leonard, and Olson, ref. 25, p.162.
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39. Newly deposited volcanic rock contains phosphorous, but a period of weathering is required for it to become available to plants.
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41. Swenson, ref. 6, pp. 25–27.
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43. For the first two years following the eruption, Spirit Lake contained a nutrient-rich organic soup of cooked vegetation supporting a massive bloom of micro-organisms. It subsequently returned to its normal low nutrient (oligotrophic) state.
44. Five amphibian species have dispersed from Spirit Lake, including: northwestern salamander, rough-skinned newt, Pacific treefrog, western toad, and Cascades frog.
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47. Adequate amphibian habitat for lake breeding amphibians consists of a shallow littoral zone, as opposed to steep cliffs which produce deep water at the shoreline.
48. Gavel, Crisafulli, and Miller, ref. 19, p. 91.
49. Before1980, the amphibian study area contained over 30 lakes, with a collective surface area of 662 ha. The same area, after the eruption, included over 163 ponds and lakes with a surface area of 1,679 ha (an increase of 253%). See: Crisafulli, Trippe, Hawkins, and MacMahon, ref. 16, p. 185.
50. Swanson and Major, ref 1, p. 42.
51. For example, western toads need 1–3 months to complete metamorphism, so ephemeral ponds suffice. In contrast, northwestern salamanders usually spend their first year in larval form and metamorphose in their second summer. Thus, they require perennial ponds or lakes. See: Jones, Leonard and Olson, ref. 25, pp. 33, 165.
52. Ovipositioning sites usually consist of woody twigs, partially or fully submerged in water, to which amphibians attach gelatinous egg masses.
53. In contrast, beaver dams on other streams caused loss of habitat for coastal tailed frog larvae, which require fast-flowing water, rather than placid pools. See: ref. 36.
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59. Examples of prolonged embryonic/larval periods in Mount St Helens amphibians include: northwestern salamander (>1 yr), long-toed salamander at high elevation (2–3 yrs.), coastal giant salamander (18–24 mos), Cascade torrent salamander (1 yr embryonic period, 4–5 yrs larval), rough-skinned newt at high elevation (1 yr), coastal tailed frog (1–4 yrs), See: Jones, Leonard, and Olson, ref. 25, pp. 33, 37, 57, 61, 77, 157.
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63. Hennigan cautions concerning Caudates: "In no way is this the final word and much baraminological research must be done to improve the precision of these estimates."; Hennigan, ref. 61, p. 17.
64. Hennigan suggests that neoteny in salamanders of the family Ambystomatidae developed only after the Flood; Hennigan, ref. 61, p.21.
65. Jones, Leonard, and Olson, ref. 25, pp. 154–157.
66. Hennigan, ref. 62, pp. 339–340.
67. Fully terrestrial woodland salamanders (ensatina, western red-backed, Larch Mountain) at Mount St Helens are very sedentary. They have no larval phase, do not metamorphose, and have no need to migrate to aquatic reproduction sites. They very likely arose by post-Flood differentiation of Ark kinds.
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